PAPER • OPEN ACCESS

XV International Conference on Mathematics, Science and Technology Education

To cite this article: A E Kiv *et al* 2023 *J. Phys.: Conf. Ser.* **2611** 011001

Наукову працю подано від установи "Інститут цифровізації освіти НАПН України"

XV International Conference on Mathematics, Science and Technology Education (ICon-MaSTEd 2023) 16/05/2023 - 19/05/2023 Kryvyi Rih, Ukraine / Eds. : A. E. Kiv, V. N. Soloviev, S. O. Semerikov, A. M. Striuk, V. V. Osadchyi, T. A. Vakaliuk, P. P. Nechypurenko, O. V. Bondarenko, I. S. Mintii, S. L. Malchenko // Journal of Physics: Conference Series. – 2023. – Vol. 2611. – Iss. 1. – 414 p. – Access mode : https://iopscience.iop.org/issue/1742-6596/2611/1

XV International Conference on Mathematics, Science and Technology Education

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Abstract. This paper introduces the Proceedings of the XV International Conference on Mathematics, Science and Technology Education (ICon-MaSTEd 2023), which took place at the Kryvyi Rih State Pedagogical University, Ukraine, from 17 to 19 May 2023. It provides background information and the organizational structure of the conference, as well as the structure of the proceedings. It also acknowledges the many people who contributed to the success of the conference.

1. Background

The **International Conference on Mathematics, Science, and Technology Education** (**ICon-MaSTEd**) stands as a prominent and esteemed platform for researchers, educators, professionals, policymakers, and practitioners to convene and exchange their cutting-edge research findings, innovative ideas, and practical applications in the realms of mathematics, science, and technology education. The conference also emphasizes technology-enhanced learning, encompassing various approaches such as blended learning, E-learning, ICT-based assessment, mobile learning, among others, to enrich and advance educational practices (figure 1).

Initiated in 2001, ICon-MaSTEd has consistently fostered interdisciplinary collaboration, bringing together experts from diverse backgrounds to address the evolving challenges and opportunities in the fields of mathematics, science, and technology education. Over the years, the conference has witnessed substantial contributions from scholars and practitioners worldwide, propelling the domain forward with promising theories, models, tools, services, networks, and communications [1–4].

The ongoing Russian invasion of Ukraine changed the conference organization. Therefore, the XV International Conference on Mathematics, Science and Technology Education (ICon-MaSTEd 2023) took place on 17–19 May 2023 at the Kryvyi Rih State Pedagogical University, Ukraine, in a hybrid format, accommodating both in-person and online participation, to ensure inclusivity and enable attendees from various regions to engage seamlessly.

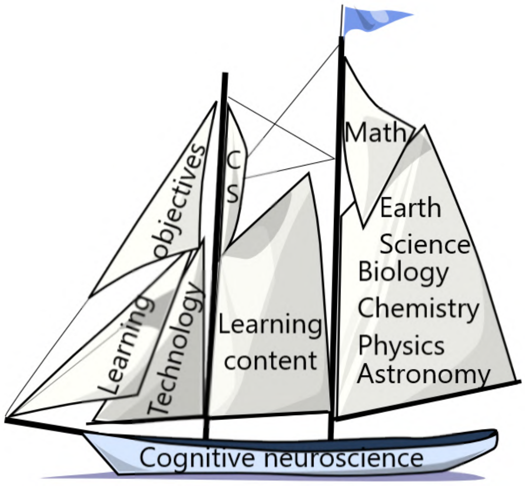

Figure 1. ICon-MaSTEd logo.

The significance of ICon-MaSTEd 2023 was evident with the participation of over 100 attendees from 7 countries, who actively joined the event using the digital platform Google Meet. The conference's program comprised a diverse array of subject areas, including Computer Science and Computer Science Education, Biology and Biology Education, Chemistry Education, Mathematics Education, Physics and Physics Education, Integrated Science Education, Educational Technology, and Technology Education.

A total of 58 submissions were received for consideration at ICon-MaSTEd 2023. Each of these submissions underwent a rigorous review process, with a minimum of three program committee members evaluating and providing feedback on each submission. After careful deliberation, the program committee selected and accepted 39 papers to be presented at the conference. These chosen papers represent the most impactful and innovative contributions to the field of mathematics, science, technology education and educational technology, and they will be showcased during the event to foster insightful discussions and knowledge sharing among the conference attendees.

To enrich the conference experience, the organizing committee curated an engaging agenda featuring both invited talks and contributed presentations. These sessions provided a comprehensive outlook on the latest developments and emerging trends in mathematics, science, and technology education. The allotted presentation slots were thoughtfully structured to encourage interactive discussions and foster meaningful exchange of ideas among participants. Invited talks spanned 25 minutes, with a 15-minute presentation followed by a dedicated 10-minute session for questions and discussions. Other talks were allocated 15 minutes, comprising a 10-minute presentation segment and an additional 5 minutes for audience engagement and inquiry.

The conference's detailed program and session information were made available to all attendees on the official website: `https://ICon-MaSTEd.easyscience.education/2023/`. Additionally, to ensure wider accessibility and reach, video recordings of all talks were uploaded to the *Not So Easy Science* YouTube channel (`https://www.youtube.com/@NotSoEasyScience`).

2. ICon-MaSTEd 2022 program committee

- *Leon Andretti Abdillah*, Universitas Bina Darma, Indonesia [5]
- *George Abuselidze*, Batumi Shota Rustaveli State University, Georgia [6]

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- *Stamatios Papadakis*, University of Crete, Greece [39]
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- *Oleg Pursky*, State University of Trade and Economics, Ukraine [41]
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- *Ivan Tsidylo*, Ternopil Volodymyr Hnatiuk National Pedagogical University, Ukraine [50]
- *Mariia Umryk*, Mykhailo Dragomanov Ukrainian State University, Ukraine [51]
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- *Kateryna Vlasenko*, Donbas State Engineering Academy, Ukraine [55]
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3. Proceedings structure

3.1. Mathematics Education

The Mathematics Education section of the ICon-MaSTEd 2023 conference showcased a diverse range of topics related to innovative teaching methods, interdisciplinary connections, and the integration of technology in the field of mathematics. The papers presented at the conference highlighted the commitment of educators and researchers to enhance mathematics learning and teaching experiences:

- *The Wheel of Mathematics Learning Methods* [57] provided insights into various pedagogical techniques aimed at making mathematics learning engaging and effective. The talk discussed different approaches to cater to students with diverse learning styles.
- *Interdisciplinary Connections of Mathematics and Literature in the preparation for External Independent Assessment of Humanities Students* [58] explored the potential synergies between mathematics and literature, illustrating how cross-disciplinary connections can enrich the learning experience for humanities students.
- *The Method of Using the Online Course 'Creative Thinking through Learning Elementary Maths' in the Mathematics Teacher Training System* [59] discussed the integration of modern online resources to enhance the training of mathematics teachers, emphasizing creative and interactive teaching methods.
- *Studies about Zones of Proximal Mathematical Development and Methods of Developmental Teaching of Mathematics* [60] delved into research related to zone of proximal development (ZPD) in mathematics education, exploring effective teaching strategies to bridge the gap between a student's current knowledge and their potential understanding.
- *Methodology of Project-Based Learning for Training Junior Students in Applied Mathematics: General Scheme of the Educational Process* [61] focused on project-based learning as an innovative approach to training junior students in applied mathematics, encouraging active learning and problem-solving skills.

- *The Use of Immersive Technologies in Teaching Mathematics to Vocational Students* [62] explored the integration of immersive technologies, such as virtual reality or augmented reality, in the teaching of mathematics to vocational students, offering new and engaging learning experiences.

Overall, the Mathematics Education section of the conference provided valuable insights into the ongoing efforts to improve mathematics education through innovative approaches, interdisciplinary connections, and the integration of modern technologies in the classroom.

3.2. Physics and Astronomy Education

The Physics and Astronomy Education section of the ICon-MaSTEd 2023 conference covered a wide range of topics related to innovative teaching methods, experimental setups, and the use of technology to enhance physics and astronomy education:

- *Measuring Earth's Mean Density Using BYOD Technology* [63] presented a fascinating approach to involving students in hands-on experiments by utilizing Bring Your Own Device (BYOD) technology. The talk demonstrated how technology can be leveraged to enhance understanding of fundamental physics principles.
- *Using Open Experimental Data of the European Organization for Nuclear Research in the Process of Studying the Physics of Elementary Particles* [64] explored how real-world data from prestigious research institutions like CERN can be incorporated into physics education to provide students with valuable insights into particle physics.
- *Design and Fabrication of an Improvised Young's Modulus Apparatus* [65] discussed the development of an innovative apparatus for measuring Young's modulus, which is essential in understanding the mechanical properties of materials. The talk highlighted the practical implications of the apparatus for physics experiments in educational settings.
- *Effects of Physics Alphabet Model on the Mean Achievement of Student's Performance* [66] explored the impact of the Physics Alphabet Model on student learning outcomes. The talk discussed how this novel teaching approach affects students' understanding and performance in physics.
- *Laboratory Equipment for Practice Learning in the Framework of Educational Course 'Molecular Physics and Thermodynamics'* [67] showcased innovative laboratory equipment designed to support hands-on learning experiences in the field of molecular physics and thermodynamics.
- *Fabrication and Applications of a Novel and Multi-Feature Spectroscope* [68] introduced a cutting-edge spectroscope with multiple features and applications. The talk highlighted the versatility of the spectroscope and its significance in various experiments.
- *Interactive Technology Use During the Study of the Universe* [69] demonstrated how interactive technology can be employed to make the study of the universe more engaging and immersive for students. The talk discussed the positive impact of interactive learning on students' comprehension and interest in astronomy.

Overall, the Physics and Astronomy Education section showcased the commitment of educators and researchers to enhance physics and astronomy learning experiences through practical experiments, novel teaching approaches, and the integration of technology.

3.3. Earth Science Education

The Earth Science Education section of the ICon-MaSTEd 2023 conference presented a collection of talks that focused on the integration of modern technologies and Geographic Information Systems (GIS) to enhance the teaching and learning experiences in the field of earth science:

- *The Use of ICT for Mathematical Calculations in Water Quality Assessment in the Teaching of Ecologists* [70] demonstrated the application of Information and Communication Technology (ICT) in the assessment of water quality. The talk discussed how ecologists can use mathematical calculations through digital tools to improve their understanding of water ecosystems.
- *Digitalization of Geographic Higher Education: Problems and Prospects* [71] explored the challenges and opportunities associated with the digital transformation of geographic higher education. The talk discussed the potential benefits of incorporating digital tools and technologies to advance geospatial learning.
- *The Use of GIS in Renewable Energy Specialist's Learning* [72] focused on the integration of Geographic Information Systems (GIS) in the education of renewable energy specialists. The talk highlighted how GIS can be leveraged to analyze spatial data related to renewable energy sources, leading to more informed decision-making in the field.

Overall, the Earth Science Education section showcased how technology, particularly ICT and GIS, plays a crucial role in advancing earth science education. By incorporating these modern tools and approaches into the teaching process, educators and students can gain deeper insights into complex environmental issues, enhance data analysis, and make more informed decisions in various earth science domains.

3.4. Computer Science Education

The Computer Science Education section of the ICon-MaSTEd 2023 conference featured talks that covered a range of topics related to teaching experiences, curriculum development, and human-computer interaction:

- *Branding Theory, Design, and Identity: Course Teaching Experience for Modern IT Specialists* [73] showcased a unique approach to teaching IT specialists by incorporating concepts from branding theory, design, and identity. The talk highlighted how these interdisciplinary elements can enhance the skillset of future IT professionals, equipping them not only with technical knowledge but also with the ability to create compelling and user-friendly products.
- *Modelling the Content of Professional Training of Future Software Engineers in the Field of Parallel Computing* [74] discussed the design of a specialized curriculum for future software engineers focusing on parallel computing. The talk delved into the importance of preparing students for the complexities of parallel processing and distributed systems, which are critical in modern computing environments.
- *Anthropologically Oriented Strategies of Interaction in the Human-Computer System* [75] explored innovative strategies of interaction between humans and computers. The talk emphasized the significance of user-centered design and human-computer interaction in creating seamless and intuitive interfaces that cater to users' needs and behaviors.

Overall, the Computer Science Education section presented valuable insights into the evolving landscape of computer science education. The talks showcased a variety of teaching approaches, including interdisciplinary concepts, specialized curriculum development, and user-centered design principles. These contributions signify the commitment of educators and researchers to equip future IT professionals with the necessary skills and knowledge to succeed in the ever-changing field of computer science. The section talks serve as an important resource for advancing computer science education and ensuring its relevance in today's technological landscape.

3.5. Technology Education

The Technology Education section of the ICon-MaSTEd 2023 conference featured talks that highlighted the use of technology in education and innovative approaches to enhancing learning experiences in technical disciplines:

- *Technology of Creating Educational Content for Open Digital Resources in General Technical Disciplines* [76] discussed an approach to developing educational content for open digital resources. The talk focused on the utilization of technology to create interactive and engaging learning materials for general technical disciplines, making them more accessible and effective for learners.
- *Project-Based Learning as an Approach to Enhance the Ecological Component in Professional Education* [77] explored the implementation of project-based learning in professional education with a focus on ecological aspects. The talk demonstrated how this pedagogical approach can deepen students' understanding of environmental issues and foster their problem-solving skills.

Overall, the Technology Education section provided valuable insights into the intersection of technology and education, emphasizing the importance of integrating innovative teaching methods and digital resources in technical disciplines.

3.6. Educational Technology

The Educational Technology section of the ICon-MaSTEd 2023 conference covered a wide range of topics related to the integration of technology in education, exploring various innovative approaches to enhance teaching and learning experiences:

- *Digital Comics for Developing Primary School Students' English Dialogic Speaking Skills* [78] demonstrated the use of digital comics as a creative tool to foster English dialogic speaking skills in primary school students. The talk highlighted the effectiveness of this approach in engaging young learners and improving their language abilities.
- *Understanding and Attitude Toward Upcycling According to the Survey of Students of Various Specialties* [79] discussed the findings of a survey that examined students' perceptions and attitudes towards upcycling. The talk shed light on how environmental consciousness and sustainable practices can be integrated into professional education.
- *Analysis of the State of the Art of Modern E-learning in Higher Education in Germany* [80] explored the current landscape of e-learning in higher education institutions in Germany. The talk provided insights into the trends, challenges, and opportunities in adopting digital learning methodologies.
- *Application of Chatbots in Business English Learning* [81] discussed the utilization of chatbots to enhance Business English learning. The talk showcased how chatbots can offer personalized and interactive language learning experiences to students.
- *Peculiarities of Foreign Language Training of Students at the Higher Education Institution in the Occupied Territories During the War in Ukraine* [82] focused on the challenges and innovative strategies of providing foreign language training in higher education institutions in occupied territories during times of conflict.
- *Selection of Pedagogical Conditions for Training STEM Teachers to Use Augmented Reality Technologies in Their Work* [83] discussed the pedagogical considerations for training STEM teachers in the use of augmented reality technologies. The talk emphasized the importance of preparing educators to leverage immersive technologies effectively in the classroom.

- *Technologization of Sudden Cardiac Death Prevention Based on the Disciplinary-Methodological Matrix of Health-Preserving Competence* [84] focused on the integration of technology in sudden cardiac death prevention strategies, combining disciplinary knowledge with health-preserving competence.
- *Enhancing Foreign Language Learning With Cloud-Based Mind Mapping Techniques* [85] discussed how cloud-based mind mapping techniques can aid in improving foreign language learning outcomes for students.
- *Challenges Facing Distance Learning During Martial Law: Results of a Survey of Ukrainian Students* [86] presented findings from a survey that explored the challenges faced by Ukrainian students during distance learning, especially in the context of martial law.
- *Digitization of Learning Environment of Higher Education Institutions: Conceptual Foundations and Practical Cases* [87] discussed the conceptual framework and practical implementations of digitizing the learning environment in higher education institutions.
- *Video Integration as an Instructional Strategy* [88] explored the use of video integration as an effective instructional strategy in educational settings.
- *Approaches to Blended Learning Organization* [89] delved into various approaches to organizing blended learning, combining traditional classroom teaching with digital resources.
- *STEM Education and Personnel Training: Systematic Review* [90] presented a systematic review of STEM education and its impact on personnel training in various fields of education.
- *Enhancing Foreign Language Learning in Ukraine: Immersive Technologies as Catalysts for Cognitive Interest and Achievement* [91] discussed the use of immersive technologies to enhance foreign language learning outcomes, particularly in the Ukrainian context.
- *The Issues of Design of a Petri Net-Based Software Component for Modelling Holistic and Coordinated Curriculum for Potential Specialists' Training* [92] focused on the design and development of a Petri net-based software component for creating holistic and coordinated curricula for specialized training.
- *Substantiation of the Sustainable Education Terms as One of the Modern Views on STEM Education Taking to Account the European Experience* [93] discussed the concept of sustainable education in the context of STEM education, considering European experiences and perspectives for Ukraine.
- *Application of Augmented Reality Technologies in the Development of Constructive Coping Strategies for Internally Displaced People* [94] explored the use of augmented reality technologies to develop constructive coping strategies for internally displaced people.
- *Artificial Intelligence in a Modernizing Science and Technology Education: A Textual Narrative Synthesis in the COVID-19 Era* [95] offered a narrative synthesis on the integration of artificial intelligence in science and technology education, particularly in the context of the COVID-19 pandemic.

The Educational Technology section of the conference showcased a diverse range of research and practical applications in leveraging technology for educational purposes. The talks demonstrated the significance of incorporating innovative approaches, digital resources, and immersive technologies to enhance teaching and learning experiences across various fields. These contributions are invaluable in advancing the field of educational technology and its impact on modern education. The section talks will serve as a valuable resource for educators, researchers, and policymakers seeking to integrate technology effectively into educational practices and improve learning outcomes.

4. Conclusion

XV installment of ICon-MaSTEd was organized by the Academy of Cognitive and Natural Sciences (https://acnsci.org) in collaboration with Kryvyi Rih State Pedagogical University, Ukraine (with support of the rector Prof. Yaroslav Shramko), Kryvyi Rih National University, Ukraine (with support of the rector Prof. Mykola Stupnik), Institute for Digitalisation of Education of the NAES of Ukraine (with support of the director Prof. Oleg Spirin) and Ben-Gurion University of the Negev, Israel (with support of the rector Prof. Chaim Hames).

We are thankful to all the authors who submitted papers and the delegates for their participation and their interest in ICon-MaSTEd as a platform to share their ideas and innovation. Also, we are also thankful to all the program committee members for providing continuous guidance and efforts taken by peer reviewers contributed to improving the quality of papers provided constructive critical comments, improvements, and corrections to the authors are gratefully appreciated for their contribution to the success of the conference. Moreover, we would like to thank the developers of Morressier, who made it possible for us to use the resources of this excellent and comprehensive conference management system, from the call of papers and inviting reviewers, to handling paper submissions and creating the volume of the conference proceedings. Special thanks to session chairs for their work on the conference and its program, excellent and gratefully appreciated conference support.

We are looking forward to excellent presentations and fruitful discussions, which will broaden our professional horizons. We hope all participants enjoy this conference and meet again in a more friendly, hilarious, and peaceful further ICon-MaSTEd 2024. The next meeting in the series is the XVI International Conference on Mathematics, Science and Technology Education, 2024, Kryvyi Rih, Ukraine (https://icon-masted.easyscience.education/2024/).

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References

[1] Kiv A E, Soloviev V N and Semerikov S O 2021 *Journal of Physics: Conference Series* **1840**(1) 011001 URL https://doi.org/10.1088/1742-6596/1840/1/011001
[2] Kiv A E, Soloviev V N, Semerikov S O, Striuk A M, Osadchyi V V, Vakaliuk T A, Nechypurenko P P, Bondarenko O V, Mintii I S and Malchenko S L 2021 *Journal of Physics: Conference Series* **1946**(1) 011001 URL https://doi.org/10.1088/1742-6596/1946/1/011001
[3] Kiv A E, Soloviev V N, Semerikov S O, Striuk A M, Osadchyi V V, Vakaliuk T A, Nechypurenko P P, Bondarenko O V, Mintii I S and Malchenko S L 2022 *Journal of Physics: Conference Series* **2288**(1) 011001 URL https://doi.org/10.1088/1742-6596/2288/1/011001
[4] Kiv A E, Semerikov S O, Striuk A M, Osadchyi V V, Vakaliuk T A, Nechypurenko P P, Bondarenko O V, Mintii I S and Malchenko S L 2023 *Journal of Physics: Conference Series* (1) 011001
[5] Abdillah L A, Sari I N and Indriani D E 2018 *International Journal of Engineering and Technology(UAE)* **7**(3) 1463 – 1467 URL https://doi.org/10.14419/ijet.v7i3.12719
[6] Abuselidze G 2018 *Journal of Applied Economic Sciences* **13**(7) 1929 – 1938
[7] Gabay J, Benson S and Schwartz M 1983 *Journal of Biological Chemistry* **258**(4) 2410 – 2414
[8] Rawat B, Bist A S, Riza B S, Oktariyani A and Rahardja U 2021 Analysis Of Examination Process During

Covid And Post Covid In Indian Context *2021 9th International Conference on Cyber and IT Service Management (CITSM)* pp 1–5 URL https://doi.org/10.1109/CITSM52892.2021.9588821

[9] Kholoshyn I, Nazarenko T, Bondarenko O, Hanchuk O and Varfolomyeyeva I 2021 *Journal of Physics: Conference Series* **1840**(1) 012017 URL https://doi.org/10.1088/1742-6596/1840/1/012017

[10] Derkach T M 2019 *Orbital* **11**(3) 219 – 227 URL https://doi.org/10.17807/orbital.v11i3.1395

[11] Zhaldak M I and Franchuk N P 2021 *Journal of Physics: Conference Series* **1946**(1) 012002 URL https://doi.org/10.1088/1742-6596/1946/1/012002

[12] Belyaeva A, Galuza A, Kolenov I and Mizrakhy S 2021 *Journal of Infrared, Millimeter, and Terahertz Waves* **42**(2) 130–153 ISSN 1866-6906 URL https://doi.org/10.1007/s10762-020-00762-7

[13] Semerikov S O, Vakaliuk T A, Mintii I S, Hamaniuk V A, Soloviev V N, Bondarenko O V, Nechypurenko P P, Shokaliuk S V, Moiseienko N V and Ruban V R 2022 Mask and Emotion: Computer Vision in the Age of COVID-19 *Digital Humanities Workshop* DHW 2021 (New York, NY, USA: Association for Computing Machinery) p 103–124 ISBN 9781450387361 URL https://doi.org/10.1145/3526242.3526263

[14] Hrybiuk O 2022 Experience in Implementing Computer-Oriented Methodological Systems of Natural Science and Mathematics Research Learning in Ukrainian Educational Institutions *Innovations in Mechatronics Engineering* ed Machado J, Soares F, Trojanowska J and Yildirim S (Cham: Springer International Publishing) pp 55–68 ISBN 978-3-030-79168-1 URL https://doi.org/10.1007/978-3-030-79168-1_6

[15] Gurieiev V, Kutsan Y, Iatsyshyn A, Iatsyshyn A, Kovach V, Lysenko E, Artemchuk V and Popov O 2020 Simulating Systems for Advanced Training and Professional Development of Energy Specialists in Power Sector *Proceedings of the 16th International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer. Volume II: Workshops, Kharkiv, Ukraine, October 06-10, 2020* (*CEUR Workshop Proceedings* vol 2732) ed Sokolov O, Zholtkevych G, Yakovyna V, Tarasich Y, Kharchenko V, Kobets V, Burov O, Semerikov S and Kravtsov H (CEUR-WS.org) pp 693–708 URL https://ceur-ws.org/Vol-2732/20200693.pdf

[16] Zinovieva I S, Artemchuk V O, Iatsyshyn A V, Romanenko Y O, Popov O O, Kovach V O, Taraduda D V and Iatsyshyn A V 2021 *Journal of Physics: Conference Series* **1946**(1) 012011 URL https://doi.org/10.1088/1742-6596/1946/1/012011

[17] Pribeanu C, Balog A and Iordache D D 2009 Measuring the usability of augmented reality e-learning systems: A user–centered evaluation approach *Software and Data Technologies* ed Cordeiro J, Shishkov B, Ranchordas A and Helfert M (Berlin, Heidelberg: Springer Berlin Heidelberg) pp 175–186 ISBN 978-3-642-05201-9 URL https://doi.org/10.1007/978-3-642-05201-9_14

[18] Aleksander M B, Dubchak L, Chyzh V, Naglik A, Yavorski A, Yavorska N and Karpinski M 2015 Implementation technology software-defined networking in Wireless Sensor Networks *2015 IEEE 8th International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications (IDAACS)* vol 1 pp 448–452 URL https://doi.org/10.1109/IDAACS.2015.7340776

[19] Kobylnyk T 2017 Statistical Software in the Higher School Educational Process *Proceedings of the 13th International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer, ICTERI 2017, Kyiv, Ukraine, May 15-18, 2017* (*CEUR Workshop Proceedings* vol 1844) ed Ermolayev V, Bassiliades N, Fill H, Yakovyna V, Mayr H C, Kharchenko V S, Peschanenko V S, Shyshkina M, Nikitchenko M S and Spivakovsky A (CEUR-WS.org) pp 311–318 URL https://ceur-ws.org/Vol-1844/10000311.pdf

[20] Kukharenko V N, Fedosova A P, Kolgatin A G and Dosov V G 1992 *Khimicheskoe I Neftegazovoe Mashinostroenie* (5) 19 – 21

[21] Komarova E V 2021 *Journal of Physics: Conference Series* **1840**(1) 012010 URL https://doi.org/10.1088/1742-6596/1840/1/012010

[22] Kramarenko T, Bondar K and Shestopalova O 2021 *Journal of Physics: Conference Series* **1840**(1) 012009 URL https://doi.org/10.1088/1742-6596/1840/1/012009

[23] Kubiatko M, Fančovičová J and Prokop P 2021 *International Journal of Science Education* **43**(9) 1426–1440 URL https://doi.org/10.1080/09500693.2021.1917790

[24] Kukharenko V 2013 Massive open online courses in Ukraine *2013 IEEE 7th International Conference on Intelligent Data Acquisition and Advanced Computing Systems (IDAACS)* vol 02 pp 760–763 URL https://doi.org/10.1109/IDAACS.2013.6663027

[25] Smyrnova-Trybulska E, Morze N, Kuzminska O and Kommers P 2018 *Journal of Information, Communication and Ethics in Society* **16** 381 – 400 URL https://doi.org/10.1108/JICES-03-2018-0028

[26] Levkivskyi V, Lobanchykova N and Marchuk D 2020 *E3S Web Conf.* **166** 05007 URL https://doi.org/10.1051/e3sconf/202016605007

[27] Ivanov M, Maksyshko N, Ivanov S M and Terentieva N 2020 Intelligent data analysis in hr process management *Proceedings of The Third International Workshop on Computer Modeling and Intelligent Systems (CMIS-2020), Zaporizhzhia, Ukraine, April 27-May 1, 2020* (*CEUR Workshop Proceedings* vol

2608) ed Subbotin S (CEUR-WS.org) pp 754–768 URL https://ceur-ws.org/Vol-2608/paper57.pdf

[28] Malchenko S L, Tsarynnyk M S, Poliarenko V S, Berezovska-Savchuk N A and Liu S 2021 *Journal of Physics: Conference Series* **1946**(1) 012010 URL https://doi.org/10.1088/1742-6596/1946/1/012010

[29] Lobanchykova N, Kredentsar S, Pilkevych I and Medvediev M 2021 *Journal of Physics: Conference Series* **1840**(1) 012022 URL https://doi.org/10.1088/1742-6596/1840/1/012022

[30] Milano F, Maggi E and Rosselli del Turco M 2000 *Radiation Protection Dosimetry* **90**(1-2) 263–266 ISSN 0144-8420 URL https://doi.org/10.1093/oxfordjournals.rpd.a033134

[31] Lytvynova S H, Semerikov S O, Striuk A M, Striuk M I, Kolgatina L S, Velychko V Y, Mintii I S, Kalinichenko O O and Tukalo S M 2021 AREdu 2021 - Immersive technology today *Proceedings of the 4th International Workshop on Augmented Reality in Education (AREdu 2021), Kryvyi Rih, Ukraine, May 11, 2021* (*CEUR Workshop Proceedings* vol 2898) ed Lytvynova S H and Semerikov S O (CEUR-WS.org) pp 1–40 URL https://ceur-ws.org/Vol-2898/paper00.pdf

[32] Camilli M, Bellettini C, Capra L and Monga M 2014 CTL Model Checking in the Cloud Using MapReduce *2014 16th International Symposium on Symbolic and Numeric Algorithms for Scientific Computing* pp 333–340 URL https://doi.org/10.1109/SYNASC.2014.52

[33] Yarkov S V, Nazarenko T H, Panteleeva N B, Bondarenko O V and Varfolomyeyeva I M 2022 *IOP Conference Series: Earth and Environmental Science* **1049**(1) 012036 URL https://doi.org/10.1088/1755-1315/1049/1/012036

[34] Nechypurenko P, Evangelist O, Selivanova T and Modlo Y O 2020 Virtual Chemical Laboratories as a Tools of Supporting the Learning Research Activity of Students in Chemistry While Studying the Topic "Solutions" *Proceedings of the 16th International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer. Volume II: Workshops, Kharkiv, Ukraine, October 06-10, 2020* (*CEUR Workshop Proceedings* vol 2732) ed Sokolov O, Zholtkevych G, Yakovyna V, Tarasich Y, Kharchenko V, Kobets V, Burov O, Semerikov S and Kravtsov H (CEUR-WS.org) pp 984–995 URL https://ceur-ws.org/Vol-2732/20200984.pdf

[35] Nosenko Y, Shyshkina M and Oleksiuk V 2016 Collaboration between Research Institutions and University Sector Using Cloud-based Environment *Proceedings of the 12th International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer, Kyiv, Ukraine, June 21-24, 2016* (*CEUR Workshop Proceedings* vol 1614) ed Ermolayev V, Spivakovsky A, Nikitchenko M S, Ginige A, Mayr H C, Plexousakis D, Zholtkevych G, Burov O, Kharchenko V S and Kobets V (CEUR-WS.org) pp 656–671 URL https://ceur-ws.org/Vol-1614/paper_84.pdf

[36] Balyk N, Vasylenko Y, Shmyger G, Oleksiuk V and Skaskiv A 2019 Design of Approaches to the Development of Teacher's Digital Competencies in the Process of Their Lifelong Learning *Proceedings of the 15th International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer. Volume II: Workshops, Kherson, Ukraine, June 12-15, 2019* (*CEUR Workshop Proceedings* vol 2393) ed Ermolayev V, Mallet F, Yakovyna V, Kharchenko V S, Kobets V, Kornilowicz A, Kravtsov H, Nikitchenko M S, Semerikov S and Spivakovsky A (CEUR-WS.org) pp 204–219 URL https://ceur-ws.org/Vol-2393/paper_237.pdf

[37] Osadchyi V V, Osadcha K P, Varina H B, Shevchenko S V and Bulakh I S 2021 *Journal of Physics: Conference Series* **1946**(1) 012022 URL https://doi.org/10.1088/1742-6596/1946/1/012022

[38] Valko N V and Osadchyi V V 2021 *Journal of Physics: Conference Series* **1946**(1) 012016 URL https://doi.org/10.1088/1742-6596/1946/1/012016

[39] Papadakis S, Kalogiannakis M, Orfanakis V and Zaranis N 2014 Novice Programming Environments. Scratch & App Inventor: A First Comparison *Proceedings of the 2014 Workshop on Interaction Design in Educational Environments* IDEE '14 (New York, NY, USA: Association for Computing Machinery) p 1–7 ISBN 9781450330343 URL https://doi.org/10.1145/2643604.2643613

[40] Panchenko L F, Korzhov H O, Kolomiiets T V and Yenin M N 2021 *Journal of Physics: Conference Series* **1840**(1) 012056 URL https://doi.org/10.1088/1742-6596/1840/1/012056

[41] Konstantinov V A, Sagan V V, Revyakin V P, Zvonaryova A V and Pursky O I 2013 *Fizika Nizkikh Temperatur* **39**(5) 606 – 610

[42] Vakaliuk T A, Kontsedailo V, Antoniuk D, Korotun O, Semerikov S and Mintii I S 2020 Using Game Dev Tycoon to Create Professional Soft Competencies for Future Engineers-Programmers *Proceedings of the 16th International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer. Volume II: Workshops, Kharkiv, Ukraine, October 06-10, 2020* (*CEUR Workshop Proceedings* vol 2732) ed Sokolov O, Zholtkevych G, Yakovyna V, Tarasich Y, Kharchenko V, Kobets V, Burov O, Semerikov S and Kravtsov H (CEUR-WS.org) pp 808–822 URL https://ceur-ws.org/Vol-2732/20200808.pdf

[43] Tarasenko R A, Usenko S A, Shapovalov Y B, Shapovalov V B, Paschke A and Savchenko I M 2021 Ontology-based learning environment model of scientific studies *Proceedings of the 9th Illia O. Teplytskyi Workshop*

on Computer Simulation in Education (CoSinE 2021) co-located with 17th International Conference on ICT in Education, Research, and Industrial Applications: Integration, Harmonization, and Knowledge Transfer (ICTERI 2021), Kherson, Ukraine, October 1, 2021 (*CEUR Workshop Proceedings* vol 3083) ed Ermolayev V, Kiv A E, Semerikov S O, Soloviev V N and Striuk A M (CEUR-WS.org) pp 43–58 URL https://ceur-ws.org/Vol-3083/paper278.pdf

[44] Osadcha K, Osadchyi V, Kruglyk V and Spirin O 2021 Modeling of the Adaptive System of Individualization and Personalization of Future Specialists' Professional Training in the Conditions of Blended Learning *Proceedings of the VI International Workshop on Professional Retraining and Life-Long Learning using ICT: Person-oriented Approach (3L-Person 2021) co-located with 17th International Conference on ICT in Education, Research, and Industrial Applications: Integration, Harmonization, and Knowledge Transfer (ICTERI 2021), Kherson, Ukraine, October 1, 2021* (*CEUR Workshop Proceedings* vol 3104) ed Lytvynova S, Burov O Y, Demeshkant N, Osadchyi V and Semerikov S (CEUR-WS.org) pp 43–54 URL https://ceur-ws.org/Vol-3104/paper138.pdf

[45] Shapovalova N, Rybalchenko O, Dotsenko I, Bilashenko S, Striuk A and Saitgareev L 2019 Adaptive Testing Model as the Method of Quality Knowledge Control Individualizing *Proceedings of the 15th International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer. Volume II: Workshops, Kherson, Ukraine, June 12-15, 2019* (*CEUR Workshop Proceedings* vol 2393) ed Ermolayev V, Mallet F, Yakovyna V, Kharchenko V S, Kobets V, Kornilowicz A, Kravtsov H, Nikitchenko M S, Semerikov S and Spivakovsky A (CEUR-WS.org) pp 984–999 URL https://ceur-ws.org/Vol-2393/paper_328.pdf

[46] Sánchez-Begínes J M, Escalona M J, Strutynska O V, Umryk M A, Wojdynski T and Mayo F J D 2017 The Importance of User in ISD. Do We Really Teach? *Information Systems Development: Advances in Methods, Tools and Management - Proceedings of the 26th International Conference on Information Systems Development, ISD 2017, Larnaca, Cyprus, University of Central Lancashire Cyprus, September 6-8, 2017* ed Paspallis N, Raspopoulos M, Barry C, Lang M, Linger H and Schneider C (Association for Information Systems) URL http://aisel.aisnet.org/isd2014/proceedings2017/Education/5

[47] Neves R G and Teodoro V D 2012 *AIP Conference Proceedings* **1479**(1) 1806–1809 ISSN 0094-243X URL https://doi.org/10.1063/1.4756529

[48] Shchokin V and Tkachuk V 2014 *Metallurgical and Mining Industry* **6**(6) 32 – 39

[49] Benitez-Paez F, Comber A, Trilles S and Huerta J 2018 *Transactions in GIS* **22**(3) 806–822 URL https://doi.org/10.1111/tgis.12449

[50] Buyak B, Tsidylo I, Kozibroda S and Repskyi V 2019 Ontological Model of Representation of University Resources *Proceedings of the 15th International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer. Volume II: Workshops, Kherson, Ukraine, June 12-15, 2019* (*CEUR Workshop Proceedings* vol 2393) ed Ermolayev V, Mallet F, Yakovyna V, Kharchenko V S, Kobets V, Kornilowicz A, Kravtsov H, Nikitchenko M S, Semerikov S and Spivakovsky A (CEUR-WS.org) pp 29–40 URL https://ceur-ws.org/Vol-2393/paper_228.pdf

[51] Morze N, Smyrnova-Trybulska E and Umryk M 2015 *International Journal of Continuing Engineering Education and Life Long Learning* **25**(4) 466–486 URL https://doi.org/10.1504/IJCEELL.2015.074230

[52] Sagdeo A, Rai S K, Lodha G S, Singh K P, Yadav N, Dhawan R, Tonpe U and Vahia M N 2010 *Experimental Astronomy* **28**(1) 11–23 ISSN 1572-9508 URL https://doi.org/10.1007/s10686-010-9183-4

[53] Panchenko L F, Vakaliuk T A and Vlasenko K V 2020 Augmented reality books: concepts, typology, tools *Proceedings of the 3rd International Workshop on Augmented Reality in Education, Kryvyi Rih, Ukraine, May 13, 2020* (*CEUR Workshop Proceedings* vol 2731) ed Burov O Y and Kiv A E (CEUR-WS.org) pp 283–296 URL https://ceur-ws.org/Vol-2731/paper16.pdf

[54] Spivakovskiy O, Kushnir N, Valko N and Vinnyk M 2017 ICT Advanced Training of University Teachers *Proceedings of the 13th International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer, ICTERI 2017, Kyiv, Ukraine, May 15-18, 2017* (*CEUR Workshop Proceedings* vol 1844) ed Ermolayev V, Bassiliades N, Fill H, Yakovyna V, Mayr H C, Kharchenko V S, Peschanenko V S, Shyshkina M, Nikitchenko M S and Spivakovsky A (CEUR-WS.org) pp 176–190 URL https://ceur-ws.org/Vol-1844/10000176.pdf

[55] Vlasenko K, Hrudkina N, Reutova I and Chumak O 2018 *Eastern-European Journal of Enterprise Technologies* **3**(1 (93)) 51–59

[56] Shepiliev D S, Modlo Y O, Yechkalo Y V, Tkachuk V V, Mintii M M, Mintii I S, Markova O M, Selivanova T V, Drashko O M, Kalinichenko O O, Vakaliuk T A, Osadchyi V V and Semerikov S O 2020 *CEUR Workshop Proceedings* **2832** 84–93 ISSN 16130073

[57] Vlasenko K V, Lovianova I V, Chumak O O, Sitak I V and Kovalenko D A 2023 *Journal of Physics: Conference Series*

[58] Vlasenko K V, Lovianova I V, Achkan V V, Armash T S and Chumak O O 2023 *Journal of Physics:*

Conference Series
[59] Achkan V V, Vlasenko K V, Lovianova I V, Sitak I V and Armash T S 2023 *Journal of Physics: Conference Series*
[60] Semenets S P, Semenets L M, Andriichuk N M, Chugunova O V and Lutsyk O M 2023 *Journal of Physics: Conference Series*
[61] Akhiiezer O B, Haluza O A, Savchenko A O, Lyubchyk L M, Protsay N T and Aslandukov M O 2023 *Journal of Physics: Conference Series*
[62] Kramarenko T H and Kochina O S 2023 *Journal of Physics: Conference Series*
[63] Zdeshchyts A V and Zdeshchyts V M 2023 *Journal of Physics: Conference Series*
[64] Kukharchuk R P, Vakaliuk T A, Zaika O V, Riabko A V and Medvediev M G 2023 *Journal of Physics: Conference Series*
[65] Patero J L 2023 *Journal of Physics: Conference Series*
[66] Samson E C, Plaza C B and Patero J L 2023 *Journal of Physics: Conference Series*
[67] Pursky O I, Gamaliy V F, Demidov P G, Dubovyk T V, Buchatska I O and Forostyana N P 2023 *Journal of Physics: Conference Series*
[68] Culaba I B, Maquiling J T and delos Santos R M 2023 *Journal of Physics: Conference Series*
[69] Malchenko S L, Poliarenko V S and Prykhozha Y O 2023 *Journal of Physics: Conference Series*
[70] Shakhman I O and Bystriantseva A M 2023 *Journal of Physics: Conference Series*
[71] Bondarenko O V, Hanchuk O V, Pakhomova O V and Varfolomyeyeva I M 2023 *Journal of Physics: Conference Series*
[72] Zinovieva I S, Iatsyshyn A V, Artemchuk V O, Stanytsina V V, Sheludchenko L S, Popov O O, Kovach V O and Iatsyshyn A V 2023 *Journal of Physics: Conference Series*
[73] Bolotina V V, Vakaliuk T A, Harbych-Moshora O R and Kontsedailo V V 2023 *Journal of Physics: Conference Series*
[74] Sitsylitsyn Y O, Osadchyi V V, Kruglyk V S and Kuzminska O G 2023 *Journal of Physics: Conference Series*
[75] Klochko O V, Fedorets V M, Klochko V I and Klochko K A 2023 *Journal of Physics: Conference Series*
[76] Dotsenko N A, Gorbenko O A and Haleeva A P 2023 *Journal of Physics: Conference Series*
[77] Derkach T M, Bilianska M M and Yaroshenko O G 2023 *Journal of Physics: Conference Series*
[78] Bazurin V M, Karpenko Y M and Pursky O I 2023 *Journal of Physics: Conference Series*
[79] Derkach T M, Bilianska M M and Yaroshenko O G 2023 *Journal of Physics: Conference Series*
[80] Osadcha K P, Osadchyi V V, Symonenko S V and Medynska S I 2023 *Journal of Physics: Conference Series*
[81] Symonenko S V, Zaitseva N V, Osadcha K P and Sliusar A I 2023 *Journal of Physics: Conference Series*
[82] Lemeshchenko-Lagoda V V and Kryvonos I A 2023 *Journal of Physics: Conference Series*
[83] Mintii M M, Sharmanova N M, Mankuta A O, Palchevska O S and Semerikov S O 2023 *Journal of Physics: Conference Series*
[84] Fedorets V M and Klochko O V 2023 *Journal of Physics: Conference Series*
[85] Amelina S M, Tarasenko R O and Semerikov S O 2023 *Journal of Physics: Conference Series*
[86] Semerikov S O, Vakaliuk T A, Mintii I S and Didkivska S O 2023 *Journal of Physics: Conference Series*
[87] Kuzminska O H, Morze N V and Osadchyi V V 2023 *Journal of Physics: Conference Series*
[88] Zaitseva N V, Symonenko S V, Vynogradova M S, Osadcha K P and Vasilyuk O M 2023 *Journal of Physics: Conference Series*
[89] Mintii I S 2023 *Journal of Physics: Conference Series*
[90] Mintii M M 2023 *Journal of Physics: Conference Series*
[91] Palamar S P, Brovko K A and Semerikov S O 2023 *Journal of Physics: Conference Series*
[92] Bilousova L I and Gryzun L E 2023 *Journal of Physics: Conference Series*
[93] Shapovalov Y B, Slipukhina I A and Shapovalov V B 2023 *Journal of Physics: Conference Series*
[94] Varina H B, Kruglyk V S, Shevchenko S V, Kovalova O V and Voloshyna V V 2023 *Journal of Physics: Conference Series*
[95] Pacala F A A 2023 *Journal of Physics: Conference Series*

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Peer Review Statement

To cite this article: 2023 *J. Phys.: Conf. Ser.* **2611** 011002

Peer Review Statement

All papers published in this volume have been reviewed through processes administered by the Editors. Reviews were conducted by expert referees to the professional and scientific standards expected of a proceedings journal published by IOP Publishing.

- **Type of peer review:** Double Anonymous
- **Conference submission management system:** Morressier
- **Number of submissions received:** 58
- **Number of submissions sent for review:** 53
- **Number of submissions accepted:** 39
- **Acceptance Rate (Submissions Accepted / Submissions Received × 100):** 67.2
- **Average number of reviews per paper:** 3.05
- **Total number of reviewers involved:** 51
- **Contact person for queries:**
  Name: Serhiy O. Semerikov
  Email: semerikov@gmail.com
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Journal of Physics: Conference Series

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The Wheel of Mathematics Learning Methods

To cite this article: K V Vlasenko *et al* 2023 *J. Phys.: Conf. Ser.* **2611** 012001

The Wheel of Mathematics Learning Methods

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Abstract. The article is devoted to the creation of a wheel of mathematics learning methods. The study analyzed how Bloom's taxonomy is used by the educational community. Special attention is paid to the study of the issue of bringing to a single system a set of disparate goals and tasks of learning in new models of education, which provide for the openness of learning to new technologies. Analysis of scientific works and resources helped to determine the structuring of the Wheel of Mathematics Learning Methods (WMLM). The authors of the article identified the areas of didactics that should fill the wheel: Competencies, Motivation, Bloom's Taxonomy, Activities, and Technologies. A structured set of hints for the teacher is presented in the form of 5 sectors of the wheel: Apply, Analyze, Evaluate, Create, Remember Understand. Each sector is a set of constituent components Methods, Forms, Tools, Activities and Active Verbs. The analysis of the results of the survey of 58 respondents proved that Bloom's taxonomy is important both in the selection of teaching methods and means and in the determination of effective forms of organization of educational activities. It was concluded that the idea of developing a methodology wheel should be based on the structuring of a set of tips for the teacher at all stages of activity from planning to implementation of mathematics education.

1. Introduction

When you come across an exciting new method for learning Mathematics, you think: 'This is cool, can I use this method in my classroom?', but then you realize that you need to think about how the use of this method can contribute to the achievement of the educational goals of the program you are teaching. It was this issue and the desire to help Mathematics teachers make the right decisions when choosing teaching methods that led to the emergence of the Wheel of Mathematics Learning Methods (WMLM). The methodology Wheel combined several different areas of didactic thinking in one diagram. In this integrated structure were placed the methods, forms and means of learning related to the educational purpose that they are most likely to serve. This then enabled mathematics teachers to identify the pedagogical place and purpose of their various technology-based learning and teaching activities in the context of their overall course objectives and regarding the wider developmental needs of their students.

What goals and specific tasks does the teacher set for himself before entering the classroom? How are they related? And how to check whether the set goals are being achieved? Bloom asked these questions in the 1950s. Trying to bring a set of disparate goals and tasks to a single system, Bloom created a theory that has been the subject of heated debate and discussion for the sixth time. In his fundamental work 'Taxonomy of Educational Objectives: The Classification of Educational Goals', Bloom [1] tried to construct a hierarchy of educational goals covering the cognitive domain, which would describe step by step the levels of human thinking and the learning tasks that follow from this. Bloom [1] divided the goals of education into three areas: cognitive (requirements for mastering the content of the subject), psychomotor (development of motor, neuromuscular activity) and affective (emotional value area, attitude to the subject). The first taxonomy, covering the cognitive domain, includes six categories of goals with their internal more fractional division.

From Bloom's point of view, learning goals directly depend on the hierarchy of mental processes, such as remembering, understanding, applying, analyzing, evaluating, and creating. At the same time, each level of the cognitive pyramid, according to Bloom, is based on the previous one. The basis of everything is memorization (knowledge), and the highest point of both cognitive abilities and learning goals is the ability to independently evaluate. The idea is clear: without memorization and knowledge, understanding is impossible, without understanding, use is impossible, without mastering the initial levels, analysis and synthesis are impossible, and without all this, one cannot imagine a creative assessment of phenomena and events.

Bloom's taxonomy has become a very important element in the educational community and has been adopted by many educational institutions in the United States and abroad [2], but in the future, due to increasing criticism, it began to be used less. According to scientists, concepts of different orders are mixed in this hierarchy, namely, specific learning results (memorization, understanding, application) and mental operations necessary to achieve these results (analysis, synthesis, evaluation). However, this did not prevent teachers from different countries from using the proposed hierarchy and creating meaningful and systematized tasks aimed at the intellectual development of students. The team of scientists Anderson et al. [3] revised the taxonomy, changing its content and swapping its levels.

After the modernization of the taxonomy, a model called 'Pedagogical Wheel' ('Pedagogical Wheel', from 'iPad) appeared in Carrington's blog [4], in which they found intersection points of the goals of Bloom's taxonomy and options for using useful iPad applications for the appropriate group.

The taxonomy also attracted the attention of scientists Ellerton et al. [5], who showed the use of the Wheel of didactics, focusing on non-trivial mathematical tasks in secondary school. The scientists described the selection of methods, forms and means of learning by young teachers according to pre-selected types of activity with the help of the developed wheel. Scientists presented fragments of classes demonstrating the use of the Wheel in high school practice.

The idea of involving the Wheel during training captured Ping and Hua [6]. The researchers developed a didactic Wheel and used it during elementary school student's mastery of division. To develop the components of the Wheel, scientists used a survey, which helped in the selection of means that can accompany the division process. The involvement of the Wheel during the educational process contributed to positive dynamics in students' learning of division actions.

The place of taxonomy in their developments was found by Bobis et al. [7], who developed a Wheel of mathematical instructions and used it to improve the motivation of high school students and their involvement in the educational process. The development of the Wheel was based on the main types of activity proposed by Bloom's taxonomy. The Wheel also offers technologies that can provide the specified activity.

Kim [8] devoted his study to the involvement of students in certain types of activity. The scientist described his experience in developing the methodology Wheel as a multidisciplinary system. This study embodies the advances from the development and application of an educational model that considers the learning of both the humanities (History, Geography, and Bibliography) and the five domains of STEAM (Science, Technology, Engineering, Art, and Mathematics) [9].

To expand the limits of creative activity of teachers and students, the Intel "Teach to the Future" program is being implemented in different countries [10]. This program has already reached more than 1.75 million teachers from 35 countries around the world. Among the tasks of the program is the promotion of the development of student and teacher skills that involve the use of high-level thinking. This list [11] is also based on Bloom's taxonomy.

So, one can endlessly argue about the values of Bloom's classification of pedagogical goals. But there is an obvious fact – taxonomy does not lose its relevance. Moreover, it is used not only in the framework of traditional education but also in completely new models that provide for the interactivity of learning and its openness to new technologies.

The purpose of our research is to develop a Wheel of Mathematics Learning Methods.

2. Method

To develop the WMLM, we used the analysis of the answers of mathematics teachers and master's students of pedagogical and classical Institutions of Higher Education. 58 respondents took part in the survey. The questionnaire contained 18 questions and was developed using an open online service and posted on the Internet at the link `https://docs.google.com/forms/d/e/1FAIpQLScpCJ6Vq4aiVqvOC-5Ln5LTDgiTOSwlxJohmnsHFBaK75rDfQ/viewform`.

All teachers agreed with the idea that several different areas of didactics should be combined in one diagram, proposed in the form of a wheel. What kind of areas is this? The driving force of any method is motivation. Motivation makes students active and is supported by the use of certain learning technologies. The chosen technologies should provide the main types of activity proposed by Bloom's taxonomy. The given types of activities should be adjusted according to the mathematical competencies that should be formed in students during the mastery of mathematical subjects (figure 1). We consider each area as a sieve through which the process of developing Mathematics learning methods is filtered. Therefore, the specified areas of didactics work like wheels that turn and move each other. There are five such wheels. It is considered in more detail.

2.1. Competencies

Competencies are at the heart of learning design. Mathematical competencies meet the long-term goals of educational programs and ensure the student's employability. The teacher must constantly review the educational program and check how much it contributes to the development of certain abilities. This means that each teacher, taking into account the opinions of employers, must formulate his expectations from students. This can be helped by asking, 'How does what I do meet certain expectations? Can the content I create help students change to meet the expectations of it?'.

2.2. Motivation

Motivation is the most important component of any method. It moves both the student and the teacher, each time providing an answer to the question 'Why am I doing this again?'. By choosing learning outcomes, and selecting types of activities, the teacher designs content and selects learning technologies to ensure student motivation, which was so well presented by Pink in his TEDtalk 'The Puzzle of Motivation' [12].

2.3. Bloom's taxonomy

Bloom's taxonomy is a tool that can help a teacher develop educational goals that ensure the formation of thinking in students, the order of which is constantly growing. It all starts with

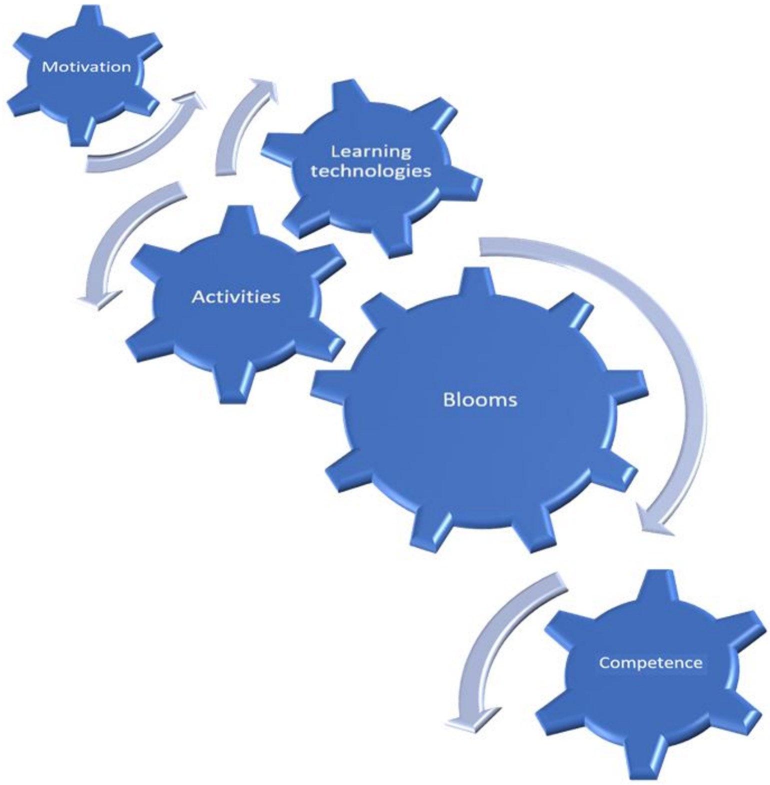

Figure 1. Wheels of didactics.

simple 'memorization and understanding', growing into 'analysis and creation' ensuring the transformation of students. This is made possible by obtaining at least one learning goal from each of the categories that work on the formation of higher-order thinking.

2.4. Activities

The transformation of students' thinking takes place in the process of organizing their activities. The correspondence of students' activities to each type of thinking is ensured through the involvement of special tasks and exercises aimed at students' mastery of knowledge and skills, the development of intellectual and cognitive processes and sustainable professional motivation to achieve success, as well as the creation of a friendly atmosphere that contributes to the disclosure and manifestation of the student's personality.

Having decided on the types of activities, we have been ready to choose learning technologies.

2.5. Technologies

The organization of certain student activities is ensured through the developed technology of teaching and learning (methods, forms, and means). Classical methods of teaching [13] and forms of organization of the learning process are accompanied by the use of learning tools that help create the necessary conditions for achieving the goal of learning. The Wheel offers learning technologies that help sustain activities by stimulating student motivation. The use of the mentioned teaching technologies and Active Verbs has a twofold nature: firstly, the teacher, implementing his educational project, promotes the development of high-level thinking skills in students, and secondly, the teacher can make sure that the implementation of such a project contributes to the development of students.

2.6. How it works

The wheel should be seen as a structured set of prompts that provide opportunities to reflect on teaching, from planning to implementation. These prompts are interconnected, like mechanical mechanisms that ensure the development of methods for learning Mathematics and the selection of its components. During their selection, one should be prepared for the fact that a decision made in one of the areas often affects other decisions (figure 2).

Figure 2. The Wheel of Mathematics Learning Methods.

3. Results

The results of an online survey of Mathematics teachers and master's students of pedagogical and classical higher education institutions, which was carried out during the study, showed the following.

Among the teaching methods that contribute to better memorization of the material by students, teachers could choose not only classical methods according to Lerner and Skatkin [14] but also active (gaming), project methods, etc. Respondents preferred the explanatory and illustrative methods (73.6%), the research method (66%), and the problem-search method (62.3%). However, active methods (business games) received support from almost 50% of respondents.

Regarding the formation of students' understanding of the material, 67.9% of teachers recognized the problem-search method as the most appropriate for this, 62.3% – chose the explanatory and illustrative method, 52.8% – the research method, and the method of building mathematical models was supported by almost 50% of teachers.

In addition, the research method was chosen by the majority of teachers (73.1%) as the most appropriate for forming students' ability to use the material, and the method of building mathematical models was chosen by 53.8%. It is interesting that, along with classical methods, teachers also actively chose project methods (52%) and game methods (52%).

The results of the questionnaire regarding the most popular methods according to the objectives of Bloom's taxonomy of methods are shown in figure 3.

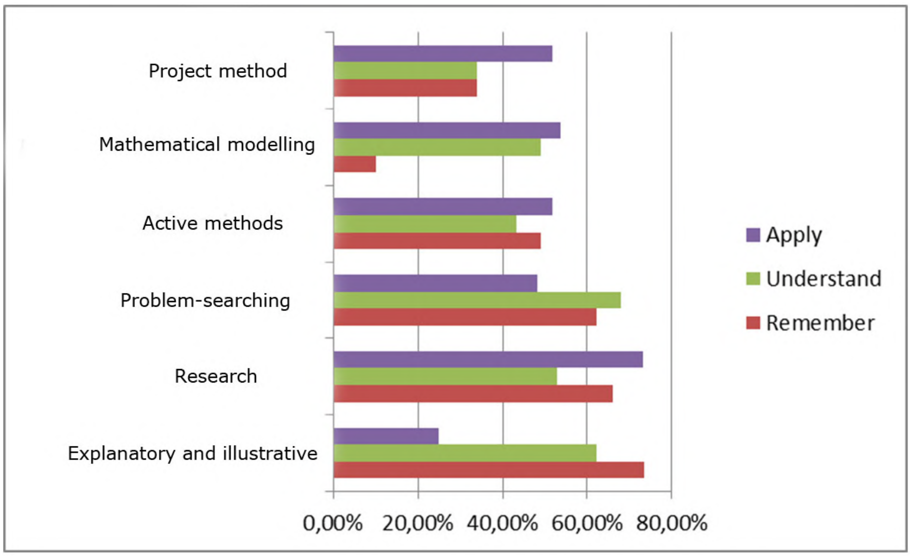

Figure 3. Distribution of teaching methods for the formation of memorization, understanding and application of the material by students.

The problem-search method (76.9%) and logical methods of cognition (75%) were recognized as the most appropriate for the formation of student's ability to analyze and synthesize. It should be noted that the research method was popular among teachers. Thus, it was chosen by 71.2% of teachers as the most appropriate for forming students' ability to evaluate phenomena and events. And logical methods of cognition were chosen by 55.8% of teachers to achieve this goal (figure 4).

As for the teaching means that are most appropriate for students to remember and understand the material, the majority of respondents chose materialized ones (images, diagrams, tables, reference notes), and noted the use of presentations, videos, slide lectures, online calculators, etc. However, most teachers (63.5%) gave preference to intellectual means (educational texts and their media: textbooks, manuals; systems of problems, questions) for the formation of students' ability to use the material. These same means were chosen by the majority of teachers (69.2%)

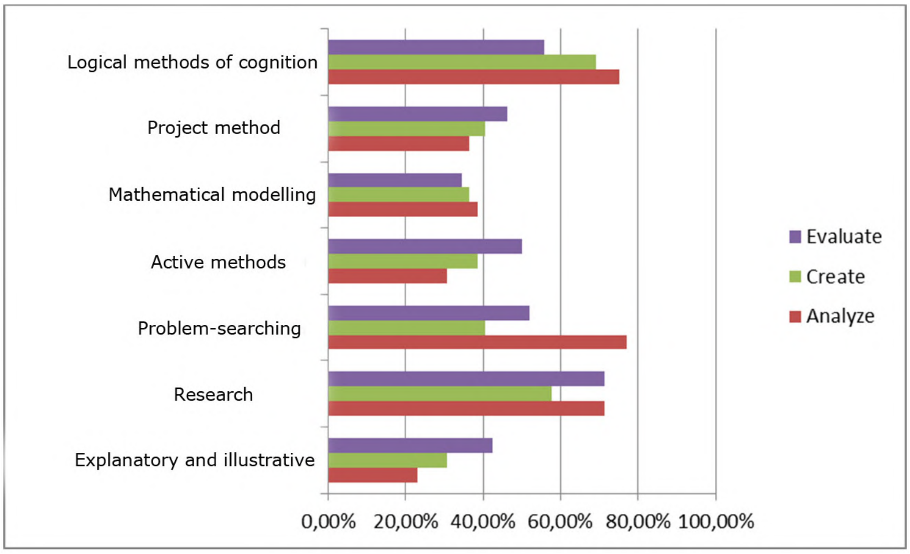

Figure 4. Distribution of teaching methods for the formation of the ability to analyze, synthesize and evaluate phenomena.

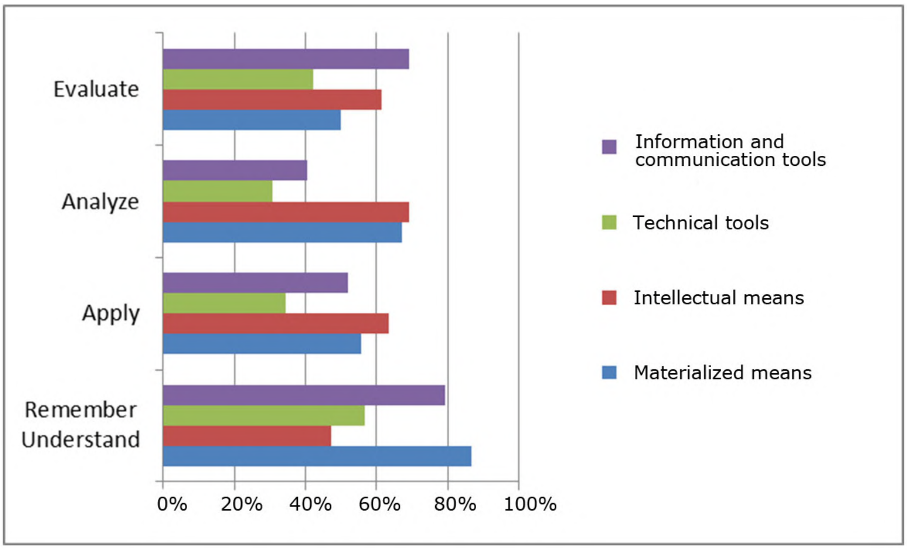

Figure 5. Distribution of learning means to achieve goals according to Bloom's taxonomy.

as the most appropriate for the formation of analytical skills.

According to the majority of respondents, information and communication tools (69.2%) and intellectual means (61.5%) are the most appropriate for forming students' ability to evaluate phenomena and events. The distribution of funds is shown in figure 5.

Organization's forms of educational activities to achieve goals concerning Bloom's taxonomy, according to respondents, were distributed as follows:

- for memorizing the material, individual forms of work were chosen as the most appropriate (66%);
- it was chosen group and pair work (64.2%) and practical and laboratory work (64.2%) to develop students' understanding of the material;

- 92.3% of respondents chose practical and laboratory work to form students' ability to use the material;
- 65.4% chose individual forms of work to develop student's analytical skills;
- practical and laboratory work (72.5%) was chosen as a leader among the forms of organization of educational activities for the formation of synthesis skills in students
- practical and laboratory work (76.9%) received the maximum number of votes for students' ability to evaluate phenomena and events.

Thus, the analysis of the received respondents' answers was laid as the basis of the WMLM.

4. Discussion

Analysis of the research papers of Carrington [4] (on the creation of the 'Pedagogical Wheel' model), Ellerton et al. [5] (on the use of the didactic Wheel), Ping and Hua [6] (about the involvement of the Wheel during learning) confirmed the relevance of the construction of the methodology Wheel, as a way of bringing to a single system a set of disparate goals and tasks of learning Mathematics. During the construction of the methodology Wheel, the authors of these studies decided on a system of principles: humanity and professional orientation, systematicity and flexibility, dynamism and variability. The author's choice of such a system of principles is consistent with Perogonchuk's research (2018) [15], which highlighted the idea of using several scientific approaches during pedagogical modelling [15].

The approach to the development of the WMLM was as follows.

It was chosen the method of analysis of theoretical and practical investigations in the field of development and involvement of the methodology Wheel, as well as the analysis of the answers of Mathematics teachers and students of higher education institutions. The need to develop a questionnaire to identify the needs of teachers and students in the learning process was confirmed by the research of Knowles and Kalata [16], Kebritchi et al. [17], Porter [18]. The analysis of respondents' answers made it possible to single out those areas of didactics that should fill the WMLM, namely: Competencies, Motivation, Bloom's Taxonomy, Activities, Technologies.

The authors of this article presented the WMLM as a structured set of tips in the form of a ring divided into 5 sectors: Apply, Analyze, Evaluate, Create, Remember Understand. The concentric layers of the ring, in turn, define a set of components, such as Active Verbs, Activities, Methods, Forms, and Tools. Thus, the authors propose a two-dimensional lattice in the form of a wheel, with each cell having a double characteristic. Bloom's taxonomy fills the content of each cell according to its characteristics. For example: in a cell characterized by the following Analyze-Methods parameters, we find the following tips corresponding to Bloom's taxonomy: reproductive, problem teaching, partial search, and research.

In this way, the WMLM contains structured tips for teachers, from which it becomes clear: 1) which teaching methods should be selected following the formation of high-level thinking skills according to Bloom's taxonomy; 2) how to decide on the types of means most appropriate for mental activity; such as memorization, understanding, analysis, evaluation of phenomena, etc.; 3) how to choose effective forms of organization of educational activities to achieve goals according to Bloom's taxonomy.

Developing structured tips for Mathematics teachers, the authors of this paper take into account the opinion of Shaikh and Khoja [19] and Vlasenko et al. [20–24], according to whom the teacher's professional activity at all its stages from planning to implementation should be aimed at achieving goals of student development.

5. Conclusions

The analysis of resources and scientific research confirmed the conclusion about the need to bring to a single system a set of different goals and tasks of learning Mathematics in the conditions of applying new education models. The educational community's use of Bloom's classification of educational goals is relevant today. This prompted the authors of this study to create the Wheel of Mathematics learning Methods, a system of structured prompts for the teacher at all stages of learning.

The development of the WMLM consisted of several stages. In the first stage, the authors of the study decided on the areas of didactics that would be presented in the form of a wheel. The results of the survey of Mathematics teachers made it possible to determine the following areas: Competencies, Motivation, Bloom's Taxonomy, Activities, and Technologies. At the next stage, it was determined the content of the 5 sectors of the Wheels. The authors filled each sector (Apply, Analyze, Evaluate, Create, Remember Understand) with tips and hints that allow the teacher to implement Activities, Active Verbs of Bloom's taxonomy and components of the classical methodological system such as methods, forms, and means.

The authors of the article established that Bloom's taxonomy has a direct advantage both at the stage of selecting teaching methods and means or tools and at the time of determining effective forms of organization of educational activities. This allowed the authors of this study to establish types of teaching methods and means that are most effective for the formation of certain high-level thinking skills concerning Bloom, as well as to rank the forms according to their effectiveness in achieving the goals based on Bloom's taxonomy.

The vector of further research is the study of the effectiveness of the WMLM on the results of Mathematics learning of students of higher education institutions.

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References

[1] Bloom B S (ed) 1956 *Taxonomy of Educational Objectives: The Classification of Educational Goals* vol Handbook 1: Cognitive Domain (Longmans) URL https://eclass.uoa.gr/modules/document/file.php/PPP242/Benjamin%20S.%20Bloom%20-%20Taxonomy%20of%20Educational%20Objectives%2C%20Handbook%201_%20Cognitive%20Domain-Addison%20Wesley%20Publishing%20Company%20%281956%29.pdf
[2] Kukharenko V, Shunevych B and Kravtsov H 2022 *Educational Technology Quarterly* **2022** 1–19 URL https://doi.org/10.55056/etq.4
[3] Anderson L W, Krathwohl D E, Airasian P W, Cruikshank K A, Mayer R E, Pintrich P R, Raths J and Wittrock M C (eds) 2001 *A Taxonomy for learning teaching and assessing: A revision of Bloom's taxonomy of educational objectives* (Addison Wesley Longman, Inc.) URL https://www.uky.edu/~rsand1/china2018/texts/Anderson-Krathwohl%20-%20A%20taxonomy%20for%20learning%20teaching%20and%20assessing.pdf
[4] Carrington A 2012 The Padagogy Wheel ... it's a Bloomin' Better Way to Teach URL https://designingoutcomes.com/the-padagogy-wheel-its-a-bloomin-better-way-to-teach/
[5] Ellerton N F, Vaiyavutjamai P and Clements M A K 2012 Reinventing the Wheel: Historical Perspectives on Theories for Interpreting Discourse Patterns in Mathematics Classrooms *Mathematics education: Expanding horizons (Proceedings of the 35th annual conference of the Mathematics Education Research Group of Australasia)* ed Dindyal J, Cheng L P and Ng S F (Singapore: MERGA) URL https://files.eric.ed.gov/fulltext/ED573200.pdf
[6] Ping O W and Hua A K 2015 *IOSR Journal of Research & Method in Education (IOSR-JRME)* **5** 52–56 URL https://doi.org/10.9790/7388-05345256
[7] Bobis J, Anderson J, Martin A and Way J 2011 A Model for Mathematics Instruction to Enhance Student Motivation and Engagement *Motivation and Disposition: Pathways to Learning Mathematics* vol 73 ed Brahier D J (Reston, US: National Council of Teachers of Mathematics) pp 31–42 URL https://www.creatingrounds.com/uploads/9/6/2/4/96240662/a_model_for_mathematics_instruction.pdf

[8] Kim P W 2016 *Eurasia Journal of Mathematics, Science and Technology Education* **12(10)** URL https://doi.org/10.12973/eurasia.2016.1263a
[9] Trubavina I, Vorozhbit-Gorbatyuk V, Shtefan M, Kalina K and Dzhus O 2021 *Educational Technology Quarterly* **2021** 51–72 URL https://doi.org/10.55056/etq.56
[10] Kramarenko T H and Shokaliuk S V 2013 *CTE Workshop Proceedings* **1** 106 URL https://doi.org/10.55056/cte.150
[11] Keynes J M 1936 *The General Theory of Employment, Interest and Money* (Harcourt, Brace and Company) URL https://www.files.ethz.ch/isn/125515/1366_keynestheoryofemployment.pdf
[12] Pink D 2009 The puzzle of motivation URL https://www.ted.com/talks/dan_pink_the_puzzle_of_motivation
[13] Semerikov S O, Teplytskyi I O, Soloviev V N, Hamaniuk V A, Ponomareva N S, Kolgatin O H, Kolgatina L S, Byelyavtseva T V, Amelina S M and Tarasenko R O 2021 *Journal of Physics: Conference Series* **1840** 012036 ISSN 17426588 URL https://doi.org/10.1088/1742-6596/1840/1/012036
[14] Lerner I I and Skatkin M N 1965 *Soviet Education* **7** 43–56 URL https://doi.org/10.2753/RES1060-9393070943
[15] Perogonchuk N 2018 Development model of professional competence of future psychologists *Development trends in pedagogical and psychological sciences: the experience of countries of Eastern Europe and prospects of Ukraine* (Riga, Latvia: Baltija Publishing) pp 151–170 URL https://dspace.uzhnu.edu.ua/jspui/handle/lib/21349
[16] Knowles E and Kalata K 2007 *Innovate: Journal of Online Education* **4**(2) 3 URL https://nsuworks.nova.edu/innovate/vol4/iss2/3/
[17] Kebritchi M, Lipschuetz A and Santiague L 2017 *Journal of Educational Technology Systems* **46** 4–29 URL https://doi.org/10.1177/0047239516661713
[18] Porter L R 2004 *Developing an Online Curriculum: Technologies and Techniques* (Information Science Publishing)
[19] Shaikh Z A and Khoja S A 2012 *Digital Education Review* (21) 23–32 URL https://doi.org/10.1344/der.2012.21.23-32
[20] Vlasenko K, Chumak O, Sitak I, Lovianova I and Kondratyeva O 2019 *Universal Journal of Educational Research* **7** 1892–1900 ISSN 23323205 URL https://doi.org/10.13189/ujer.2019.070907
[21] Vlasenko K, Chumak O, Achkan V, Lovianova I and Kondratyeva O 2020 *Universal Journal of Educational Research* **8** 3527–3535 ISSN 23323205 URL https://doi.org/10.13189/ujer.2020.080828
[22] Vlasenko K, Chumak O, Lovianova I, Kovalenko D and Volkova N 2020 *E3S Web of Conferences* **166** 10011 ISSN 25550403 URL https://doi.org/10.1051/e3sconf/202016610011
[23] Achkan V, Vlasenko K, Chumak O, Sitak I and Kovalenko D 2022 *Journal of Physics: Conference Series* **2288** 012020 URL https://doi.org/10.1088/1742-6596/2288/1/012020
[24] Vlasenko K, Rovenska O, Lovianova I, Tarasenkova N and Achkan V 2022 *Journal of Physics: Conference Series* **2288** 012019 URL https://doi.org/10.1088/1742-6596/2288/1/012019

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Interdisciplinary connections of Mathematics and Literature in the preparation for External Independent Assessment of Humanities students

To cite this article: K V Vlasenko *et al* 2023 *J. Phys.: Conf. Ser.* **2611** 012002

Interdisciplinary connections of Mathematics and Literature in the preparation for External Independent Assessment of Humanities students

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Abstract. This article examines the issue of finding new methodological approaches to the development of problems that can contribute to the preparation of 'Humanities' students to pass the state final certification in the format of External independent assessment (EIA). The study analyzes the existing development of methods of qualitative mathematical training of students of humanities classes who study Mathematics according to the basic level program. In particular, the authors of the article were interested in the use of interdisciplinary connections between Mathematics and humanitarian disciplines. The authors of the article identified cross-curricular problems as a means of forming students' motivation to study Mathematics, as well as a toolkit for measuring their level of readiness to solve typical problems of EIA. The researchers set a goal to develop cross-curricular problems following the EIA program based on the plot of Bulgakov's novel 'The Master and Margarita'. An experiment was conducted to confirm the effectiveness of the use of the system of interdisciplinary problems in the preparation for the EIA of humanitarian students. The obtained results confirmed that the implementation of problems in which the intersubject connections of Mathematics and Literature are realized has a more significant effect on both increasing the motivation of students to study Mathematics and their mathematical preparation.

1. Introduction

Since 2021, passing the final state certification in the format of EIA has become mandatory in Ukraine for all graduates of secondary education institutions. The statistics of the results of the 2021 EIA show that more than 32% of high school students did not pass the EIA in Mathematics, which is almost twice the number of students who did not pass the EIA in other academic subjects. Such results are explained by the low level of motivation of students studying in humanities classes to learn mathematical disciplines. Therefore, to increase the interest of these high school students, and to help them prepare for the EIA in Mathematics, the authors of the article come up with a proposal to develop interdisciplinary Mathematics problems for students of humanities classes, which are based on the content of specialized disciplines.

The purpose of the article is to develop and implement cross-curricular problems per the extracurricular program based on the plot of Bulgakov's novel 'The Master and Margarita' [1] to prepare students of humanities classes for the state final certification in Mathematics in the format of EIA.

2. Related works

Investigating the problem of the relationship between Mathematics and Art, Damrau et al. [2] devoted their work to the following areas: mathematical learning based on artistic procedures, artistic objects as a source of inspiration for studying Mathematics, Image Statistics, Symmetry and Geometry. Analyzing the conclusions of scientists, the authors of this article chose mathematical learning based on works of art as their direction.

Searching for research in this area helped the authors of this paper get acquainted with the work of Fujiwara [3], who believes that although Literature and Mathematics are related to creativity and appreciate beauty and harmony, their methodologies differ. Mathematics is based on universal logic pursued by a mathematical sense and an aesthetic sensibility, while Literature requires originality and sensitivity to words. We accepted this challenge and decided to combine the aesthetic sensibility of Mathematics with the literary sensibility of words. It was also decided to show that it is possible to connect Literature and Mathematics for Humanities students to increase their interest in studying Mathematics and increase their basic knowledge. This opinion is consistent with the conclusions of researchers Johansen et al. [4], who see that the involvement of creativity (the nature of problems and the way they are presented) in Mathematics classes contributes to increasing the interest of students in studying and researching mathematical problems, improves their basic knowledge of the subject. We agree that mathematical problems related to literary works will help students in the Humanities to become interested in Mathematics and prepare for EIA.

Tisngati and Genarsih [5] assign a significant role in the study of Mathematics to mathematical problems. In their opinion, there is a clear connection between solving mathematical problems and students' mathematical and reflective thinking. That is why we have created a system of mathematical problems for the preparation of high school students who study in humanities classes and classes with a creative inclination for the EIA in Mathematics.

Weinstein [6] believes that children's literature is an alternative method of learning Mathematics for elementary school students. She sees the advantages of using children's literature in the fact that, thanks to the books, students can understand where exactly the knowledge of Mathematics is used in everyday life and how it is related to other educational subjects. Based on this idea, the scientist wrote a book that helps students learn to add and subtract fractions using different calculation methods.

Ochkov and Andreas [7] give examples of the integration of Classical Literature in Mathematics classes. They analyzed such works of art as Chekhov's 'The Tutor', Dostoevsky's 'The Gambler', Verne's 'Twenty Thousand Leagues Under the Sea', Molière's 'Le Bourgeois Gentilhomme', Rachinskij's '1001 Tasks for Mental Calculation' [8] and demonstrated what mathematical problems can be developed on their basis. We studied the researchers' approach and decided to demonstrate the connection of Bulgakov's novel 'The Master and Margarita' [1] with Mathematics by the method of composing a system of mathematical problems.

3. Methods

The system of problems was compiled following the six content lines (sections) of Mathematics (Numbers and Expressions; Equations, Inequalities and their Systems; Functions; Combinatorics, Probability Theory, Statistics; Planimetry; Stereometry) and types of problems that are found in EIA. When compiling the problems, it was taken into account that all problems will be open-ended with a short answer. We also used the following methods:

- primary research and information gathering: analysis of external independent assessment tests in Mathematics of previous years from the main, additional and trial sessions [9];
- systematization and structural analysis: selection of the main content lines and their sections, which are found in EIA;
- data processing: the creation of a system of problems with an open, short answer for preparation for the EIA in Mathematics based on the plot of Bulgakov's novel 'The Master and Margarita'.

Based on such research methods, a system of problems was compiled for the preparation for the EIA in Mathematics of high school students who study in 'Humanities' and classes with a creative inclination. It is given examples of problems of the developed system (table 1).

Table 1: A system of problems in Mathematics for preparation for EIA, based on Bulgakov's novel 'The Master and Margarita'.

Academic discipline	Section	Topic	Problem
Algebra and Analysis	Numbers and Expressions	Real numbers	Two friends read the novel 'The Master and Margarita'. One of them took the book from the library, which had 382 pages, and the second read the book online, which had 124 pages. It is known that the second friend read 105 pages. Determine how much does this compare with the pages of a book on paper?
		Relationships and proportions Percentages. Text problems	In Mikhail Bulgakov's novel 'The Master and Margarita', the story about Pontius Pilate occupies three chapters in a ratio of 19:108. Find the number of pages of this story, if it is known that the rest of the novel is 324 pages. Calculate the percentage ratio of this story in the novel, and round the result to the nearest hundredth.
		Exponential, logarithmic, trigonometric expressions and their transformations	Calculate $\log_{a+b} c$, where a is the floor of Lesha Lykhodeev's apartment, b is the entrance number of the house where Lesha Lykhodeev lived, and c is the number of Margaritas found by Woland's entourage in Moscow.
		Rational, irrational, power expressions and their transformations	Calculate $\frac{(a+7)^2 4b}{c^2}$, where a is the room number of the master in the Stravinsky clinic, b is the number of chapters in the novel 'The Master and Margarita', c is the amount of money that the police confiscated from Nikanor Ivanovich.
		Linear, quadratic, rational equations and systems of equations	x_1 and x_2 are the roots of the equation $x^2 - \frac{a}{2}x - b = 0$, where a is the entrance number of the house where Lesha Lykhodeev lived, b is the floor of Lesha Lykhodeev's apartment. Calculate $x_1^2 + x_2^2$ without solving the equation.

Continued on next page

Table 1 – continued from previous page

Academic discipline	Section	Topic	Problem
		Irrational, trigonometric equations and systems of equations	Solve the equation $8\sqrt{x-a} = b$, where a is Lesha Lykhodeev's apartment number, and b is the number of chapters in the novel 'The Master and Margarita'.
		Exponential, logarithmic equations and systems of equations	Solve the equation $2^{x-a} = \frac{1}{b}$, where a is the entrance number of the house where Lesha Lykhodeev lived, and b is the number of chapters in the novel 'The Master and Margarita'.
		Inequalities and systems of inequalities	Solve the inequality $(x-\sqrt{a})^2 < b$, where a is the number of Margaritas found by Woland's entourage in Moscow, and b is the amount of money that the police seized from Nikanor Ivanovich. Write down the largest integer in the answer.
		Solving problems using equations and systems of equations	As you know, Lesha Likhodeev lived on Sadova Street in house number 302-bis, apartment 50. Find out at which entrance and on which floor this apartment is located, if it is a five-story building and if there are no apartments in the first five entrances on the first floors. Keep in mind that there are two apartments on the other floors.
	Functions	Number sequences	As you know, there was a deposit of 10,000 in the Master's savings account. What amount of the deposit would be in the master's savings account in three years, if the annual interest rate was 15%?
		Functional dependence	Find the domain of the function $y = \sqrt[n-1]{a-3x}$, where a is Lesha Lykhodeev's apartment number, and n is the floor on which Lesha Lykhodeev's apartment is located. In the answer write down the largest two-digit number that belongs to the domain of the function.
		Linear and quadratic functions	Find the maximum value of the function $y = c - bx - x^2$, where b is the entrance number of Lesha Lykhodeev's house, and c is the denomination of banknotes that fell into the hall during Woland's performance in Variety.
		Power, exponential, logarithmic and trigonometric functions	Specify the smallest value of the function $y = acos(2xb) + a$, where a is the denomination of banknotes that fell into the hall during Woland's performance in Variety, b is the amount of money that the police confiscated from Nikanor Ivanovich.

Continued on next page

Table 1 – continued from previous page

Academic discipline	Section	Topic	Problem
		The derivative of a function	Find the value of the derivative function $f(x) = \sqrt{a - \frac{b}{2}x}$ at the point $x_0 = -\frac{b}{3}$, where a is the denomination of banknotes that fell into the hall during Woland's performance in Variety, b is the entrance number of Lesha Lykhodeev's house.
		Anti-derivative and definite integral	Calculate the area of the shape bounded by the lines $y = x^{a/2}$, $y = \frac{b}{c}$, $x = 0$, where a is the entrance number of the house where Lesha Likhodeev lived, b is the amount of money that the police seized from Nikanor Ivanovich, c is the apartment number of Lesha Lykhodeev.
	Combinatorics	Combinatorial analysis	As Koroviev said, the hostess of the ball must certainly have the name of Margarita. In Moscow, they found 121 Margaritas. In how many ways can you choose the 2 Margaritas you need?
		The probability of a random event	As we know, Margarita marked with her fingernail one of the points on the seven of the spades map to check the accuracy of Azazello's shooting. What is the probability that she hit the top right corner point?
Geometry	Planimetry	Elementary geometric shapes on the plane	The segment, the length of which is equal to $(a + 10)$ cm, where a is the number of the entrance of Lesha Likhodeev's house, is divided by points into four equal segments. Determine the distance between the midpoints of the obtained extreme segments.
		Triangles	In the MNKP rectangle: $MN = a$ cm, $NK = a + 2$ cm, A and B are the midpoints of the sides NK and KP, respectively. Find the area of the triangle MAB (in cm^2), if a is the number of the entrance of Lesha Likhodeev's house.
		Right triangles	The hypotenuse AC of an isosceles right triangle ABC is $(a - 1.4)$ dm. The square MNKP is inscribed in this triangle, two of whose vertices are on the hypotenuse, and the other two are on the legs, where a is the number of the entrance of Lesha Likhodeev's house. 1. Determine the area of triangle ABC (in dm^2). 2. Calculate the area of the square MNKP (in dm^2).

Continued on next page

Table 1 – continued from previous page

Academic discipline	Section	Topic	Problem
		Parallelogram, rhombus, trapeze, circle. Polygons	In a rectangular trapezoid MNKP (MP‖NK), the diagonal MK is perpendicular to the lateral side of KP. Find the length of this diagonal (in cm), if MP= $3a$ cm, NK= $c-2$ cm, where a is the number of the entrance of Lesha Likhodeev's house, c is the denomination of the banknotes that fell into the hall during Woland's performance in Variety.
		Rectangle Square	The bisector of angle A of rectangle ABCD intersects its long side BC at point K. Determine the radius of the circle (in cm) circumscribing the rectangle if BC= $4c$ cm, AK= $2a\sqrt{2}$ cm, where a is the floor of Lesha Likhodeev's apartment, c is the number of Lesha Likhodeev's entrance.
		Circle. Polygons	During the execution of Yeshua, at the foot of Bald Mountain, the ala cordoned off the hill. Calculate the length of the radius of the base of the hill, if it is known that the hill was cordoned off by 50 soldiers, each of which occupied 1 meter, and the free rise from the Jaffa Road was 4 meters.
		Coordinates and vectors on the plane. Geometric displacements	In the Cartesian coordinate system, a circle is described near the triangle ABC, given by the equations $x^2 + y^2(2ac) = 10a + 3c$. Determine the length of the side BC if $\angle\text{A} = 9a^\circ$, where a is the floor of Lesha Likhodeev's apartment, and c is the number of the entrance of Lesha Likhodeev's house.
	Stereometry	Coordinates and vectors on the plane. Geometric displacements of lines and planes in space	The base of a straight prism $ABCDA_1B_1C_1D_1$ is an isosceles trapezoid ABCD. The base AD of the trapezoid is equal to its height and c times greater than the base BC. A plane is drawn through the side edge CC_1 of the prism parallel to the edge AB. Find the area of the resulting section (in cm^2), if the volume of the prism is $112c$ cm^3 and its height is $(c+2)$ cm, where c is the number of the entrance to Lesha Likhodeev's house.
		Prism	The 'Drumlit House', where the critic Latunsky lived, has 8 floors, each 3 meters high, the base of the house is a square with a side of 7 meters. Calculate the volume of this building.

Continued on next page

Table 1 – continued from previous page

Academic discipline	Section	Topic	Problem
		Pyramid	In a regular quadrangular pyramid, the side edge is $3a$ cm, and the side of the base is $(2a1)\sqrt{2}$ cm. Determine the volume of this pyramid (in cm^3), if a is the floor of Lesha Likhodeev's apartment.
		Bodies of rotation	The volume of a body created by the rotation of an isosceles triangle about a height drawn to its base, equal to $0,5a$ cm, is $10a\pi$ cm^3. Calculate the length of the generatrix of the body of revolution (in cm), if a is the number of chapters in the novel 'The Master and Margarita'.
		Coordinates and vectors in space	In the Cartesian coordinate system, the points A$(c;4;b)$ and B$(2a;b;7)$, are given in space, where a is the number of the floor on which the apartment of Lesha Likhodeev was located, b is the denomination of the banknotes that fell into the hall during the time of Woland's performance in the Variety with c – the number of chapters in the novel 'The Master and Margarita'. Point C is the midpoint of segment AB. 1. Find the abscissa of point C. 2. Calculate the vector length $\overline{\text{AC}}$.

4. Results

We conducted the experiment to determine the effectiveness of the preparation of humanities students for the EIA in Mathematics. The basis of the research was secondary education institutions in which masters of the speciality 014 Secondary Education (Mathematics) completed a pedagogical internship in the 11th grade, who study Mathematics at the standard level: Kryvyi Rih educational complex No. 81, Kostyantynivskyi institution of general secondary education I-III degrees No. 1, Kostyantyniv educational complex 'General education school of I-III degrees', Kramatorsk educational complex 'General education school of I-III degrees No. 6', Kryvyi Rih general education schools No. 75 and No. 122. Masters who were involved in the experiment attended training to get acquainted with its purpose and tasks and took part in the development of methods for conducting classes using a complex system of problems. The teachers were warned about conducting the experiment and helped the students in conducting it.

The main tasks of the experiment were:

- analysis of test tasks of external independent assessment in Mathematics;
- a study of the process of preparing high school students for EIA in Mathematics in secondary education institutions, for Humanities students;
- development and introduction into the educational process of a system of problems for preparation for the EIA in Mathematics based on Bulgakov's novel 'The Master and Margarita';

- analysis of the results of the experiment.

Control (CG) and experimental groups (EG) were formed in a non-random manner. To ensure equal conditions for conducting the experiment, the formed groups were examined for statistical equivalence by analyzing the level of knowledge and skills shown by students during the monitoring trial testing of the EIA in Mathematics at the beginning of the experiment.

The experiment was conducted for six weeks, and 145 students took part in it: 70 in CG and 75 in EG:

- the control group (CG) included students from the following schools: Kryvyi Rih educational complex No. 81, Kostyantynivskyi institution of general secondary education of I-III degrees No. 1, Kryvyi Rih general education school No. 75. Preparation for the EIA in Mathematics in these classes was carried out according to traditional methods. Students were offered mathematical problems for repetition on various topics of the school Mathematics course, which are presented at the external examination;
- to the experimental group (EG) – students of the following schools: Kostyantyniv educational complex 'General education school of I-III degrees'„ Kramatorsk educational complex 'General education school of I-III degrees No. 6', Kryvyi Rih general education school No. 122. Preparation for the EIA in Mathematics in the classes of the experimental group was carried out according to the method of implementing a system of problems, in which the interdisciplinary connections of Mathematics and Literature are implemented, the problems were developed based on the plot of Bulgakov's novel 'The Master and Margarita'.

After the end of the experiment, the final trial test of the secondary school in Mathematics of EC and CG students was conducted to determine the level of their mathematical preparation. To determine the level of knowledge and skills of high school students, the following distribution of points was used, under the official report on the conduct of external examinations in 2021 [10]: 0 points – failed; 1-9 points – elementary level; 10-19 points – average level; 20-34 points is a sufficient level; 35-50 points is a high level, according to the orders of the Ukrainian Center for Evaluation of the Quality of Education [11, 12] (table 2).

Table 2. The results of the trial test of the external examination in Mathematics of high school students of the control and experimental groups.

Level	Number of students			
	EG		CG	
	At the beginning of the experiment	At the end of the experiment	At the beginning of the experiment	At the end of the experiment
Failed (0 points)	2	0	1	0
Elementary (1-9 points)	13	8	11	9
Average (10-19 points)	29	20	27	23
Sufficient (20-34 points)	23	35	22	28
High (35-50 points)	8	12	9	10
In total	75	75	70	70

The results of the tests are presented in figure 1 for the EG and figure 2 for the CG.

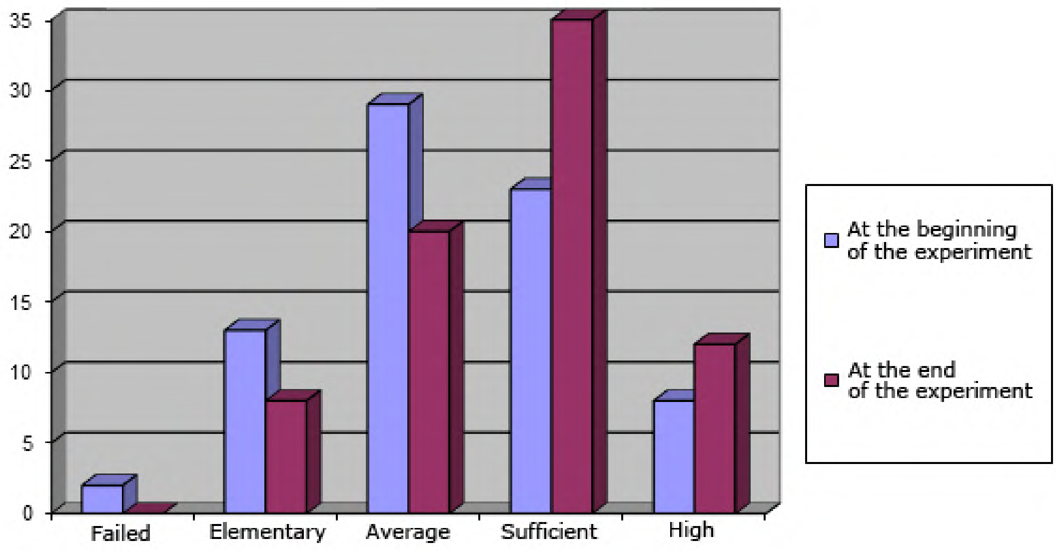

Figure 1. Comparative analysis of the results of the trial test in Mathematics at the beginning and the end of the experiment of high school students of the EG.

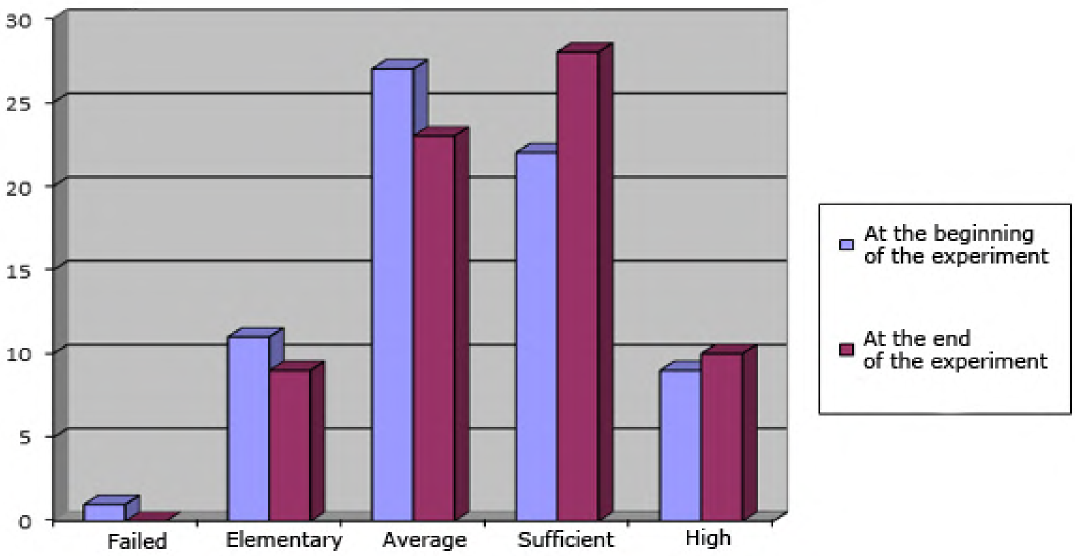

Figure 2. Comparative analysis of the results of the trial test in Mathematics at the beginning and the end of the experiment of high school students of the CG.

The histograms figure 1 and figure 2 show that the level of students' (CG, EG) knowledge and skills have increased. However, in CG the average score increased by 2.4, and in EG – by 5.9, which indicates that the implemented system of problems has a more significant effect on both increasing the motivation of students to study Mathematics and their mathematical preparation.

5. Discussion

The relevance of the development of cross-curricular problems for learning Mathematics to humanitarian students is confirmed by the opinion of Pesakovic et al. that such tasks contribute to the formation of mathematical competence as a key [13].

The works of Furner and Duffy [14, 15], in which the advantages of using Literature in learning Mathematics are defined, such as the development of mathematical thinking, the use of historical, cultural and practical applications, promoting the use of certain mathematical manipulations related to history, ensuring the exchange of experience both for students and for the teacher allowed the authors of this article to make sure of the relevance of developing a system of problems for preparing for the EIA in Mathematics of high school students who study in humanities classes and classes with a creative inclination. Moreover, we support Furner's point of view [16, 17] on the current issue, when it is crucial to interest young people in Mathematics in our high-tech STEM world in which we live [18]. At the scientist's suggestion, mathematical ideas are presented in the context of the story. The results of such use of Literature in learning Mathematics can help reduce Math anxiety and awaken students' interest and confidence in Mathematics and STEM fields.

For students who master Mathematics at the basic level of training, this subject is not a profile, so it is extremely important to motivate them to learn mathematics through the involvement of interdisciplinary problems related to the humanitarian profile of education. This means that it is possible to teach students mathematical modelling while mastering each academic discipline. This opinion is confirmed by the work of Little [19], who investigates the relationship between Mathematics and other sciences and looks for ways so that high school students do not consider mathematics inappropriate, questioning the benefits of studying it.

Arpin [20] advocates the implementation of interdisciplinary connections with benefits both for the educational needs of a specific educational profile and for Mathematics. Toliver [21] assures in his studies that the synergy between Mathematics and Literature should not be too surprising: Literature and Mathematics have many common themes. Both deal with patterns and relationships. There is a natural connection between these two subjects. And this, in turn, emphasizes that the system of problems created by the authors of this article is aimed at the formation of such mathematical skills: gathering information and choosing the appropriate recording and display method; finding regularities in various forms of writing and expressing them in mathematical terms; development of calculation skills when analyzing information.

The idea of creating a system of problems is based on the plot of a well-known Bulgakov novel 'The Master and Margarita'. The same idea is also reflected in the research of Look [22], who analyzes the works of different authors, such as Jules Verne, Anton Chekhov, etc. and offers ideas for further problems that can be reformulated in terms of simple mathematical equations.

All in all, the authors of this article set a goal to develop problems that demonstrate such types of interdisciplinary connections of Mathematics with Literature, such as parallel learning and the application of the method of mathematical modelling. Since Bulgakov's novel 'The Master and Margarita' is studied in the first half of the 11th grade according to the curriculum of the 'Foreign Literature' discipline, and preparation for the external examination and general repetition in Mathematics takes place in the second half, this allowed to demonstrate the method of parallel learning. At the same time, the content of the novel is saturated with a sufficient number of facts, which are presented in numerical form, which in turn allows applying the method of mathematical modelling and using these facts to construct problems of mathematical content. When developing problems, the authors followed the principle of building competence-oriented tasks. According to this principle, the problem contains the so-called 'informational noise' and purely mathematical content. In the proposed system of problems, the mathematical content was built based on numerical data taken from the plot of the novel, and the 'informational noise' was connected with the emotional style of the novel and therefore did not distract students, but on the contrary, created an interdisciplinary connection between Mathematics and Literature. In this way, the developers of the problems managed to combine the aesthetic sensitivity of Mathematics with the literary sensitivity to words.

The results obtained during the experiment confirm the effectiveness of the influence of interdisciplinary problems both on the motivation of students and on their general and mathematical preparation. This result is consistent with the conclusions of the Interdisciplinary Laboratory of Literature and Mathematics [23], made as a result of a review of the advantages of combining Literature and Mathematics, namely:

- in the sense of general development – helps the student to adapt to different learning styles, and develops their critical and logical thinking;
- in the sense of motivation – attracts students, improving their attitude to Mathematics;
- from the point of view of mathematical preparation – helps the student develop and visualize multiple representations of mathematical concepts, reduces anxiety associated with the study of Mathematics, improves mathematics performance, provides a specific context for understanding Mathematics, helps connect Mathematics with personal experience, develops reasoning, mathematical thinking and ability solve mathematical problems.

6. Conclusions

The comprehensive and multifaceted interdisciplinary connections of Mathematics with other school subjects, in particular the humanities cycle, can become a guide for Humanities students to study the academic discipline of Mathematics, which is not a profile for them. In the study, using the example of the implementation of a system of mathematical problems, in which the interdisciplinary connections of Mathematics and Literature are implemented, the effect on increasing the motivation of humanitarian students to study Mathematics is shown.

The researchers recommend the search for new methodical approaches to the development of problems that contribute to the preparation of students of humanities classes to pass the state final certification in Mathematics in the format of external examinations. Regarding the selection and systematization of interdisciplinary problems, the researchers suggest choosing a system of problems that is developed based on Bulgakov's novel 'The Master and Margarita' and in which the interdisciplinary connections of Mathematics and Literature are realized. Such problems, with their plot and content, on the one hand, interest students, and on the other hand, contribute to their mathematical training.

The effectiveness of the system of problems built on the plot of a literary work depends on several factors: first, a literary work that is interesting to students and already known to them from the school curriculum must be chosen; secondly, it is appropriate to choose a work that allows its plot to create a situation that requires the construction and study of its mathematical model; thirdly, it is important to choose the principle of construction of problems of a certain type, for example, competence or application; and finally, an important factor in the construction of problems is the combination of the aesthetic sensitivity of Mathematics with the literary sensitivity to words.

To implement the proposed system of problems in Mathematics learning, it is recommended to classify the problems according to the sections of Mathematics that correspond to the program of the EIA. In particular, the authors of this article developed a system of problems with an open short answer, which demonstrates such types of interdisciplinary connections between Mathematics and Literature as parallel learning and the application of the mathematical modelling method. For this, the authors of this article used: the method of primary research of the EIA tests in Mathematics of previous years, as well as the method of analysis and selection of the main content lines presented in the external independent assessment in Mathematics. The authors of this article also propose to consider the problems of the system as a toolkit for measuring the level of preparedness of students of the humanitarian profile to solve typical tasks of the EIA.

The positive results of the implementation of the system of interdisciplinary problems, which were developed based on the plot of a literary work, in the preparation for the EIA of humanitarian students is evidenced by the increase in the level of motivation of students and their mathematical training, which were confirmed during the experiment.

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References

[1] Bulgakov M A 2023 *The Master and Margarita* (Moscow) URL https://www.masterandmargarita.eu/en/02themas/index.html
[2] Damrau Milena snd Skrodzki M, Hartkopf A M, Broeders R M, Hahn K, Honda D, Holden J and Feijs L 2021 *w/k – Between Science & Art* URL https://doi.org/10.55597/e6876
[3] Fujiwara M 2018 *Asymptote Journal* URL https://www.asymptotejournal.com/nonfiction/masahiko-fujiwara-literature-and-mathematics/
[4] Johansen A, Mogstad E, Gajić B and Bungum B 2018 *Nordic Studies in Science Education* **18** 98–111 URL https://doi.org/10.5617/nordina.8620
[5] Tisngati U and Genarsih T 2021 *Journal of Physics: Conference Series* **1776** 012035 URL https://doi.org/10.1088/1742-6596/1776/1/012035
[6] Weinstein K 2017 *Children's literature as a tool to teach mathematics* Senior honors thesis Eastern Michigan University URL https://commons.emich.edu/honors/516/
[7] Ochkov V F and Look A 2015 *Journal of Humanistic Mathematics* **5**(2) 121—132 URL https://doi.org/10.5642/jhummath.201502.11
[8] Rachinskij S A 2005 *1001 tasks for mental calculation* URL https://www.gutenberg.org/files/16527/16527-h/16527-h.htm
[9] 2023 EIA tests online in Mathematics URL https://zno.osvita.ua/mathematics/
[10] 2021 The official report on the conduct of the EIA in 2021 URL https://testportal.gov.ua//wp-content/uploads/2021/11/ZVIT_ZNO_2021-Tom_2_.pdf
[11] 2021 Order on the approval of the Instructions for establishing the "passed/failed" threshold for determining the results of an external independent assessment of learning outcomes obtained based on full general secondary education URL https://testportal.gov.ua//wp-content/uploads/2022/02/Instruktsiya-z-ustanovlennya-poroga-sklav-ne-sklav.pdf
[12] 2021 Order on the approval of the schemes for awarding points for the performance of the tasks of certification works of external independent assessment in 2022 URL https://testportal.gov.ua//wp-content/uploads/2021/11/Nakaz-UTSOYAO-147-Shemy-narahuvannya-baliv-ZNO_2022.pdf
[13] Pesakovic D, Flogie A and Abersek B 2014 *Journal of Baltic Science Education* **13**(5) 740–755 URL https://doi.org/10.33225/jbse/14.13.740
[14] Furner J M 2017 *Journal of Advances in Education Research* **2**(2) 103–112 URL https://doi.org/10.22606/jaer.2017.22006
[15] Furner J M and Duffy M L 2002 *Intervention in School and Clinic* **38**(2) 67–74 URL https://doi.org/10.1177/10534512020380020101
[16] Furner J M 2017 *Pedagogical Research* **2**(1) 1–11 URL https://doi.org/10.20897/pedre.201701
[17] Furner J M and Kenney C 2017 *Pythagoras* **32**(2) 7 URL https://doi.org/10.4102/pythagoras.v32i2.133
[18] Hrynevych L, Morze N, Vember V and Boiko M 2021 *Educational Technology Quarterly* **2021** 118–139 URL https://doi.org/10.55056/etq.24
[19] Little J 2019 Connecting mathematics with science to enhance student achievement - a position paper *Mathematics Education Research: Impacting Practice (Proceedings of the 42 nd annual conference of the Mathematics Education Research Group of Australasia)* ed Hine G, Blackley S and Cooke A (Perth:

MERGA) pp 452–459 URL https://merga.net.au/common/Uploaded%20files/Annual%20Conference%20Proceedings/2019%20Annual%20Conference%20Proceedings/RP_Little.pdf

[20] Arpin R 2007 *Approche par compétences : l'enseignement des mathématiques a-t-il un avenir dans les programmes d'études techniques au collégial?* Mémoire présenté comme exigence partielle de la maîtrise en mathématiques Université du Québec à Montréal Montréal URL https://cdc.qc.ca/pdf/786689_arpin_memoire_MA_UQAM_2007.pdf

[21] Toliver K 2013 Literature in the Mathematics Classroom URL https://thefutureschannel.com/literature-in-the-mathematics-classroom/

[22] Ochkov V F and Look A 2015 *Journal of Humanistic Mathematics* **5**(2) 121–132 URL https://doi.org/10.5642/jhummath.201502.11

[23] 2016 Qu'est-ce qu'une œuvre littéraire? URL https://www.usherbrooke.ca/litt-et-maths/fondements/quest-ce-quune-oeuvre-litteraire/

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The method of using the online course "Creative Thinking through Learning Elementary Maths" in the Mathematics teacher training system

To cite this article: V V Achkan *et al* 2023 *J. Phys.: Conf. Ser.* **2611** 012003

The method of using the online course "Creative Thinking through Learning Elementary Maths" in the Mathematics teacher training system

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Abstract. The article offers the method of using the online "Creative Thinking through Learning Elementary Maths" and the results of checking the effectiveness of the implementation of this course in the mathematics teacher training system. The research substantiates the possibility of three methodological options for combining educational materials of the online course with the study of the educational discipline "Elementary Mathematics". The methodological options are chosen depending on the number of credits assigned to the study of the elementary mathematics course at the university. Practical tasks of the course were focused on the organization of students' activities (recognition, classification, solving and creation) with Rich tasks of three levels of complexity. The results of control tests in Elementary Mathematics give grounds for concluding about the effectiveness of the developed method.

1. Introduction

1.1. Problem statement and its topicality substantiation

As noted in the Professional Standard "Teacher of General Secondary Education" [1] and Standards for preparing teachers of Mathematics, developed by the Association of Mathematics Teacher Educators [2], creativity is an important component of the professional competence of a mathematics teacher. The formation and development of all the key personality qualities of a would-be mathematics teacher take place in the process of studying professional disciplines, which are divided into normative and variable. Elementary Mathematics is one of the key normative disciplines for the training of would-be mathematics teachers.

According to Vlasenko et al. [3, 4], it is during the study of this discipline that repetition, generalization and expansion of students' knowledge of mathematical concepts and facts, which were considered in the school mathematics course, takes place. In addition, the goal of studying the discipline is the formation of skills and abilities of would-be teachers to creatively use the acquired skills in practical activities. In the absolute majority of universities, Elementary Mathematics is studied from the first year, so in this process, students adapt to the requirements, opportunities and features of learning at a Higher Education Institution, which increasingly goes beyond classrooms.

We agree with Bilousova et al. [5], Bringula et al. [6], Lin et al. [7], and Mintii [8], who note that in modern conditions of digitalization of society, traditional face-to-face education is being replaced by blended learning [9]. We also agree with Attard et al. [10], Fazal et al. [11], Kovalchuk et al. [12], and Martyniuk et al. [13] that the COVID-19 pandemic only accelerated the process of active implementation of blended learning, which was inevitable. Today, education faces the task of finding ways that enable the organization of mixed learning among students both in the classroom and outside the classroom. Therefore, in modern conditions of education development, online courses are becoming more and more widespread as a form of distance organization or a component of mixed learning. Therefore, it became appropriate to develop an online course "Creative Thinking through Learning Elementary Maths" [3], which focused on the development of creative thinking in the process of activity with systematized types of problems. This determines the relevance of the problem of organizing blended learning of Elementary Mathematics with the involvement of the online course "Creative Thinking through Learning Elementary Maths".

2. Literature review

2.1. Organization of blended learning of Mathematics

Rifa'i and al. [14], Fazal et al. [11], Attard et al. [10], Bringula et al. [6], Jamil et al. [15] investigate the organization of blended learning of junior high school students in Mathematics classes using smartphones and analyze the attitude towards the usage of smartphones in the educational process and the opportunities they provide for the organization of blended learning in Mathematics. Fazal et al. [11], compared the effectiveness of traditional and blended learning of Mathematics in middle-aged schoolchildren and concluded the special effectiveness of blended learning of Mathematics to overcome students' issues in the process of studying certain topics. Bringula et al. [6] analyzed the issues in the organization of blended learning of Mathematics in the conditions of the pandemic and possible ways to overcome these in the process of implementing online courses. Jamil et al. [15] investigated the effectiveness of blended learning of Mathematics using active learning methods. Attard et al. [10] investigated the usage of blended learning technologies in Mathematics by Australian schoolchildren in the context of the COVID-19 pandemic to improve the individualization and differentiation of mathematics learning, implement visualization and establish the relationship and interaction of the teacher and students.

All scientists agree that the organization of blended learning contributes to improving the performance and attitude of students toward Mathematics, and most researchers emphasize the expediency and effectiveness of using online courses within the framework of blended learning.

2.2. Development and method of online course implementation in mathematics education

Various aspects of the development and methodological aspects of the online courses' implementation in learning Mathematics are devoted to the study of Vlasenko et al. [16], Trenholm et al. [17], Ahn et al. [18], Radmehr et al. [19], Schallert et al. [20] and others. Research by Vlasenko et al. [16] presents the methodology for creating an electronic learning environment for training mathematics teachers. Trenholm et al. [17] present a thorough analysis of the differences between face-to-face and online learning and suggest ways to improve the organization of online courses. A study by Ahn et al. [18], devoted to the use of an open e-learning platform for the organization of learning based on an activity approach. Radmehr et al. [19] analyze the experience of switching to distance learning of Mathematics of Norwegian students and the importance of online courses in this process as well. Schallert et al. [20]

emphasize the effectiveness of the use of flipped learning technology in the process of organizing online courses in Mathematics.

The above-mentioned scientists agree that online courses are an effective component of both distance and blended learning of Mathematics and should be organized based on an activity-based approach to learning.

2.3. An active approach as a basis for building a Mathematics online course

An active approach in the process of organizing blended or distance learning is considered in the research of Noreen et. al. [21], Agyei et. al. [22], Hjalmarson [23], Negara et. al. [24] and others. Agyei et. al. [22] substantiated and experimentally proved the effectiveness of organizing group activities for solving problems using information technologies. Noreen et. al. [21] emphasized the importance and effectiveness of learning mathematics to elementary school students based on the activities of students with a specially selected system of problems. Negara et. al. [24] substantiated the feasibility and effectiveness of implementing activity-based online courses for learning Mathematics to high school students. The results of Hjalmarson's study [23] confirm that it is during specially organized practice-oriented activities in the distance learning process that all the key personality traits of a mathematics teacher development. The development of the idea of organizing practice-oriented activities can also be found in the work of Kajander et al. [25], who emphasize the importance of a specially selected system of tasks in this process.

Gojak [26], and Yeo [27] express similar views, agreeing with the expediency of developing students' creativity in the process of solving certain types of problems. Among the means, the usage of which promotes the development of student's creative thinking, scientists single out Rich tasks. This idea is consistent with the findings of the study by Vlasenko et al. [3].

Scientists consider Rich tasks from Elementary Mathematics as problems that contribute to increasing interest in Mathematics as a science, because they allow students to 'discover' new mathematical rules (concepts, regularities), act outside the norm, develop creative thinking, and interest in creating their mathematical product. In the same paper, open and integrative Rich tasks are distinguished as five main components of the development of student's creative thinking. There are the ability to identify and pose a problem, the ability to generate a significant number of ideas; flexibility or the ability to produce different ideas, originality or the ability to act out of the box, and the ability to improve the subject with added details. For the effective formation of the specified components of creative thinking, scientists recommend the development of an online course 'Creative Thinking through Learning Elementary Maths' [28]. The idea of creating this online course was caught on by the International Conference 'ICon-MaSTed' [29]. The model for organization training with the online course was also approved [29]. While developing the course application methodology, it was taken into account the opinion of Attard et al. [10]. Online courses can be not only an independent component of distance learning but also an effective component of blended learning. Therefore, the purpose of the article is to present the method of using the online course 'Creative Thinking through Learning Elementary Maths' [28] as a component of the study of Elementary Mathematics and to confirm the effectiveness of the implementation of this course in the process of training would-be Mathematics teachers.

3. Method

An active approach to learning was the basis of the development of the method for using the 'Creative Thinking through Learning Elementary Maths' [28]. Based on the analysis of the opinions of scientists presented in table 1 and the experience of the authors, a method of using an online course in the process of studying Elementary Mathematics was developed. This method provides three options for combining an online course and learning Elementary Mathematics.

These options are detailed below.

Table 1. Analysis of the views of scientists and online resources regarding the combination of blended learning of the discipline and the usage of an online course at the same time.

Scientists	Used during the study (subject, age group)	How the online course and the study of the discipline were combined
Rifa'i and Sugiman [14]	Mathematics, students in high school	Two forms of interaction: an online course is offed only for theoretical support of flipped learning and an online course for support of flipped learning (including online consultations)
Attard & Holmes [10]	Mathematics, students in primary school	The online course is considered an aid in blended learning of the subject
Lin, Tseng, Chiang [7]	Mathematics, students in primary school	The online course is considered an aid in blended learning of the subject
Ahn and Edwin [18]	Mathematics, students in higher school	Two forms of interaction: the online course is considered as an aid in blended learning of the subject and the online course is a course to support flipped learning (including conducting online consultations).

(i) Students who studied the course of Elementary Mathematics during classroom training or blended learning simultaneously studied the online course "Creative Thinking through Learning Elementary Maths". If necessary, in addition to online consultations on the platform [28], offline consultations were received.

(ii) Students used the online course as a platform to support flipped learning. That is, they familiarized themselves with the material of the lectures and performed practical tasks presented on the online course platform. Most of the practical tasks were presented and discussed by the students during the study of Elementary Mathematics. Depending on the epidemiological situation, the discussion took place in an online format or an offline format (in the audience). This group of students worked with the online course during the semester they were finishing their Elementary Math course.

(iii) Students used online course materials as part of flipped learning (lecture sessions). Students received practical tasks as part of studying Elementary Mathematics and reported in the online or offline format during classes or consultations. The third option differed from the second one in that students used the online course platform to get answers to questions related to both online course learning and Elementary Mathematics learning in general.

It is described the structure and the general aspects of the organization of studying Elementary Mathematics using the online course and features for each of the groups separately. The online course is provided in Ukrainian and is designed for four weeks. The course contains six topics, each of which involves lectures and practical tasks. The course considers the concept of creative thinking and the role of Elementary Mathematics in the process of its development. Also, in the course of classes, students get acquainted with Rich problems and their types.

The choice of the option in which the online course is used may depend on the number of hours allocated to studying the Elementary Mathematics course at the university.

According to the first option, students started their studies in the online course at any convenient time for them during the last semester in which Elementary Mathematics was studied. Students worked through the online course at their own pace. The only requirement was to complete the online course three weeks before the test (exam) in Elementary Mathematics. The total estimated time of working on the course is 24 hours. The content of the course and the course learning model is described in detail in [29]. It should be noted that the completion of all problems of the online course: 1) allows students to score 6 "bonus" points in elementary mathematics; 2) contributes to the development of their creative thinking, which is reflected in the results of passing the test (exam) in Elementary Mathematics.

The second option provided that students who worked with the online course were instructed to process the materials of six lecture classes by a specific deadline. For example, students had to familiarize themselves with the first lecture on "Creative thinking and its structure" before the first-semester colloquium. During the colloquium or (in its absence) at the final class of a certain content module, a short discussion was held based on the lecture material, the teacher answered the questions that arose from the students. For example, the question of the interdependence of creative abilities and creative thinking caused a lively discussion.

The second lecture was on the topic "The role of Elementary Mathematics in the development of creative thinking. Rich tasks" students were introduced to a certain practical class (as a rule, the final class of the first or second content module of the course). A short discussion was organized, and aspects that were not clear to individual students were discussed. For example, several students were interested in the relationship between traditional and Rich tasks in the learning process aimed at developing creative thinking. To which the teachers noted that the ratio of Rich tasks and other tasks depends on the purpose of training and the level of preparedness of the students. If we are talking about the development of creative thinking, Rich tasks should prevail.

With the final sixth lecture on the topic "Types of integrative problems in Elementary Mathematics", students were introduced to the last or penultimate lecture (if there are lectures on Elementary Mathematics in the university curriculum. During the discussion, the students actively discussed whether it is appropriate to single out STEM problems as a separate type of integrative problem or to equate STEM problems with integrative problems. Summarizing the results of the discussion, the teachers emphasized that STEM problems are only a subset of the third type of integrative problems, that is, problems that arose outside the boundaries of Mathematics, but their solution requires the use of mathematical methods.

After working through the theoretical classes, the students completed the relevant practical tasks posted on the online course platform and presented them at the practical classes. Practical tasks were focused on the following activities from the Rich task: recognition, classification, solving, and creation. For example, students performing practical tasks before the second class analyzed the problems proposed by the developers of the online course and substantiated whether they belong to the Rich task. In the same session, students presented their examples of problems that, in their opinion, belong to the Rich task. We will give two examples of problems proposed by students.

Problem 1. It is necessary to place a lighting device above the centre of the circular platform. The radius of the site is 10 m. At what height is the best place to place the lighting device so that it illuminates the path bordering the site as best as possible?

Problem 2. What method is used to solve this problem? Find all values of the parameter a for which the equation $a^2 \cos^4 x + x^2 - a = 0$, has a single root. Give two examples of inequalities that are solved in the same way.

Note that according to the second option, students could also score 6 "bonus" points in Elementary Mathematics.

Students who worked with the online course in the third option worked with lecture tasks in a similar mode to the second group. At the same time, they received practical tasks from teachers. Depending on the mode of study of the university, students presented the performance of tasks and participated in the discussion either remotely or in the classroom. For example, with the third lecture on the topic “Open problems in Elementary Mathematics”, students were introduced to the second-semester colloquium or before the end of half of the content modules of the Elementary Mathematics course this semester. During the discussion, students actively debated the full or almost complete transition to learning (including schooling) through Rich tasks. Summarizing the results of the discussion, the teachers emphasized that the complete rejection of traditional (“closed”) problems is not advisable, since they are necessary for the formation of algorithmic activity skills, the formation in the shortest possible time of the ability to solve basic problems on a certain topic.

Students were introduced to the fifth lecture on “Integrative problems in Elementary Mathematics” before the last practical class of the penultimate content module of the Elementary Mathematics course. The issue of the balance of interdisciplinary and intradisciplinary integration caused a lively discussion. The majority of students were interested in problems that demonstrate the application of Elementary Mathematics in other mathematical disciplines (for example, Linear Algebra, Mathematical Analysis) and other sciences (Physics, Biology, Economics, etc.). So, teachers emphasized the importance and role of the integration of abilities, skills and experience in several sections of Elementary Mathematics.

In table 2 shows several examples of problems aimed at implementing the main types of activities from the Rich task.

Table 2: Examples of problems aimed at the implementation of the main types of activities with the Rich task.

Type of activity with Rich task	Class's number	Example task	Methodical comment
Recognition	1-2	1. Which of the following problems can be classified as open Rich tasks? Justify your opinion. • Solve the inequality $\sqrt{x^4 - 2x^2 + 1} > 1 + x$, • Based on the analysis of textbooks on Elementary Mathematics, identify the methods of solving logarithmic equations and inequalities and the approximate bases of activities using these methods.	While solving tasks, such a component of creative thinking as the ability to pose a problem and such components of mathematical and key competencies as the ability to analyze, compare and draw conclusions are formed.

Continued on next page

Table 2 – continued from previous page

Type of activity with Rich task	Class's number	Example task	Methodical comment
Classification	3-6	What types of Rich tasks are the problems? • Eight friends decided to hold a chess tournament so that everyone would play one game against each other. Can Peter win if he loses 4 games and draws 2? • A stand for stationery has the shape of a regular triangular prism without an upper base. The perimeter of the side face of this stand is 40 m. Complete the condition (no more than one condition can be added), create 3 problems and solve them. • Two rooms are separated from each other by a wall with an area of $S = 12x^2$. The sound pressure levels in the rooms where the sound source is located and where the sound is perceived are $Ł_e = 110$ dB and $Ł_0 = 63$ dB. Determine the sound absorption in the room where the sound is perceived, if the sound insulation level of the wall is $R = 41$ dB.	While solving such a problem, students determine whether the given problems belong to open or integrative Rich tasks, in the future, they learn to distinguish between open and integrative Rich tasks. The such activity contributes to the formation of such components of creative thinking as the ability to pose a problem and flexibility, as well as such components of mathematics and key competencies as the ability to analyze, compare, classify, and draw conclusions.

Continued on next page

Table 2 – continued from previous page

Type of activity with Rich task	Class's number	Example task	Methodical comment
Solving	3-6	1. A sphere is inscribed in a straight prism, the sides of which are equal to 8, 9, and 10 m. Create at least three problems using these conditions (you can add no more than one condition). Divide tasks according to difficulty levels. 2. Classify the types of problems from the topic "Polygons", and indicate the main methods of solving problems according to two of the types proposed by you. 3. Andriy poured little buckwheat groats into the pot, which has the shape of a cylinder, and asked his mother: "How much water do you need to pour to cook delicious porridge?" – "That's very simply answered by my mother. – Tilt the pan, tap so that the cereal spills over and covers exactly half of the bottom. Now fix a point on the wall of the pan near the edge to which the groats have risen. It is necessary to pour water to this level." – "But cereals can be poured more or less, and the pans are different – wide, narrow," said Serhiy. – "It doesn't matter, this method will come in handy in any case" – answered mother. Is it so?	While completing tasks, students learn to generalize, apply mathematical apparatus outside the boundaries of Mathematics, and understand the relationship between Elementary Mathematics and Mathematical Analysis (while solving the third problem). They develop such components of creative thinking as the ability to generate a significant number of ideas, flexibility and originality.

Continued on next page

Table 2 – continued from previous page

Type of activity with Rich task	Class's number	Example task	Methodical comment
Creation	4-6	1. Create two problem situations from the section "Planimetric shapes". 2. Create one problem at a time with an open ending, in the condition of which the following will appear: inequalities, polygons, vectors. 3. Create one problem each, the solution of which will contribute to the understanding of the relationships between Elementary Mathematics and Mathematical Logic, Mathematical Statistics and Mathematical Analysis.	While constructing varieties of open and integrative Rich tasks, students develop such components of creative thinking as the ability to generate a significant number of ideas, flexibility, originality, the ability to improve the subject, and such components of mathematical and key competencies as the ability to establish relationships between elementary and individual sections of Higher Mathematics, ability to systematize types of tasks.

Students presented the results of tasks in classes or during consultations. Completing all the tasks of the online course allowed students to score 6 "bonus" points in Elementary Mathematics.

4. Results

The effectiveness of the implementation of the online course in the mathematics teacher training system was tested in February-December 2021 for students of the 1st-2nd years of Berdyansk State Pedagogical University, Kryvyi Rih State Pedagogical University, Pavlo Tychyna Uman State Pedagogical University, Oleksandr Dovzhenko Hlukhiv National Pedagogical University. 98 students of 1-2 second years participated in the experiment. At the beginning of the experiment, the participants were randomly divided into a control group (CG) and an experimental group (EG). In the control group, 47 students studied a course in Elementary Mathematics using traditional methods. In the experimental group, 51 students studied Elementary mathematics in parallel with the online course 'Creative Thinking through Learning Elementary Maths' [28]. All three options for using the course described above were used (17, 16, and 18 students for each option).

The homogeneity of the groups at the beginning of the experiment was checked based on the results of control tests in Elementary Mathematics. The results of performing diagnostic tests on Elementary Mathematics at the beginning of the experiment are shown in table 3.

As we can see in table 3 and figure 1, the results of the control test in the control and experimental groups at the beginning of the experiment almost do not differ. In particular, the largest difference of 2% was observed between students who scored 76-89 points in favour of the EG. To make sure that the existing difference between the results of the control test in the control and experimental groups is not statistically significant, Fisher's statistical test φ^* was used.

We formulated statistical hypotheses: Null hypothesis H_0 : the level of formation of students' educational achievements of the control and experimental groups at the beginning of the experiment does not differ statistically significantly.

Table 3. The results of diagnostic tests in Elementary Mathematics at the beginning of the experiment.

The level of educational achievements of CG students				of EG students			
1–49 points	50–75 points	76-89 points	90–100 points	1–49 points	50–75 points	76-89 points	90–100 points
1 (2 %)	17 (36 %)	19 (41 %)	10 (21 %)	1 (2 %)	19 (37 %)	20 (39 %)	11 (22 %)

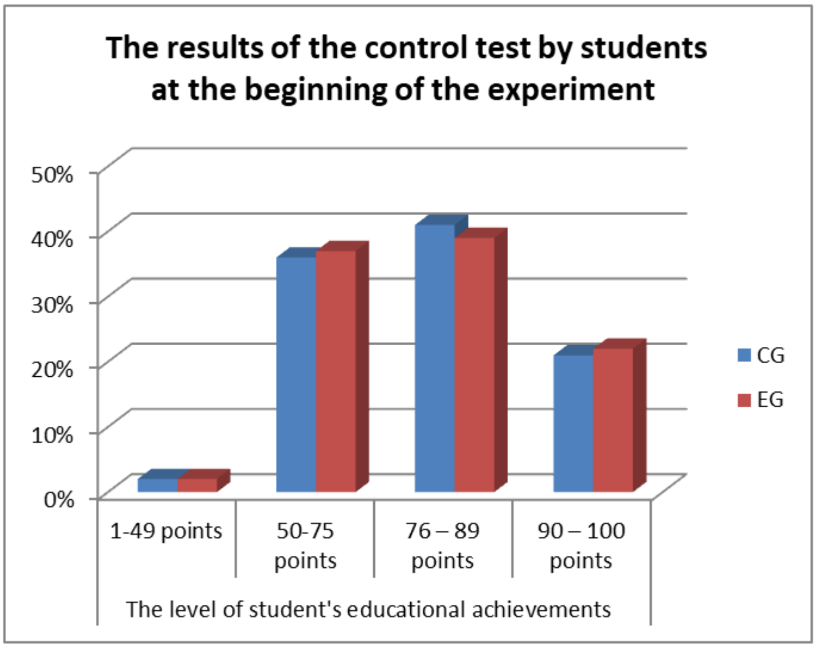

Figure 1. The results of the control test by students at the beginning of the experiment.

Then the alternative hypothesis H_1 : the level of students' formation of educational achievements in the control and experimental groups at the beginning of the experiment is statistically significantly different.

In table 4 for calculating φ^* when comparing the level of students' educational achievements at the end of the experiment.

According to the angle determination table φ :

$\varphi_1(62\%) = 1.813$ and $\varphi_2(61\%) = 1.793$.

Hence, we have an empirical value φ^* :

$\varphi^*_{emp.} = (\varphi_1 - \varphi_2)\sqrt{\frac{n_1 n_2}{(n_1+n_2)}} = 0.099$.

At the same time, the critical value φ^* for any n_1, n_2 is equal to: $\varphi^*_{cr.} = 1.64$ $(p < 0.05)$ or $\varphi^*_{cr.} = 2.31$ $(p < 0.01)$.

Since $\varphi^*_{emp.} < \varphi^*_{cr.}$ the hypothesis H_0 is accepted and H_1 rejected. Thus, the level of formation of educational achievements of students of the control and experimental groups does not differ statistically significantly.

CG students studied a course in Elementary Mathematics at universities using traditional

Table 4. Table for calculating Fisher's statistical test when comparing the level of students' educational achievements at the the beginning of the experiment.

Group	"There is an effect", and received points from 76 to 100	"There is an effect" received points from 1 to 75	Together
Control	29 (62 %)	18 (38 %)	47
Experimental	31 (61 %)	20 (39 %)	51
Together	60	38	98

methods. EG students studied the same course in parallel with the online course "Creative Thinking through Learning Elementary Maths" on the online platform "Higher School Mathematics Teacher" [28]. At the same time, with the help of the Google Class service, students had the opportunity to send the completed problems to the teacher for review. Assessment of problems was carried out on a scale of "passed" or vnot "passed". The teacher pointed out mistakes and drawbacks in the completed problems and provided an opportunity to correct them in the event of receiving a "failed" grade.

At the end of the experiment, the students also passed elementary mathematics tests, which consisted equally of traditional and Rich tasks. The students' results are shown in table 5 and figure 2.

Results of tests in Elementary Mathematics at the end of the experiment.

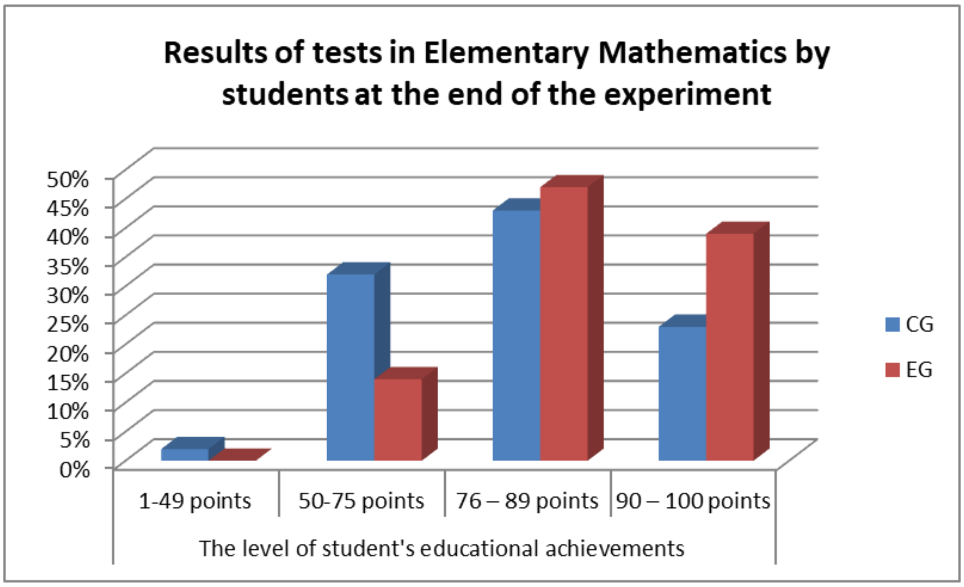

Figure 2. Results of tests in Elementary Mathematics by students at the end of the experiment.

As we can see in table 5 and figure 2, the results of the tests in the control and experimental groups at the end of the experiment are significantly different. In particular, the largest difference of 18% was observed between students who scored 50-75 points in favour of the CG, while a difference of 16% was observed between students who scored 90-100 points in favour of the EG.

To make sure that the existing difference between the results of the tests in control and experimental groups is statistically significant, Fisher's statistical test φ^* was used.

Table 5. The results of diagnostic tests in Elementary Mathematics at the end of the experiment.

The level of educational achievements of CG students				of EG students			
1–49 points	50–75 points	76-89 points	90–100 points	1–49 points	50–75 points	76-89 points	90–100 points
1 (2%)	15 (32%)	20 (43%)	11 (23%)	0 (0%)	7 (14%)	24 (47%)	20 (39%)

It formulated statistical hypotheses: Null hypothesis H_0 : the level of formation of students' educational achievements in the control and experimental groups at the end of the experiment does not differ statistically significantly.

Then the alternative hypothesis H_1 : the level of formation of students' educational achievements in the control and experimental groups at the end of the experiment is statistically significantly different.

In table 6 for calculating φ^* when comparing the level of students' educational achievements at the end of the experiment.

Table 6. Table for calculating Fisher's statistical test when comparing the level of students' educational achievements at the end of the experiment

Group	"There is an effect", and received points from 76 to 100	"There is an effect" received points from 1 to 75	Together
Control	31 (66 %)	16 (34 %)	47
Experimental	44 (86 %)	7 (14 %)	51
Together	75	23	98

According to the angle determination table $\varphi_1(86\%) = 2.373$ and $\varphi_2(66\%) = 1.897$. Hence, the empirical value φ^* is: $\varphi^*_{emp.} = 2.36$. At the same time, the critical value φ^* for any n_1, n_2 is equal to: $\varphi^*_{cr.} = 1.64$ ($p < 0.05$) or $\varphi^*_{cr.} = 2.31$ ($p < 0.01$). So, according to $\varphi^*_{emp.} = 2.36$ it is got that $\varphi^*_{emp.} > \varphi^*_{cr.}$.

Since $\varphi^*_{emp.} > \varphi^*_{cr.}$, the hypothesis H_0 is rejected and H_1 accepted.

And the data presented in table 5 gave grounds for asserting that the level of student's educational achievements at the EG is higher than at the CG.

Statistically, the verification based on the results of the tests allowed us to assert the effectiveness of using the online course "Creative Thinking through Learning Elementary Maths" [28] in the mathematics teacher training system.

5. Discussion

As pointed out by Balentyne et al. [30], Fazal et al. [11] and Boyd [31] the present and the future of modern education are related to the active implementation of blended learning. This is consistent with the conclusions of Attard et. al. [10], who claim that one of the effective forms of organizing blended learning of Mathematics is the combination of studying a certain discipline in face-to-face or mixed format with studying an online course. At the same time, the online course can be either a course to support and accompany the academic discipline or a course that complements and expands individual components of the study of the academic discipline. This is exactly what the online course "Creative Thinking through Learning Elementary Maths" is.

The development of the method for using the online course was based on the ideas of Rifa'i et al. [14], Lin et. al. [7], and Evendi et al. [32]. We singled out three options for using the online course in the mathematics teacher training system: the parallel study of the online course "Creative Thinking through Learning Elementary Maths" and the Elementary Mathematics course; the usage of the online course as a platform to support flipped learning in two options: only for familiarization with theoretical material and obtaining practical tasks, or for organizing feedback.

In the development of the method for the implementation of the online course in the training of mathematics teachers, we took into account the researcher's opinions of Hjalmarson [23], Klang et al. [33] and Jojo [34] regarding the importance of a special selection of activities for the development of student's personal qualities. It is in the process of four types of activities (recognition, classification, solving, creation) with Rich tacks that both the students' mathematical competencies and the components of their creative thinking are formed. For example, to solve Rich Tacks, it is necessary to be able to formulate a problem (formation of the ability to identify and pose a problem), "discover", propose an unusual (unknown) method, and method of solving (formation of originality and the ability to generate a significant number of ideas), clarify, change the course of solving in case of difficulties (formation of flexibility and ability to improve the subject, add details). To create Rich Tacks, you need to be able to think outside the box, modify, improve the condition, and adapt them to the needs of students (formation of originality, flexibility and the ability to generate a significant number of ideas). All these skills and abilities are integral components of key and mathematical competencies.

6. Conclusions

The analysis of resources and research papers confirmed the relevance of using online courses in the mathematics teacher training system. One of the possible options for such use is the combination of studying Elementary Mathematics and the online course "Creative Thinking through Learning Elementary Maths" [28]. Such a combination, depending on the number of credits assigned to the study of Elementary Mathematics at the university, should be carried out in three options: the parallel study of Elementary Mathematics and the online course; using the platform [28] to get acquainted with the theoretical material, subject to the presentation and taking problems in Elementary Mathematics classes and using the platform to get acquainted with the theoretical material and receive feedback on issues related to both the online course and from the study of Elementary Mathematics. In any case, placing the course on the "Higher School Mathematics Teacher" platform [28] made it possible to provide a wide range of students with access to it, and with activities with Rich tasks of three levels of complexity.

For the effective learning of Elementary Mathematics and the development of student's creative thinking, it is advisable to organize students' activities on recognition, classification, solving and creation of open and integrative Rich tasks. Such activities positively contributed to the development of the ability to analyze, compare, pose a problem, generate new ideas, classify, do conclusions, establish relationships between elementary and separate sections of Higher Mathematics, flexibility and originality. Experimental verification of the implementation of the developed course with the usage of diagnostic tests confirmed the effectiveness of using the course for the formation of mathematical competencies and the development of creative thinking of students.

We see further prospects in the development of methods of using online courses, focused on the formation of mathematical competencies and the development of creative thinking of students based on activities with Rich tacks in Higher Mathematics and Mathematics in high school.

Acknowledgments
We are grateful to all teachers and students who participated in the experiment.

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References

[1] Ministry of Economic Development, Trade and Agriculture of Ukraine 2020 On the approval of the professional standard for the professions 'Teacher of primary classes of a general secondary education institution', 'Teacher of a secondary education institution', 'Teacher of primary education (with a junior specialist diploma)' URL `https://osvita.ua/legislation/Ser_osv/78704/`
[2] Association of Mathematics Teacher Educators 2017 *Standards for Preparing Teachers of Mathematics Includes bibliographical references, Association of Mathematics Teacher Educators* (Association of Mathematics Teacher Educators) URL `https://amte.net/sites/default/files/SPTM.pdf`
[3] Vlasenko K, Achkan V, Chumak O, Lovianova I and Armash T 2020 *Universal Journal of Educational Research* **8**(7) 2853–2863 URL `https://doi.org/10.13189/ujer.2020.080712`
[4] Khyzhniak I, Vlasenko K, Viktorenko I and Velychko V 2021 *Educational Technology Quarterly* **2021**(1) 103–117 URL `https://doi.org/10.55056/etq.23`
[5] Bilousova L, Gryzun L and Zhytienova N 2021 *Educational Technology Quarterly* **2021**(3) 415–428 URL `https://doi.org/10.55056/etq.34`
[6] Bringula R, Reguyal J J, Tan D and Ulfa S 2021 *Smart Learn. Environ* **8**(22) URL `https://doi.org/https://doi.org/10.1186/s40561-021-00168-5`
[7] Lin Y W, Tseng C L and Chiang P J 2017 *EURASIA Math Sci Tech Ed* **13**(3) 741–770 URL `https://doi.org/10.12973/eurasia.2017.00641`
[8] Mintii I S 2023 *Educational Dimension* URL `https://doi.org/10.31812/ed.539`
[9] Vlasenko K V, Lovianova I V, Rovenska O G, Armash T S and Achkan V V 2021 *Journal of Physics: Conference Series* **1946**(1) 012001 ISSN 17426588 URL `https://doi.org/10.1088/1742-6596/1946/1/012001`
[10] Attard C and Holmes K 2022 *Mathematics Education Research Journal* **34**(4) 719–740 ISSN 2211-050X URL `https://doi.org/10.1007/s13394-020-00359-2`
[11] Fazal M and Bryant M 2019 *Journal of Online Learning Research* **5**(1) 49–64 URL `https://eric.ed.gov/?id=EJ1208816`
[12] Kovalchuk V I, Maslich S V and Movchan L H 2023 *Educational Technology Quarterly* **2023**(1) 1–17 URL `https://doi.org/10.55056/etq.49`
[13] Martyniuk O O, Martyniuk O S, Pankevych S and Muzyka I 2021 *Educational Technology Quarterly* **2021**(3) 347–359 URL `https://doi.org/10.55056/etq.39`
[14] Rifa'i A and Sugiman T 2018 *Journal of Physics: Conference Series* **1097** 012153 URL `https://doi.org/10.1088/1742-6596/1097/1/012153`
[15] Jamil H, Ramli H M and Leong E 2022 Advocating blended learning for university undergraduate level mathematical instruction beyond covid-19 *Engineering and Sciences Teaching and Learning Activities: New Systems Throughout COVID-19 Pandemics* (*Studies in Systems, Decision and Control* vol 381) ed Abdul Karim S A and Husain S A (Cham: Springer International Publishing) pp 33–45 ISBN 978-3-030-79614-3 URL `https://doi.org/10.1007/978-3-030-79614-3_4`
[16] Vlasenko K, Chumak O, Achkan V, Lovianova I and Kondratyeva O 2020 *Universal Journal of Educational Research* **8**(8) 3527–3535 URL `https://doi.org/10.13189/ujer.2020.080828`
[17] Trenholm S and Peschke J 2020 *International Journal of Educational Technology in Higher Education* **17** 37 URL `https://doi.org/10.1186/s41239-020-00215-0`

[18] Ahn J Y and Edwin A 2018 *International Review of Research in Open and Distributed Learning* **19**(5) 255–267 URL https://eric.ed.gov/?id=EJ1198098
[19] Radmehr F and Goodchild S 2022 *International Journal of Research in Undergraduate Mathematics Education* **8**(2) 277–297 URL https://doi.org/10.1007/s40753-021-00162-9
[20] Schallert S, Lavicza Z and Vandervieren E 2022 *International Journal of Science and Mathematics Education* **20**(2) 277–297 ISSN 1573-1774 URL https://doi.org/10.1007/s10763-021-10167-0
[21] Noreen R and Rana A M K 2019 *Bulletin of Education and Research* **41**(2) 145–159 URL https://eric.ed.gov/?id=EJ1229426
[22] Agyei D D and Voogt J M 2014 *Technology Pedagogy and Education* **25**(1) 1–21 URL https://doi.org/10.1080/1475939X.2014.928648
[23] Hjalmarson M A 2017 *Journal of Mathematics Teacher Education* **20**(3) 281–301 ISSN 1573-1820 URL https://doi.org/10.1007/s10857-015-9323-x
[24] Negara H R P, Nurlaelah E, Wahyudin, Herman T and Tamur M 2021 *Journal of Physics: Conference Series* **1882** 012050 URL https://doi.org/10.1088/1742-6596/1882/1/012050
[25] Kajander A, Manuel D and Sriraman B 2013 Exploring creativity: from the mathematics classroom to the mathematicians' mind URL https://www.researchgate.net/publication/324543387
[26] Gojak L 2017 A Key to Deep Understanding: The Importance of Rich Tasks in K-12 Mathematics URL https://www.mheducation.com/unitas/school/explore/research/reveal-math-rich-tasks-white-paper.pdf
[27] Yeo J B W 2017 *International Journal of Science and Mathematics Education* **15**(1) 175–191 ISSN 1573-1774 URL https://doi.org/10.1007/s10763-015-9675-9
[28] 2023 Higher School Mathematics Teacher URL http://formathematics.com/
[29] Achkan V, Vlasenko K, Chumak O, Sitak I and Kovalenko D 2022 *Journal of Physics: Conference Series* **2288** 012020 URL https://doi.org/10.1088/1742-6596/2288/1/012020
[30] Balentyne P and Varga M A 2017 *Journal of Online Learning Research* **3**(1) 55–72 URL https://eric.ed.gov/?id=EJ1148593
[31] Boyd P 2020 *Teacher Education Advancement Network Journal* **12**(1) 4–15 URL https://ojs.cumbria.ac.uk/index.php/TEAN/article/view/637
[32] Evendi E, Kusaeri A, Pardi M H H, Sucipto L, Bayani F and Prayogi S 2022 *Eurasia Journal of Mathematics, Science and Technology Education* **18**(7) 12161 URL https://doi.org/10.29333/ejmste/12161
[33] Klang N, Karlsson N, Kilborn W, Eriksson P and Karlberg M 2021 *Frontiers in Education* **6** 710296 URL https://doi.org/10.3389/feduc.2021.71029
[34] Jojo Z 2022 *Perspectives in Education* **40**(1) 196–211 URL https://doi.org/10.18820/2519593X/pie.v40.i1.12

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To cite this article: S P Semenets *et al* 2023 *J. Phys.: Conf. Ser.* **2611** 012004

Studies about zones of proximal mathematical development and methods of developmental teaching of Mathematics

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Abstract. The work develops the doctrine of the zones of the nearest mathematical development in the education seekers, reveals their content, substantiates the classification basis, and establishes typological characteristics. The structural and functional features of the studied phenomenon are represented by the principle of developmental continuity of Mathematics education and the task structure of educational and mathematical activities. In this way, compliance with the deductive essence of Mathematics was ensured, and emphasis was also placed on the phenomenological characteristics of mathematical abilities – the ability to generalize the content of mathematical education. Taking into account the established zones of the nearest mathematical development of the students of education, using the system approach and the modeling method, a theoretical-probabilistic methodical model of the developmental teaching of Mathematics was built, and the content of its stages was revealed. It was established that the method of developmental teaching of Mathematics involves the following stages: determination of areas of actual mathematical development; creation of areas of proximal mathematical development; transformation of zones of the nearest mathematical development into zones of actual mathematical development; designing the zones of the nearest mathematical development in the education seekers. Taking into account the problem raised in the work, the results of a pilot study on the manifestations of mathematical abilities of education seekers, significant factors of their development, as well as the effectiveness of the methodology of developmental teaching of Mathematics were experimentally verified.

1. Introduction

The modern renewal of the goals and content of Mathematics education is closely related to the problem of harmonious development of the personality, comprehensive disclosure of aptitudes, abilities and gifts of the subjects of the educational process. In fact, the competence of mathematical education involves the latest scientific rethinking of mathematical abilities as a present internal characteristic of mathematical competence, as an immanent attribute that prevails in its personal and psychological dimension. The isolation of mathematical abilities in the structure of the internal manifestation of mathematical competence requires a revision of both the content-procedural and control-evaluation components of the methodology of teaching Mathematics. However, educational realities testify to the establishment of practice, when the method of developing the mathematical competence of education seekers is replaced by the method of forming mathematical knowledge and skills, and the actual mathematical competence is measured on the basis of the ability to act in view of the solution of an applied problem in Mathematics, correctly done or the chosen answer. The existing contradictions are due to the lack of research in which the problem of the development of mathematical competence and mathematical abilities of students of education is studied in terms of the doctrine of the zones of proximal mathematical development and the theory of developmental teaching of Mathematics [1]. The problem area consists of the content and typology of the areas of proximal mathematical development of the education seekers, the development and theoretical justification of the methodology of developmental teaching of Mathematics.

2. Literature review

In modern scientific and methodical research, they study issues closely related to the problem raised in the work. Thus, in individual scientific works, attention is focused on the following:

- the development of creative thinking in the teaching of elementary Mathematics (on the example of the introduction of an online course) [2];
- the development of students' mathematical ideas when solving problems in geometry based on the cognitive style of learning [3];
- actualization of the high level of mathematical abilities of secondary school students through reflexive abstraction in the teaching of quadratic equations [4];
- development of mathematical logical thinking of students in agricultural areas [5];
- improving the quality of students' mathematical education (analytics and diagnostics) [6];
- development of logical thinking of high school students through a problem-based approach to teaching Mathematics [7]
- improving the competence of mathematical interpretation in the conditions of portfolio application [8];
- creative mathematical reasoning of future teachers in solving problems based on the capabilities of working memory [9];
- the influence of Mathematics on the sustainable development of young people's thinking [10].

In our previous study, the role and place of mathematical abilities in the three-dimensional structure of the internal manifestation of mathematical competence was substantiated, and a substantive and systematic analysis of the structural components of the phenomenon under study was made. The existence of complex correlations of four structural components of mathematical abilities (systematic, coding-formalized, cognitive-generalizing, mnemonic-generalizing) with three dimensions of the external manifestation of mathematical competence (content-theoretical, procedural-active, personal-psychological) has been established. The idea that the development of mathematical abilities is ensured due to the actualization of external dimensions of mathematical competence in educational and mathematical activities is introduced. Based on the results of the implementation of such an idea, a methodology for the development of mathematical abilities of students of education was developed, and its effectiveness was experimentally verified [11].

Well-known methodologists-mathematicians [12] implemented a competence approach to the systematization of mathematical problems in a specialized school [13].

The purpose of the work is to develop the doctrine of the zones of proximal mathematical development of the education seekers, to create and scientifically substantiate a theoretical-probabilistic methodical model of developmental Mathematics education, to experimentally verify the effectiveness of the developed methodology.

3. Methods

To achieve the goal, the following research methods were used: content-theoretical and structural-systemic analysis (in revealing the content and typological characteristics of the areas of proximal mathematical development, in highlighting the cycle of developmental Mathematics education, in substantiating the theoretical foundations of the methodology), abstraction and modeling (when building a theoretical-probabilistic methodical model of developmental Mathematics education), ranking (when determining the hierarchy of the nearest mathematical development zones, establishing the phasing of Mathematics education), statistical (in the course of a pilot study and experimental verification of the methodology), substantive generalization (in the presentation of results and formulation of conclusions).

3.1. A pilot study of the problem

Our pilot study included an expert assessment of the importance of factors in developmental Mathematics education. Among experienced Mathematics teachers, 10 experts were selected and participated in the survey. They ranked the main manifestations (factors) of mathematical abilities.

Factor 1. Speed, ease and depth of assimilation of mathematical material.

Factor 2. Interest in Mathematics.

Factor 3. Aptitude for mathematizing applied problems, building and implementing mathematical models.

Factor 4. Ability to generalize the content of mathematical material (facts of the theory, techniques, ways and methods of solving problems).

Factor 5. Memory for mathematical material implemented at several levels of generalization.

Factor 6. Mathematical intuition (the ability to holistically “grasp” a problematic problem situation), yes-experiences in the process of solving problems.

The results of the survey are summarized in the table (table 1).

Table 1. Main factors of mathematical abilities.

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	
Expert 1	3	4	5	2	6	1	
Expert 2	1	3	2	6	5	4	
Expert 3	1	3	2	5	6	4	
Expert 4	1	5	3	4	6	2	
Expert 5	2	3	5	1	4	6	
Expert 6	3	1	5	2	6	4	
Expert 7	1	3	2	6	5	4	
Expert 8	1	3	2	4	5	6	
Expert 9	1	2	5	4	3	6	
Expert 10	1	2	5	3	4	6	
Total	15	29	36	37	50	43	210
The square of the sum	225	841	1296	1369	2500	1849	8080

After the survey, the consistency of experts' judgments was checked. For this, Kendall's concordance coefficient (multiple rank correlation coefficient) was calculated

$$W = \frac{12S}{m^2(n^3 - n)},$$

where m – the number of experts in the group, n – the number of studied factors,

$$S = \sum_{i=1}^{n} \left(\sum_{j=1}^{m} R_{ij} \right)^2 - \frac{\left(\sum_{i=1}^{n} \sum_{j=1}^{m} R_{ij} \right)^2}{n}$$

$W < 0.35$ – agreement of experts is low.
$0.35 \leq W < 0.55$ – agreement between experts is average;
$0.55 \leq W < 0.75$ – agreement of experts is sufficient;
$0.75 \leq W < 1$ – agreement between experts is high;
$W = 1$ – experts' judgments coincide.
Based on the obtained data, the Kendall concordance coefficient was calculated.

Therefore, the agreement of expert teachers regarding the main manifestations of mathematical abilities is average. In our opinion, the obtained result is due to the specificity of mathematical abilities, but at the same time, the ambiguity of the accepted characteristic features, as well as the lack of awareness even of experienced teachers in the content and structure of the studied phenomenon. In fact, it is time to scientize Mathematics education in order to implement its developmental function.

An expert assessment the work carries out of the importance of factors for the development of mathematical abilities in education seekers.

Factor 1. Professional and personal qualities of the teacher (pedagogical and mathematical abilities, professional competence, ability to interest in Mathematics, creative thinking, love for children, patience, etc.)
Factor 2. Methods of teaching Mathematics.
Factor 3. Mathematical skills.
Factor 4. Learning motivation (cognitive interest).

Based on the results of the survey, a table was compiled (table 2).

Table 2. Significance of factors for the development of mathematical abilities.

	Factor 1	Factor 2	Factor 3	Factor 4	
Expert 1	4	3	1	2	
Expert 2	4	3	1	2	
Expert 3	3	4	1	2	
Expert 4	2	4	3	1	
Expert 5	2	3	4	1	
Expert 6	2	4	1	3	
Expert 7	2	4	1	3	
Expert 8	3	4	1	2	
Expert 9	3	4	1	2	
Expert 10	3	4	1	2	
Total	28	37	15	20	100
The square of the total	784	1369	225	400	2778

Kendall's concordance coefficient was calculated $W = 0.56$.

Therefore, the agreement of expert teachers regarding the factors of development of mathematical abilities of students is sufficient. The majority of experts named mathematical abilities and cognitive interest as the primary factors, but the least significant was the modern method of teaching Mathematics. Educators believe that the development of mathematical abilities to a greater extent ensures the solution of problems for proof and research, teaching education seekers algorithmic and heuristic methods of mental activity. The surveyed teachers emphasize the problem of methodological support for the development of mathematical abilities, the lack of a scientifically based developmental methodology for teaching Mathematics.

3.2. Theoretical justification of the research problem. Methods of developmental teaching of Mathematics

The concept of "zone of proximal development" was introduced by psychologist Lev Semyonovich Vygotsky [14], who substantiated its theoretical significance in pedagogical psychology (developmental psychology). According to the scientist, learning is related to development, but these processes do not take place evenly and in parallel, learning is not the same as development, it creates a "zone of proximal development", awakens internal processes that, through cooperation (interaction), become the property of the child himself. The zone of proximal development is the distance between the level of the child's actual development, determined by his independent achievements, and the level of possible development, outlined by tasks that are solved by adults, primarily parents, educators, and teachers [15].

It is from the activity cooperation of the teacher (lecturer) and education seekers, as well as their collaboration, which acquires collective and collectively distributed forms of work (group, pair), that the effectiveness of solving educational tasks depends, and most importantly, the course of the process of development of individual and psychological qualities of the personality. The low independence level of education seekers (high level of assistance) involves educational work aimed at establishing areas of understanding of the problem situation (such as its structure, content of conditions and requirements, conceptual component, relations and their properties, necessary and sufficient conditions), actualization of theoretical thinking and activation of collectively distributed educational activities. Under such conditions, the process of internalization takes place – the student's assimilation of external actions and social forms of communication, formation of mental actions and consciousness. In this way, the transition from collective to individual activity takes place, the area of actual development expands and, therefore, the cycle of developmental learning is completed (figure 1).

In view of the above, we believe that the zone of proximal development is such a component of training which: firstly, based on the results of joint activities, a degree of independence of education seekers in mastering a cultural form of behavior is established; secondly, an expedient collective (collectively distributed) educational activity is organized to master this form; thirdly, the phenomenological characteristic of such training is internalization, as a result of which the cultural form of behavior becomes an individual function of the students of education.

The definition of the generic category of the research problem makes it possible to formulate the definition of the species concept. The zone of proximal mathematical development is such a component of Mathematics education which: firstly, based on the results of the joint activity, the measure of the student's independence in mastering the method of action in the process of solving a new type of problem is established; secondly, an expedient collective (collectively distributed) educational and mathematical activity is organized in order for the learner to master new knowledge and skills; thirdly, the phenomenological characteristic of such training is internalization, as a result of which students solve certain types of problems independently, and their individual psychological qualities have a higher level of development.

The course of the transforming process of the zone of proximal development into the zone of actual development depends, first of all, on the psychologically weighted and methodically perfected organization of educational and mathematical activities. Here we focus on the fact that the way of educational cognition should be distinguished from the traditionally

Journal of Physics: Conference Series **2611** (2023) 012004 doi:10.1088/1742-6596/2611/1/012004

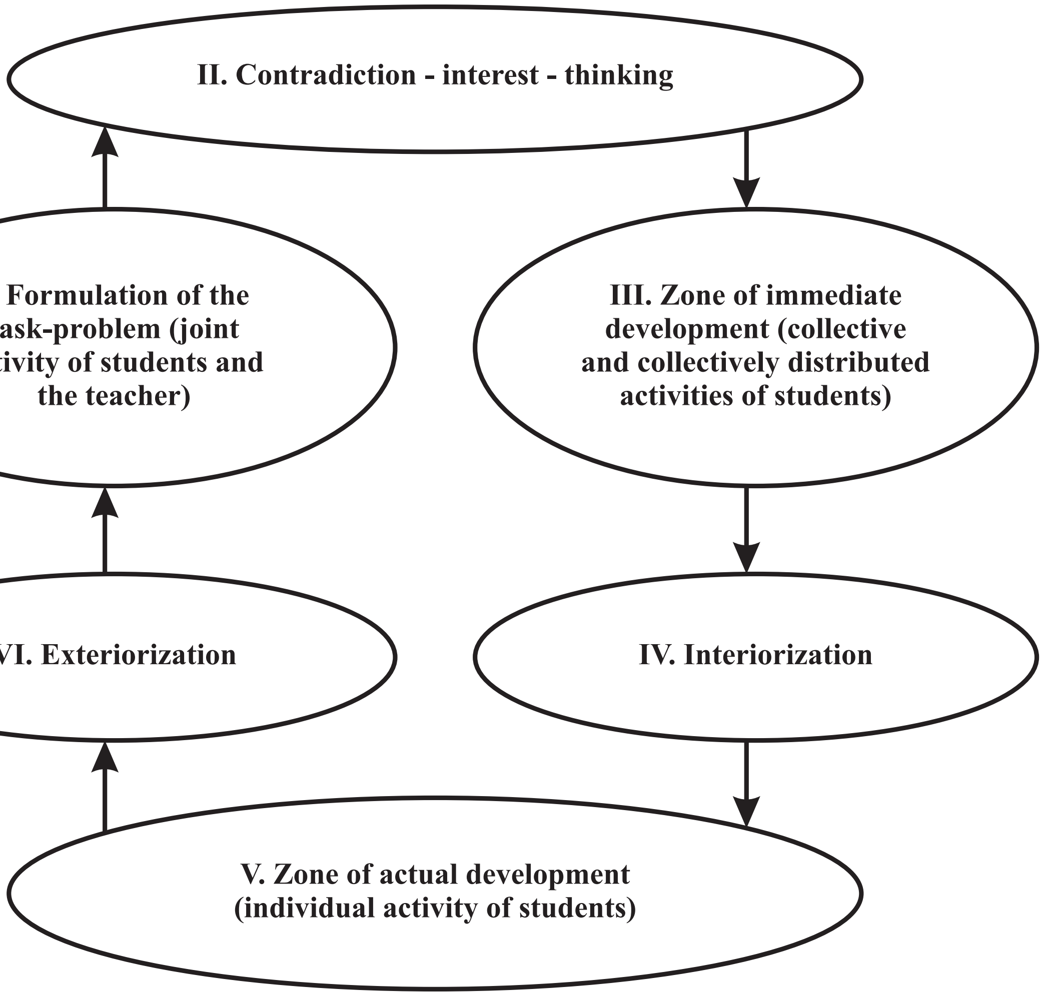

Figure 1. Developmental learning cycle.

established, exploiting the zone of actual development: the theory ⇔ the tasks ⇔ knowledge and skills ⇔ control and evaluation. Developmental training should be interesting, stimulate the thinking process, focus, first of all, on understanding (comprehension), and not on reproduction through memorization of ready-made algorithms. Therefore, a non-linear organization of Mathematics education should be implemented, a problem-based approach to the organization of mathematical activities and the development of mathematical abilities of students should be implemented.

The conceptual position of the research is the judgment that the structural and functional features of the zones of proximal mathematical development represent the principle of developmental continuity of Mathematics education and the task structure of educational and mathematical activity. In this way, compliance with the deductive essence of Mathematics was ensured, and emphasis was also placed on the phenomenological characteristics of mathematical abilities – the ability to generalize the content of mathematical education.

According to the principle of developmental continuity, each subsequent type of problem differs from the previous one by a higher level of content-theoretical generalization. This is how the problem-based system of teaching Mathematics correlates with the zones of the nearest mathematical development of the education seekers. This makes it possible to distinguish four zones of the nearest mathematical development: *basic, educational, educational-theoretical and* *educational-research.*

1st level: basic zone – basic (applied) problems in Mathematics are formulated and solved, the ability to create mathematical models is formed, to establish methods of action in the process of solving partial problems in Mathematics, to plan them, to monitor their execution and to assess the degree of mastery.

2nd level: educational zone – educational problems in Mathematics are formulated and solved, the ability to create educational models is formed, to establish methods of action in the process of solving typical problems in Mathematics, to plan them, to perform self-monitoring and self-correction, to carry out self-assessment of the degree of mastery.

3rd level: educational-theoretical zone – educational-theoretical problems in Mathematics are formulated and solved, the ability to create educational-theoretical models, to establish and to apply methods of solving problems of content mathematical lines, general logical and general mathematical methods of solving (proof and research), as well as the ability to perform self-monitoring and self-correction, to self-assess the degree of assimilation.

4th level: educational and research zone – educational and research problems in Mathematics are formulated and solved, research and mathematical skills are formed, as well as the ability to make a theoretical analysis of educational and scientific-mathematical literature, to apply methods of mathematical knowledge and research, to determine meaningful components of scientific research (object, subject, goal, task, hypothesis, scientific novelty, mathematical methodology). Elements of scientific novelty of the obtained results serve as an important attribute of the educational and research zone of the nearest mathematical development.

Using a systematic approach and a modeling method, we will build a methodical model for the mathematical abilities development of students. In the course of building the model, we proceed from the following basic provisions:

1. System-forming components of the model of the mathematical abilities development are the zones of actual and proximal mathematical development of the education seekers.
2. The phasing of Mathematics education involves the determination of the zones of actual mathematical development, the creation of zones of the nearest mathematical development, and the transformation of the nearest zones of development into actual ones.
3. Zones of the closest mathematical development of the education seekers correlate with the level of content generalization of tasks in the structure of educational and mathematical activity.
4. In the process of solving problems (basic, educational, educational-theoretical, educational-research), the main components of mathematical abilities are updated – system-building, coding-formalized, cognitive-generalizing, mnemonic-generalizing.
5. Each of the stages of educational cognition (development of mathematical abilities) ends with a reflection of the process of learning Mathematics.
6. Probabilistic factors determined by the level of mathematical training (the area of actual mathematical development) and the existing level of development of mathematical abilities of the education seekers are taken into account in the design of the methodological model for the development of mathematical abilities.

The probabilistic (randomly) deterministic structural components that are determined at the first stage of model implementation and determine the content and specifics of the course of subsequent stages allow it to be classified as theoretical-probabilistic methodical models (figure 2).

A theoretical-probabilistic methodical model will be understood as a system that, on the one hand, outlines the essential connections of the studied phenomenon, reveals its structure and

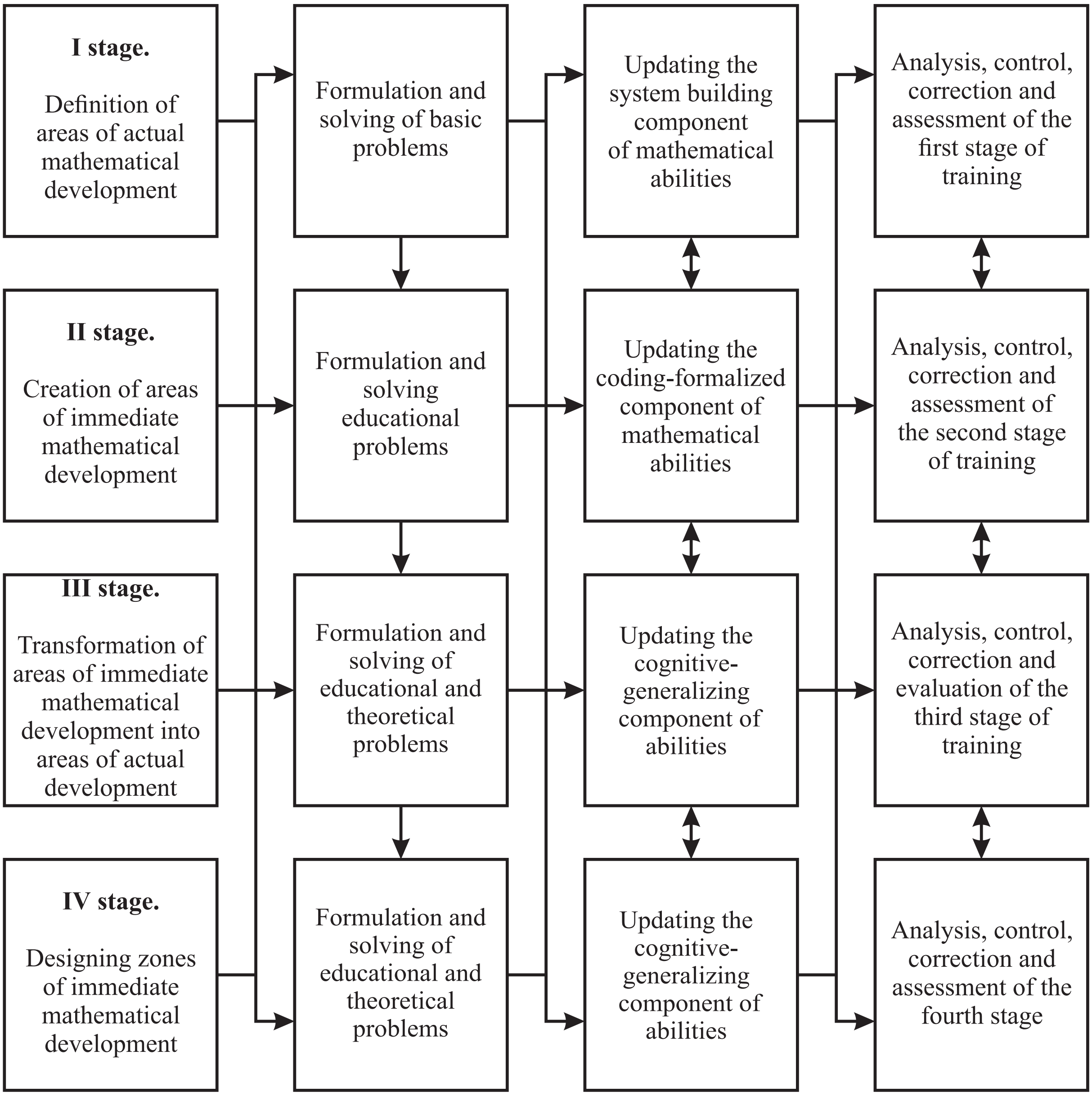

Figure 2. Theoretical and probabilistic methodical model of development of mathematical abilities of students.

phenomenological characteristics, and on the other hand, represents probabilistic factors and indicates exactly how and in what way its full-fledged (holistic) functioning (development) is achieved.

We will reveal the content of the methodology of developmental teaching of Mathematics.

I stage. *Determination of areas of actual mathematical development of education seekers.*

The essence of this stage consists in formulating and solving basic problems in Mathematics, as a result of which the methods of action that the education seekers have already mastered are established. Here it is possible to establish a pre-basic zone of actual mathematical development, within which the methods of action are not formed. The highest level of substantive generalization of the problem situation corresponds to the formulation of educational

(educational and theoretical) problems in Mathematics, clarification of the action methods formation in the process of solving typical problems. In this way, it is established what form of cultural behavior the education seekers have mastered, what tasks (types of tasks) they cope with independently. In view of the studied material, analysis, control, correction and assessment of its assimilation are made, and the question of what is the zone of actual mathematical development is answered: pre-basic, basic, educational, educational-theoretical, educational-research. As a result, a matrix of correspondence between zones of actual mathematical development and zones of the nearest mathematical development is created, which provides a list of education seekers, their zones of development, types of problems to be solved, forms and means of educational work.

II stage. *Creation of the closest mathematical development zones of education seekers.*

At the second stage, a problem-solving situation is created which education seekers cannot cope with on their own. An applied problem in Mathematics is formulated, involving the study of new material. Under collective and collectively distributed forms of educational work, a basic (applied) problem in Mathematics is solved, the method of mathematical modeling is implemented, and a mathematical model is built. Taking into account the zones of actual development established at the first stage, educational (educational and theoretical) tasks are formulated and solved. Based on the results of collective educational and mathematical activities, an educational (educational and theoretical) model of solving typical problems is developed. As a result, a generalized method of action is built (heuristic and algorithmic prescriptions are formulated) in the process of solving typical problems in Mathematics, analysis, control, correction and evaluation of its assimilation are carried out. A special place is given to group and pair forms of work. In addition to the above, the second stage enables the formulation of an educational and research task, and thus the creation of an educational and research zone for the nearest mathematical development of the most capable education seekers.

III stage. *Transformation of the proximal mathematical development zones of the students into zones of their actual mathematical development.*

At the third stage, individual forms of educational work prevail, the process of internalization is ensured. Here, the created educational (educational-theoretical) models are implemented, basic (educational, educational-theoretical) problems in Mathematics are solved individually, actions are performed independently in the process of formulating and applying mathematical concepts and theorems. The most capable perform tasks of a research and mathematical content, implement the methodology of mathematical research in the preparation of works of the National Academy of Sciences of Ukraine. The quintessence of this stage is self-analysis, self-control, self-correction and self-assessment of mastering a generalized method of action in the process of solving typical problems. A qualified reflection of the process and results of learning Mathematics testifies to a new intellectual quality, to the level of mathematical abilities development of each education seeker. So, it is determined individually whether the nearest zone of mathematical development has actually transformed into an actual one. Therefore, the results of the implementation of the third stage of training are the verification (confirmation of the truth) of a probable fact: whether a new, higher zone of actual mathematical development has been reached in comparison with the zone that was established at the first stage of training.

IV stage. *Designing zones of the nearest mathematical development of education seekers in teaching Mathematics.*

The zones of actual mathematical development of the education seekers established at the third stage serve as a basis for designing their zones of proximal mathematical development. Taking into account the educational and mathematical achievements of students, the types of problems solved by them independently, the matrix of correspondence of the zones of actual mathematical development and the zones of the nearest mathematical development is adjusted. The main types of problems are specified, in the process of solving which zones of actual mathematical development are established and zones of nearest mathematical development are created, as well as forms and means of educational work are indicated. The adjusted correspondence matrix serves as the basis for the further implementation of the methodical model, starting with the second stage – the creation of the closest mathematical development zones of the education seekers.

3.3. Experimental verification of the effectiveness of the developmental teaching of Mathematics method

Experimental training was organized in high school Mathematics classes. The minimum sample volume, which provides reliable estimates of the general population parameters, was calculated according to the formula

$$n = \frac{\omega(1-\omega)\cdot t^2}{\Delta^2},$$

where ω – selective part ($0 < \omega < 1$), Δ – margin error of the confidence interval, t – the argument of the Laplace integral function.

Assuming a confidence probability (reliability) $P(|p-\omega| < \Delta) = 0.96$, according to the tables, the value of the argument of the Laplace integral function is obtained $t = 2.10$. Taking into account the selective part $\Delta = 0.04$, the minimum sample size is calculated

$$n = \frac{0.5\cdot(1-0.5)\cdot 2.1^2}{0.04^2} \approx 441.$$

466 high school students took part in the experiment, therefore, the statistical requirement for the sample size was met, and its results with a reliability of 0.96 and a margin of error of 0.04 were extended to the entire general population.

Taking into account the components of mathematical abilities, the research developed an experimental content structure of the development of the named phenomenon, in which indicators for diagnosing levels of development were specified:

1) interest in studying Mathematics;
2) the ability to formalize, create and research symbolic interpretations (models) of problem situations;
3) abilities to generalize the content of the educational material of Mathematics, mental "grasp" of a formal structure (algorithm) based on a partial case;
4) the ability to memorize mathematical material at different levels of theoretical generalization, memory of typical relations (formulas), general schemes of reasoning (algorithms), the structure of methods and ways of solving problems (proofs, research).

Considering the specified indicators, the sets of tasks were developed, which included:

1) testing interest in studying Mathematics;
2) construction of a mathematical model;
3) drawing up an algorithm for solving typical problems;
4) establishing correspondences;
5) solving proof problems (research);
6) solving Olympiad tasks.

According to the 100-point evaluation scale, low, average, sufficient and high levels of development of mathematical abilities were diagnosed. The creative level was ascertained when the Olympic task was solved at a high level.

The training of high school students of the control group (CG) was carried out according to the traditional method, and the experimental group (EG) according to the developed method. The analysis of the results of the initial sections proved that the empirical distributions in CG and EG did not differ, and therefore, the groups were homogeneous. A comparison of the results of the control sections in the EG and CG of high school students showed that the empirical distributions of the development of the individual and psychological formation of high school students began to differ after the introduction of the experimental method. In EG, the number of tenth-graders with a creative level of development of mathematical abilities increased by 2%, eleventh-graders – by 3%, high level of development – by 5% and 4%, respectively, and sufficient level – by 4% and 11%, respectively. The total number of students with an average level of development of mathematical abilities, on the contrary, decreased. In the tenth grade, the number of high school students with an average level of mathematical abilities decreased by 5%, in the eleventh grade by 6%, and the number of students with a low level decreased by 4% and 12%, respectively (figure 3, figure 4).

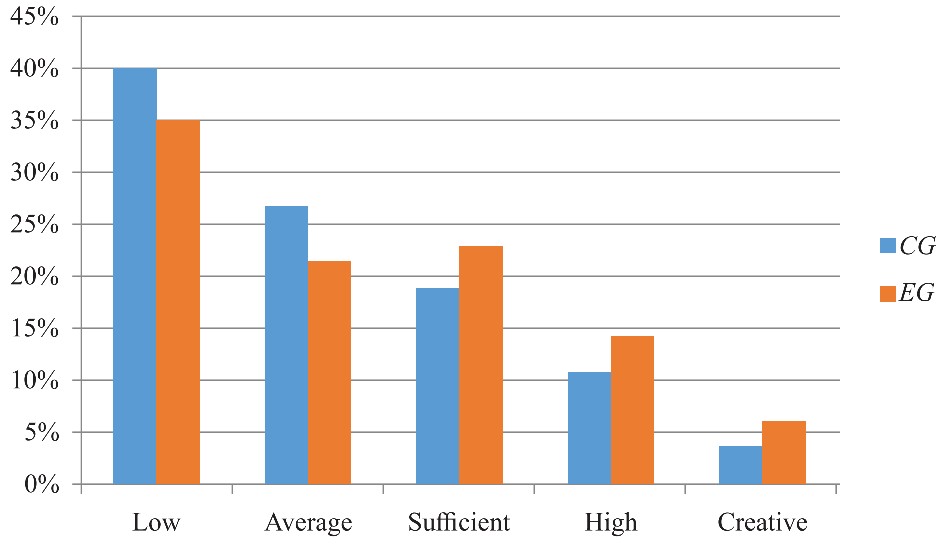

Figure 3. Levels of mathematical abilities development of tenth graders.

The positive dynamics of the development of mathematical abilities in the EG of high school students is observed during two years of study (figure 5, figure 6).

It is noteworthy that the greatest effect of the implementation of the method was observed in the eleventh grade, in the second year of experimental education. In our opinion, such a phenomenon is explained by the existence of a latent adaptation period, as well as the need to choose a profession, prepare for external independent assessment in Mathematics in the context of the introduction of innovative teaching methods.

After the end of the pedagogical experiment, the methods of mathematical statistics were used: λ – the Kolmogorov-Smirnov test and φ – Fisher's angular transformation. The first method made it possible to find the point at which the sum of the accumulated discrepancy between the distributions in EG and CG of high school students is the largest, as well as to assess the reliability of the discrepancy. Another method is to assess the reliability of the differences between the percentages in EG and CG.

We formulate two alternative hypotheses: H_0 – empirical distributions of the development of mathematical abilities in CG does not differ from empirical distributions in EG; H_1 – empirical distributions of the development of mathematical abilities in CG differs from empirical distributions in EG.

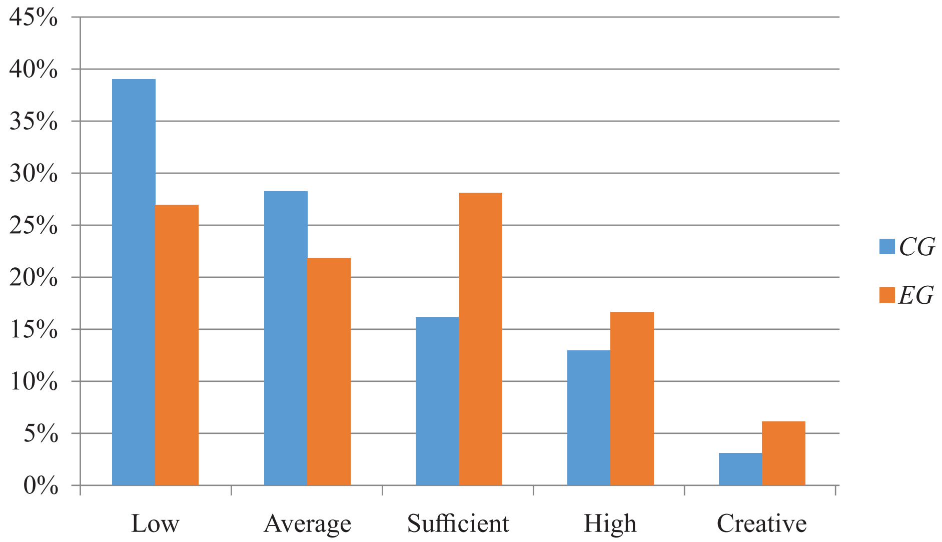

Figure 4. Levels of mathematical abilities development of eleventh graders.

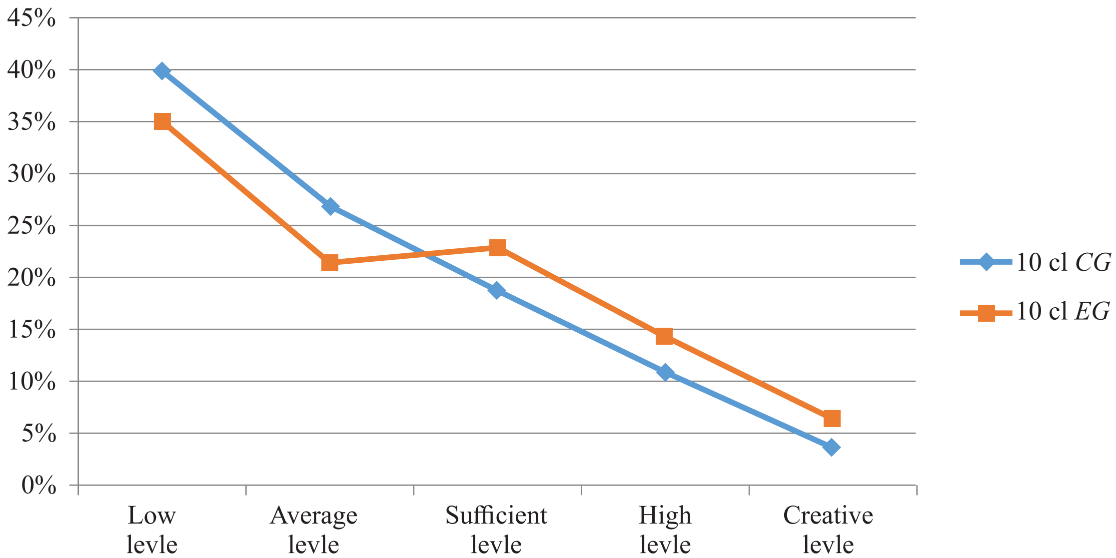

Figure 5. Dynamics of mathematical abilities of tenth graders.

According to the results of the λ-criterion calculation, we have $d_{max} = 0.136$ (table 3). We calculate the value of the Kolmogorov-Smirnov test according to the formula:

$$\lambda = d_{max} \cdot \sqrt{\frac{n_{EG} \cdot n_{CG}}{n_{EG} + n_{CG}}} = 1.47.$$

The obtained value λ corresponds to the statistical significance of $\rho = 0.02$. Since $\lambda > \lambda_{0.05}$, the differences between the empirical distributions in CG and EG are reliable. Therefore, the hypothesis H_1 is accepted.

Let's estimate the reliability of the differences between the percentage shares using the Fisher exact test statistic (table 4). The results of the calculations show that the maximum difference between the accumulated empirical frequencies was found at the average level of development. We will use the upper limit of this category as a criterion for dividing both samples into subgroups

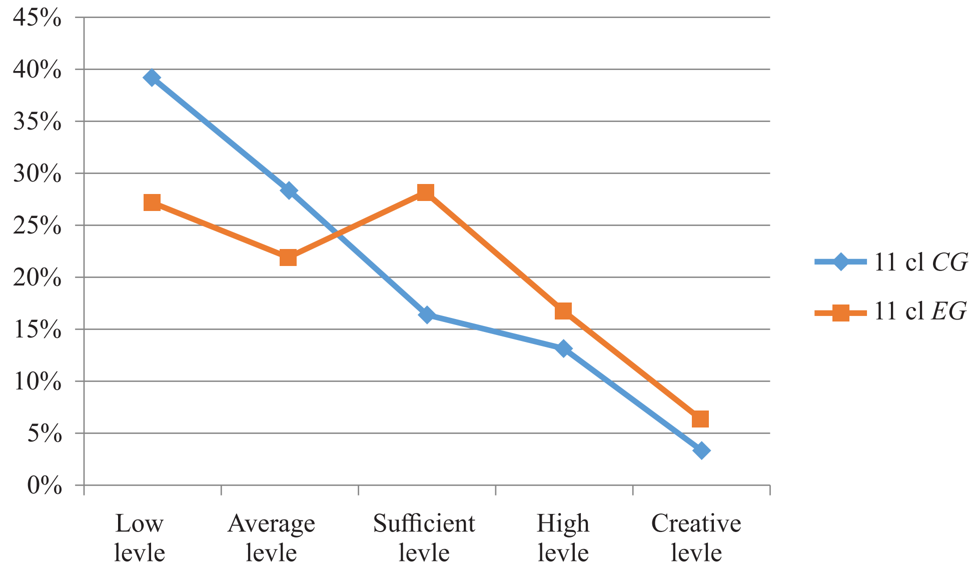

Figure 6. Dynamics of mathematical abilities of eleventh graders.

Table 3. Calculation of the criterion for comparing empirical distributions in EG and CG.

Levels of development	Empirical frequencies		Empirical relative frequencies		Accumulated empirical relative frequencies		$d = \sum f^*_{EG} - \sum f^*_{CG}$
	f_{EG}	f_{CG}	f^*_{EG}	f^*_{CG}	$\sum f^*_{EG}$	$\sum f^*_{CG}$	
Low	75	91	0.318	0.396	0.318	0.396	0.078
Average	51	63	0.216	0.274	0.534	0.670	**0**.136
Sufficient	59	41	0.250	0.178	0.784	0.848	0.064
High	36	27	0.153	0.117	0.936	0.965	0.029
Creative	15	8	0.064	0.035	1.000	1.000	0.000
Total	236	230	1.000	1.000			

Table 4. Fisher exact test statistic.

	There is an effect		There is no effect		
	Number of subjects	%	Number of subjects	%	
EG	110	46.6%	126	53.4%	236
CG	76	33.0%	154	67.0%	230
	186		280		466

where "there is an effect" (creative, high and sufficient levels) and "there is no effect" (low and medium levels).

We determine the Fisher exact test statistic value is 0.0033. The result is significant at $p < 0.01$. Therefore, the hypothesis H_0, is rejected, and the hypothesis H_1 is accepted: the percentage of high school students who have better indicators of the development of mathematical abilities is greater in EG. The effectiveness of the experimental methodology for the development of mathematical abilities has been confirmed by the methods of mathematical statistics.

4. Results

The implementation of the experimental method gives the following results:

1. High school students of experimental group have a more developed educational and cognitive interest in studying Mathematics, the system-building component of their mathematical abilities serves more successful educational and mathematical activities.
2. Compared to control group, experimental group of high school students distinguish concepts and relations more clearly, have a better command of theoretical concepts (formulate definitions), name the main theorems and their methods of proof, distinguish the main types of problems and name the methods (ways) of their solution, compose generalized methods of actions (algorithms) for implementation in typical problem situations. The mentioned characteristics testify to the positive dynamics of the cognitive-generalizing component of the mathematical abilities of the education seekers.
3. High school students of experimental group have a better command of the method of mathematical modeling, more skillfully solve applied problems in Mathematics. Compared to control group, they better build mathematical interpretations of problem situations (functions, equations, inequalities, their systems and aggregates), implement mathematical models. This is achieved due to the quality of the coding and formalization component of mathematical abilities.
4. High school students of the experimental group have a more developed memory for typical relations (formulas), general schemes of reasoning (algorithms), content and structure of methods and ways of solving problems (proof and research). The mentioned qualitative characteristics testify to the better developed mnemonic and generalizing component of the mathematical abilities of the education seekers.
5. Mathematical Olympiad tasks are better solved by high school students of experimental group. Here, the number of students who independently find ways of acting in atypical problem situations, and integrally “grasp” the leading mathematical idea, has increased. The educational and mathematical activity of high school students of the creative level of developing mathematical abilities is accompanied by aha-experiences and has signs of heuristics.
6. The percentage of respondents with the pre-basic area of actual mathematical development has dropped to zero. Positive changes can be traced in the basic area of actual mathematical development, it has expanded to the educational area. Therefore, the percentage of students with the educational and theoretical zone of the closest mathematical development is increasing.

5. Conclusions

In summary, we formulate the following conclusions:

1. It is time to scientize mathematical education in terms of its content, manifestations, structure, and factors of development of mathematical abilities as an immanent attribute of the mathematical competence of students, dominant in its personal and psychological dimension. Until now, a scientifically based method of developing mathematical abilities of education seekers is in demand in educational practice.
2. Teaching about the zones of proximal mathematical development reveals their content, based on the processes of interiorization and exteriorization, and illuminates the cycle of developmental learning of Mathematics. Structural and functional features of the zones of proximal mathematical development are represented by the principle of developmental continuity of Mathematics education and the task structure of educational

and mathematical activity. According to the levels of content generalization of the problem-based system of teaching Mathematics, four zones of proximal mathematical development are distinguished: basic, educational, educational-theoretical and educational-research.

3. The theoretical-probabilistic methodical model of the development of mathematical abilities of education seekers is a system that, on the one hand, outlines the essential connections of the studied phenomenon, reveals its structure and phenomenological characteristics, and on the other hand, represents probabilistic factors and indicates exactly how and in what way its full (holistic) functioning is achieved. It reveals the stages of learning, defines the types of problems to be solved, highlights the actualized components of mathematical abilities and provides for the reflection of each stage of educational knowledge.
4. The developed methodology of developmental teaching of Mathematics is implemented according to the following stages: identification of areas of actual mathematical development; creation of zones of the nearest mathematical development; transformation of zones of the nearest mathematical development into zones of actual mathematical development; designing the zones of the nearest mathematical development of the education seekers. An important attribute of this methodology is the correspondence matrix of the zones of actual mathematical development and the zones of the nearest mathematical development of the education seekers.
5. Verification of the created model and the developed methodology in the course of experimental teaching of Mathematics for high school students allows us to assert the developmental effect, the achievement of the developmental function of education. All structural components of mathematical abilities undergo positive changes: system-building, coding-formalized, cognitive-generalizing, mnemonic-generalizing.

The acute social demand for a competence-oriented methodology for teaching Mathematics, the need to substantiate the methodological foundations of the implementation of a problem-based approach to the development of the mathematical competence of students determine the prospects of our further research.

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References

[1] Roth W M 2020 Zone of Proximal Development in Mathematics Education *Encyclopedia of Mathematics Education* ed Lerman S (Cham: Springer International Publishing) pp 913–916 ISBN 978-3-030-15789-0 URL `https://doi.org/10.1007/978-3-030-15789-0_156`
[2] Achkan V V, Vlasenko K V, Chumak O O, Sitak I V and Kovalenko D A 2022 *Journal of Physics: Conference Series* **2288**(1) 012020 URL `https://doi.org/10.1088/1742-6596/2288/1/012020`
[3] Adnan S, Juniati D and Sulaiman R 2019 *Journal of Physics: Conference Series* **1417**(1) 012049 URL `https://doi.org/10.1088/1742-6596/1417/1/012049`
[4] Cahyani L, Masriyah and Rahaju E B 2019 *Journal of Physics: Conference Series* **1417**(1) 012044 URL `https://doi.org/10.1088/1742-6596/1417/1/012044`
[5] Garcia Quintero C L and Durán Chinchilla C M 2019 *Journal of Physics: Conference Series* **1408**(1) 012013 URL `https://doi.org/10.1088/1742-6596/1408/1/012013`
[6] Hrynevych L M, Khoruzha L L and Proshkin V V 2022 *Journal of Physics: Conference Series* **2288**(1) 012022 URL `https://doi.org/10.1088/1742-6596/2288/1/012022`
[7] Lovianova I V, Kaluhin R Y, Kovalenko D A, Rovenska O G and Krasnoshchok A V 2022 *Journal of Physics: Conference Series* **2288**(1) 012021 URL `https://doi.org/10.1088/1742-6596/2288/1/012021`

[8] Niño Villan M L, Gallardo Pérez H J and Villamizar Jaimes D 2019 *Journal of Physics: Conference Series* **1408**(1) 012022 URL https://doi.org/10.1088/1742-6596/1408/1/012022
[9] Palengka I, Juniati D and Abadi 2019 *Journal of Physics: Conference Series* **1417**(1) 012055 URL https://doi.org/10.1088/1742-6596/1417/1/012055
[10] M C Santiago Carrillo M V and Rojas Suarez J P 2019 *Journal of Physics: Conference Series* **1408**(1) 012012 URL https://doi.org/10.1088/1742-6596/1408/1/012012
[11] Semenets S P, Semenets L M, Andriichuk N M and Lutsyk O M 2022 *Journal of Physics: Conference Series* **2288**(1) 012023 URL https://doi.org/10.1088/1742-6596/2288/1/012023
[12] Lovianova I, Krasnoschok A, Kaluhin R, Kozhukhar O and Dmytriyev D 2021 *Educational Technology Quarterly* **2021** 331–346 URL https://doi.org/10.55056/etq.14
[13] Vlasenko K V, Lovianova I V, Armash T S, Sitak I V and Kovalenko D A 2021 *Journal of Physics: Conference Series* **1946**(1) 012003 URL https://doi.org/10.1088/1742-6596/1946/1/012003
[14] Vygotski L S 1929 *The Pedagogical Seminary and Journal of Genetic Psychology* **36** 415–434 URL https://doi.org/10.1080/08856559.1929.10532201
[15] Vygotsky L S 1997 *Educational Psychology* (CRC Press) URL https://doi.org/10.4324/9780429273070

Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

Methodology of project-based learning for training junior students in applied mathematics: general scheme of the educational process

To cite this article: O B Akhiiezer *et al* 2023 *J. Phys.: Conf. Ser.* **2611** 012005

Methodology of project-based learning for training junior students in applied mathematics: general scheme of the educational process

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Abstract. An original methodology of the project-based learning for junior students of the specialty applied mathematics is proposed in the paper. A complete step-by-step diagram (as a BPMN diagram) of the process of the project-based learning as a business process with a description of the specific actions of all its participants is given. The paper specified and clearly describes all the main aspects of the work on the project, starting from the criteria that the project problem must satisfy, and ending with the form of project defense. The roles of both students within the project team and all teachers are described in detail. Special attention is paid to all documents accompanying the work on the project, which should be submitted by the project team. The results of the article may be useful to those teams of teachers who are just starting to work on the implementation of project-based learning into the educational process for the specialty of applied mathematics or related ones.

1. Introduction

Project-based learning (PBL) is a framework of teaching and learning in which students learn by actively engaging in real-world practically meaningful projects. PBL may be considered as a student-centered pedagogy as a style of active learning and inquiry-based learning [1]. As the Buck Institute for Education (BIE) explains, with PBL, students "investigate and respond to an authentic, engaging, and complex problem or challenge" with deep and sustained attention [2]. Projects are complex problems, based on challenging questions or inquiries, which involve students in problem solving, decision making, data analysis, design or investigative activities; its solving gives students the opportunity to work in a team for long periods of time and leads to a realistic product.

PBL engages students in solving a real-world problems or challenges, by seeking answering on complex practically oriented questions. Students involved in PBL should demonstrate their knowledge and skills by creating a real product along with presentation for an interested audience. As a result, students under project learning develop not only deep content knowledge in their training field and problem-solving skills, but also such important soft skills such as critical thinking, collaboration, creativity, and personal communication.

Moreover, the project is the vehicle for teaching students the important knowledge and skills that are critically need to learn for their future successful professional career. For most modern qualified workers in any fields of industry, their careers will be marked by a series of projects rather than years of service to a specific organization [3]. Traditional lecture-based teaching, particularly in subjects such as engineering, no longer provide the broad professional skills needed by contemporary graduates in response to a perceived need for university graduates to be equipped with skills relevant to future employers.

For students of 21st century, more important than classical learning, is learning to work in a community, thereby taking on social responsibilities [4]. Implementation of PBL also requires from student development of various forms of communication to work as a team for working together to accomplish specific goals an atmosphere of shared responsibility. PBL is done collaboratively and within groups or project teams. Students must collaborate, expanding their active soft skills and focused communication, to take ownership of their success. The essence of PBL stimulates building intrinsic motivation because it centers student learning and self-study around a central interesting and important question or problem and a practically meaningful outcome.

Students learn about a subject by working for an extended period to investigate and respond to a complex question, challenge, or problem. At that emphasizes individual learning activities that are long-term, interdisciplinary and practical-centered. Typical projects present a specific problem to solve or unusual phenomenon to investigate for developing abilities students; for nonstandard problems solving and creative making of products.

PBL instructor/teacher must structure the proposed question/problem to direct the students toward successful problem solving, regulate the project execution process using ongoing assessment and feedback to ensure the achievement of intermediate goals and the successful completion of the stated task [5]. The learning process can be made more effective manageable by chunking the project into smaller parts, with frequent checkpoints built into the timetable. Instead of a traditional summative exam, final assessments can be obtained by communicating not only with teachers but also with professionals in the field.

Since PBL starts with a problem to be solved, students working in a PBL environment must become skilled in problem solving, creative thinking, and critical thinking. The student's role is to think about how rationally to solve stated problem, to build necessary knowledge, and determine an effective real-world solution to the issue/question. Team members can perform various functions based on their roles. Assigning student roles in a team based on a joint consensus decision between the instructor and the team members is a critical factor in the success of a project [6].

Following last years of distilled educational experience, the Buck Institute for Education identified seven essential elements for PBL that focus on project design, collectively these elements are called Gold Standard PBL [7]. Project-based learning is often differentiated by the following characteristics:

Inter-disciplinary: real-world challenges are rarely solved using information or skills from a single subject area, what require students to use content knowledge and skills from multiple academic domains;

Rigorous: challenges set out in PBL often require the application of knowledge and skills, not just recall or recognition;

Student-centered: in PBL, the role of the teacher shifts from content-deliverer to facilitator, coach or project manager. Students work more independently, with the teacher providing support only when needed.

Typically, PBL takes students through the following phases or steps: identifying a problem, agreeing on potential solution path to the problem, designing and developing a prototype of the solution, refining the solution based on feedback from experts, instructors, and/or peers. Implementing of PBL in turn includes several key processes:

- defining problems in terms of given constraints or challenges, PBL projects should start with students asking questions about a problem;
- generating multiple ideas in order to solve a given problem, students should be given the opportunity to brainstorm and discuss their ideas for solving the problem;
- prototyping as potential problem solutions is to concretization of ideas generated during the brainstorming phase, and to quickly description a how a solution to the problem might look;
- testing the developed solution allows students to glean how well their products or services work in a real setting.

A huge literature is devoted to the theory and practice of project learning; there are a number of useful reviews [8]. Particular attention is paid to PBL in training in technical and engineering specialties, which, among other things, contribute to the formation of students' skills in systems thinking [9, 10].

In this regard, the intensively developing international educational initiative CDIO™ INITIATIVE [11] for design training is of particular interest. CDIO is an innovative educational framework for producing the next generation of engineers. The framework provides students with an education stressing engineering fundamentals set in the context of Conceiving – Designing – Implementing – Operating (CDIO) real-world systems and products. Within the CDIO Initiative framework, extensive documentation has been developed, including standards, syllabuses, and methodological materials [12]. There are many examples of the successful implementation of this methodology in the context of project training for engineering students [13].

Recently, the attention of specialists has been attracted by the implementation of the ideas of PBL in the preparation of specialists in science-intensive specialties, in particular, in applied mathematics (AM). The implementation of this approach made it possible not only to improve the level of training of applied mathematicians, but also to significantly increase their competence in solving applied problems. Incorporating PBL in mathematics fosters positive connections between math and the real world [14–16]. PBL in general terms is described in the literature [1–3, 6], but when implementing it in the educational process, a lot of problems arise, both fundamental and technical. This paper describes an original implementation of PBL for the preparation of junior students of the specialty 113 – "Applied Mathematics" of the educational program "Intellectual Data Analysis" at the Department of Computer Mathematics and Data Analysis of the National Technical University "Kharkiv Polytechnic Institute" [17,18]. The main problems faced by the authors are described, and methods for their solution are proposed. A complete scheme of the PBL process has been built with a description of the actions and roles of all participants in the process.

2. The main problems of PBL implementation

The theoretical foundations of PBL are well-known, but they are too general and do require nonobvious specifications on a case-by-case basis.

When attempting to apply these principles, teachers will inevitably face a number of challenges, just like the authors of the work at the beginning of the implementation of PBL. This paper presents solutions to key issues that authors faced implementing PBL in training applied mathematics junior students.

The main problems are:

1) choosing and formulating the problem statement,

2) organization of teachers' work,
3) organization of the work of a team of students,
4) organization of interaction between teams of students and teachers,
5) format of the project delivery,
6) grading the project team.

In addition, the problematic issues were the number of students in the project team (PT) and the number of such teams.

These problems, as well as proposed approaches to their solution, are discussed below.

3. The statement of the project problem

The first challenge for the authors was the choosing the projects problem that should take into account the specifics of the specialty and the educational program. It turned out that one teaching experience is not enough to set this kind of problem. Scientific and practical experience is needed since the task must be of a complex applied nature. Ideally, the problem should be proposed by a real customer from the outside (if there is none, teachers take on this role). Furthermore, it is necessary to take into account the level of students and give them the problems with an appropriate level of complexity. Accordingly, the development of problems for the projects becomes a problem itself.

Long-term experience in the PBL usage eventually made it possible to formulate the criteria that the problem of the project in the specialty AM should satisfy:

1. The result of the project should be a software or a software-hardware product ready for a presentation on the market.
2. Accordingly, the problem should have a relevant applied nature.
3. The solution to the problem should require the application of knowledge from different domains.
4. The problem must necessarily imply the mathematical modeling of objects and/or processes. The problem should not have a solution obviously following from the problem statement.
5. The problem can be decomposed into several separate, independently-running subproblems (students within the team should be able to work in parallel (acquisition of teamwork skills)).
6. The impossibility of completing the task on time by one person.
7. The models and methods used in solving the problem generally correspond to the curricula.

Below are examples of project problems successfully completed by students and one of them will be analyzed in detail in terms of the listed criteria:

Example 1. The customer is a fruit processing factory. Create software and hardware complex that physically sorts apples into separate containers according to three degrees of ripeness in real-time.

Example 2. The customer is a garment factory. Create software that builds a diagram of the optimal cutting of sheet material given the parameters of the geometry of the parts and the original fabric.

Example 3. The customer is a mobile operator. Develop software that allows, according to a given configuration of towers of the mobile phone network, to choose the optimal distribution of towers' power, maximizing the coverage area.

Let's analyze the last example in terms of compliance with the above criteria.

Criterion 1. The product can be used by mobile operators.

Criterion 2. Application of the results of this project can improve the quality and reduce the cost of operator services.

Criterion 3. To solve this problem, knowledge is required from the field of radiophysics (to plot the dependence of the coverage radius of the tower on its power), computational geometry (to calculate the total coverage area), multidimensional optimization (to determine the optimal power distribution), programming (to create software).

Criterion 4. To solve this problem, it was necessary to build the following mathematical models: a coverage area model for each tower, a model for the connection between the area of the network coverage and transmitter power, and a model for the total coverage area (objective function). In addition, it is necessary to develop algorithms for calculating the coverage area and maximizing it. All these are non-obvious subproblems that do not have a trivial solution.

Criterion 5. The tasks listed in the description of criterion 4 are largely independent. Moreover, such types of work as the development of the front-end software, reviewing the literature and input data preprocessing (ordering, labeling, etc.) can be carried out in parallel. This will require communication between students and will inevitably lead to the acquisition of teamwork skills.

Criterion 6. It is impossible to complete all the listed subtasks, write software and accompanying documentation, and prepare a project for the defense to one student in the allotted three months (the project execution time).

Criterion 7. This task fully corresponded to the level of knowledge, skills and abilities of second-year students of the specialty AM of a technical university. Information outside the syllabus was obtained from literature reviews or from consultants.

Therefore, before the problem is transferred to the PT, it must be subjected to a complex procedure for the formation of a problem statement, which involves the customer and the team of teachers. This is due to the fact that customers mostly have no idea about the curriculum and the level of students' training and hence, can not assess whether the problem meets the criteria. Therefore, at this stage, there is an agreement and, if necessary, adjustment of the problem statements.

The sequence of work on the problem statement is shown in figure 1 as a Business Process Model and Notation (BPMN) diagram that satisfies the requirements of Process modeling conformance [19]. The customer gives a semantic statement of the problem in the form of text in natural language. Further, a team of teachers (TT) checks this problem for the criteria. If the problem does not fit the criteria and cannot be corrected, it is rejected. If it can be corrected, then the TT corrects the problem statement and agrees on a new version with the customer. When the criteria are met, the TT determines the difficulty level of the problem and selects an adequate project team. After that, the customer issues the problem to the project team.

Hereinafter, the team of teachers is continuously involved in the project implementation process. Each teacher has their own functions, which are described in the next section.

4. Organization of the teachers team work

The composition of the teachers team and the responsibilities of each of its members will be discussed below.

The peculiarity of our projects is that they imitate the work of a development team on a real project in an IT company. Accordingly, the character "customer" must be present, who sets the problem and accepts the results of the work. But, since the project is training, our experience has

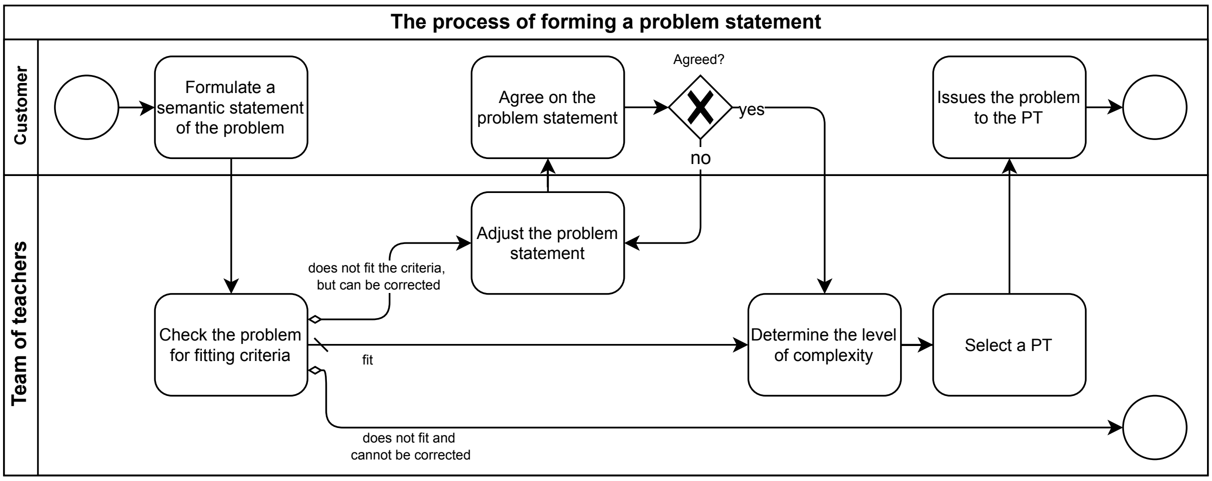

Figure 1. Scheme of the problem statement forming process.

shown that for the effective PBL implementation, it is also necessary to introduce the following characters, who must work coherently:

- project manager,
- project team coach,
- project team supervisor,
- advisors (in mathematics, programming, knowledge domains).

Consider the functionality of each character.

The least obvious is the presence of such a character as a project manager, that is, a person who would coordinate and build all the work processes of both students and teachers. Our experience has shown that having a manager is essential for a successful PBL. His responsibilities also include monitoring the deadlines of all work stages of all project teams. The manager, in fact, must fully control the formal course of project activities, from the first meeting of the teaching team to the project defenses.

The coach, like the manager, works simultaneously with all project teams. However, his task is not formal control over the project stages, but the actual training of the project management. The functions of the coach are: (i) to introduce the students to the project form of activity and give them a simplified model of real projects in the IT market; (ii) to help students to understand their roles and responsibilities in this process; (iii) to teach students to work effectively in a team; (iv) to provide students with the documentation format; (v) to teach students to present their results, to share observations, to self-reflect and, as a result, (vi) to develop strategies for more effective interaction with all participants in the process. Thus, the coach must help students develop competencies that correspond to the so-called soft skills. The coach organizes and moderates regular general meetings (training) of all project groups, where organizational problems are discussed and methods for solving them are developed, as well as the exchange of achievements between groups. The topics of all training and their brief descriptions are given in section 8. In addition, another goal of general meetings is to stimulate the activity of students and increase their motivation.

Each project team has a supervisor, whose main responsibility is to monitor and evaluate the completion of all stages of the project in accordance with the requirements of the coach and on time. Moreover, his task is to coordinate the work of the members of the project team, help in determining the sequence of actions and in dividing the problem into subproblems, etc.

Of all the teachers, the supervisor is the most active in contact with the PT, and the quality of the project as a whole largely depends on the quality of his work. The supervisor also acts as a psychologist and must neutralize conflicts in the team, and teach project team members to concentrate on work regardless of interpersonal relationships, that is, just like a coach helps students develop their soft skills.

The specific nature of the projects under consideration is that students develop their hard skills in applied mathematics and programming. As practice has shown, it is difficult for junior students to see the relationship between individual mathematical concepts and real problems, as well as having scattered knowledge of programming disciplines, it is difficult to write full-fledged software. Here they come to the aid of advisors in mathematics, programming, and knowledge domain, who control and guide the members of the project team at all stages of the project. It should be underlined that an adviser in any case must not offer his own solution, but only guide towards the right path if PT members choose a fundamentally wrong problem decision. Knowledge domain advisors, ideally, should be teachers from relevant departments, universities, or employees of specialized enterprises and organizations.

The functions of a customer are: to give a semantic statement of the problem, to approve the technical specification (TS), and to accept and grade the project for compliance with the TS. Ideally, a customer should be a real employee of any industry. However, this is not always possible, so a teacher can play the role of the customer.

Upon completion of the work, all members of the TT take part in the project grading, each in their own area of responsibility.

In practice, it has been found that supervisors and advisors often begin to identify themselves with the PT and, as a result, impose their solution to the problem on the group. It is crucial that they should not go beyond their duties, although this requires some effort. Otherwise, project grading becomes biased, as teachers will eventually grade themselves.

In the process of working on a project, teachers should work in concert. The semester should begin with a general meeting of a team of teachers, where the goals of the learning process are set, the levels of students of the current year of study are discussed, and the roles of teachers are distributed. The manager organizes this process. The details of the work of all members of the TT will be described in a separate article.

It should also be noted that in the process of work, it is advisable for teachers to hold regular (at least once a month) meetings to discuss the work of each PT and coordinate actions.

Not less important issue than the organization of the work of the team of teachers is the correct organization of the work of students within the project team.

5. Organization of the project team work

Our experience has shown that the PT should consist of 3 to 5 (optimally, 4) students. This is determined, firstly, by the number of conditionally independent problems within the project, and secondly, by the short time allocated for work (less than 1 semester). Within the framework of the project, there are four main tasks that can be largely parallelized: building a mathematical model and its software implementation, software interface implementation, software testing, and documentation writing. Accordingly, a responsible member of the project team is assigned to each of these tasks. At the same time, due to the specifics of training projects, all team members should be involved to some extent in the process of solving all tasks (this distinguishes a training project from a real one). This is due to the fact that all students should receive the same set of competencies as a result of working on the project. Consequently, the person responsible for each of the tasks should not solve it independently but should coordinate the work of the team on it. The overall coordination of the work of the entire team (project manager functions), as a rule, is carried out by the person responsible for the documentation (most often it becomes the team leader), since he builds the general logic of work in the technical report, understands well the connection between all tasks of the project.

If the team consists of 3 students, those responsible for software development can also be responsible for testing it. In the case of 5 people in a team, the fifth member can act as a project manager who coordinates the work of all team members (but at the same time, like the rest of the team, is involved in solving tasks).

When forming a PT, it is desirable to include an informal leader in it. But it is highly undesirable to include two informal leaders in the team since the possibility of interpersonal conflicts may affect the overall effectiveness of the team's work on the project.

It is important to reiterate that all team members must know and understand the tasks of other participants and the methods they have chosen to solve. To do this, they need to establish constant communication within the team (the supervisor should help them with this). According to a survey of students who have already defended projects, the biggest mistake, in their opinion, was the lack of constant communication and interaction with each other within the team. Everyone thought that he could handle his own task, and then, towards the end of the project, all of them would just combine their parts of the work. That is a misconception. Due to the age-specific features of psychological development, students do not understand the importance of communication during working on a common problem.

6. Basic documentation and presentation of the results of the project

An essential part of the project is a set of documents that contains complete information about the project. The project documentation set consists of:

- technical specification,
- technical report,
- presentation,
- software sources.

The technical specification is the key document, which is the basis for starting work on the project. TS is developed by PT. During the development of the TS, the PT finds out from the customer all his requirements for the presentation of input and output data, the software interface, limitations imposed on the input data, the procedure for submitting the project to the customer, etc. All these requirements are described in detail in the TS and are supplemented by a work schedule. The TS is agreed with the advisors, thereafter it is signed by the customer and the PT. Our experience has shown that as soon as a workable version of the software (beta version) is ready, the PT must demonstrate it to the customer in order for him to have the opportunity to make changes to the program interface, input/output data format and other changes that do not require a radical change in the models and algorithms.

The technical report in its structure corresponds to a course or thesis project and consists of the following sections: introduction, literature review, problem statement, description of the mathematical model, description of algorithms and data structures, description of the software, and conclusions.

The technical report is the core document that reflects all aspects of the work. It should be a coherent text, all sections should be logically connected and give an exhaustive description of the relevant aspects of the work. As practice shows, working on this document is one of the most difficult stages, since for the most part students have not encountered this type of work before. Meanwhile, the skills to clearly, coherently, fully, and easily express one's thoughts, to be able to collect, process, analyze, and systematize scientific and technical information, formalize problems, formulate and present thoughts and ideas, develop presentations and publications are the most important competencies for future specialists. In most cases, the PT delays the start of work on the report until the software is completed and, as a result, poorly handles processing a large amount of information. Because of this, the work on the technical report should be carried out throughout the entire work on the project, and each of its stages should result in the writing of the corresponding section of the report. While working on the technical report, the team should be significantly assisted by the supervisor, who helps them to build the general logic of the report, monitors the completeness and non-redundancy of the text, as well as enforces compliance with the formatting rules.

The third component of the set of documents is a slideshow presentation. If in real projects the presentation has rather an auxiliary function, then in training projects the presentation is an obligatory element, while working on which students develop a number of compulsory competencies [17, 18]. Besides, it is a required document for the presentation of the project for public defense.

The software source code must be in the form of a project that can be opened in an appropriate development environment, compiled, and run. Accordingly, all used non-standard libraries, files with additional data, etc. should be attached to it.

A PT is allowed to defend in the presence of a project set, which, in addition to the above documentation, also includes a software distribution kit. For PT the work on the project ends with a grade getting. The resulting grade is complex and consists of several components. The grading system is briefly described in the next section.

7. The grading system

In the process of working on the project, students must master a large number of various competencies, both general and professional, which are required by the Standard of Higher Education of Ukraine in the specialty 113 – “Applied Mathematics” and the educational program “Intellectual Data Analysis” [17, 18]. Accordingly, when grading project work, not only the quality of the project itself is assessed, but also the level of mastery of these competencies. In the case of teamwork, a significant problem is the problem of individual grading of team members. An original grading system that allows solving this problem is proposed.

The final grade of each member of the PT is given after the defense and is aggregated from several independent grades, which ensures impartiality and an integrated approach. The defense of the project is public and can be broadcast on Youtube; everyone is invited to it. On defense, the work is graded by a commission consisting of independent experts. The customer grades the quality of the project, and the supervisor and advisors grade the acquisition of the necessary competencies.

The supervisor during the whole work at each meeting grades each PT member separately. Besides, at the same meetings, PT members evaluate themselves and each other (this process is controlled by the supervisor). This is what provides a differentiated approach to the grading of each member of the PT.

All grades are given according to the original methodology, the description of which is beyond the scope of this work.

8. General organization scheme of work on the project

In the study, a sequence of actions for all participants in the PT was built, which is the result of many years of work by the staff of the department and proved to be optimal in the current conditions.

The following is a complete workflow for working on one project from the point of view of one project team. The work consists of 4 stages:

I. The preparatory stage, during which the PT:

1) takes part in the training "The basics of project management". During the training, the coach talks about the project activities, its general goals, and objectives, the project participants and their functions, and introduces the team to the supervisor;
2) receives from the customer a problem previously agreed upon with a team of teachers;
3) explores the subject domain, which includes the search and analysis of the literature.

II. The stage of development of the TS, during which the PT:

4) takes part in the training "Technical specification development". During the training, the coach discusses with the participants the essence, functions, and structure of the TS and the stages of work on the project;
5) develops TS;
6) agrees (and corrects, if necessary) TS with advisors in the subject domain, mathematics, and programming (in this order);
7) agrees on the TS with the customer (with adjustments if necessary).

III. The project implementation stage during which the PT:

8) takes part in the training "Development of mathematical models and software". During the training, the coach discusses with the PT the requirements for the math models, algorithms, and data structures, as well as the interface of software products, design of program code, etc.;
9) develops mathematical models;
10) agrees on the mathematical model with knowledge domain and mathematical advisors (in that order);
11) creates the mockup of the software (in parallel with steps 9) and 10));
12) develops a beta version of the software and submits it to the customer for testing;
13) revises the TS in accordance with the wishes of the customer (if necessary);
14) develops the production version of the software;
15) agrees on the production version of the software with a programming advisor;
16) takes part in the training "Preparation of a technical report and presentation", during which the trainer issues requirements for the design of documentation and presentation;
17) prepares technical report and presentation;
18) agrees on the technical report and presentation with the supervisor (and corrects if necessary);
19) assembles the project set (which includes TS, software, technical report, and presentation) and uploads it to the cloud storage, to which the team of teachers has access; sends copies of the project set to the customer and supervisor;
20) takes part in the training "Public defense of the project". During the training, the coach tells the format and regulations of the defense, analyzes the cases of previous defenses, etc.

IV. Defense of the project (PT is allowed only if grades have been received from the customer, all advisors, and the supervisor) during which the PT:

21) defends the project publicly;
22) self-reflects after receiving a grade: analyzes what was done well, what was not finalized, and why. The results of the analysis are transferred to the manager.

This sequence is shown as a BPMN diagram in figures 2 (steps 1 – 11) and 3 (steps 12 – 22), where the numbers of objects correspond to the numbers of steps of the sequence. The first action of the customer ("Formulate the problem statement") is a subprocess described in detail in section 3 and presented in figure 1. Those events and actions that distinguish the training project from a real one are highlighted in grey. At these moments teachers have an opportunity to influence the progress of work on the project. In the figures, the advisers' lines are abbreviated as KDA (knowledge domain adviser), MA (mathematics adviser), and PA (programming adviser).

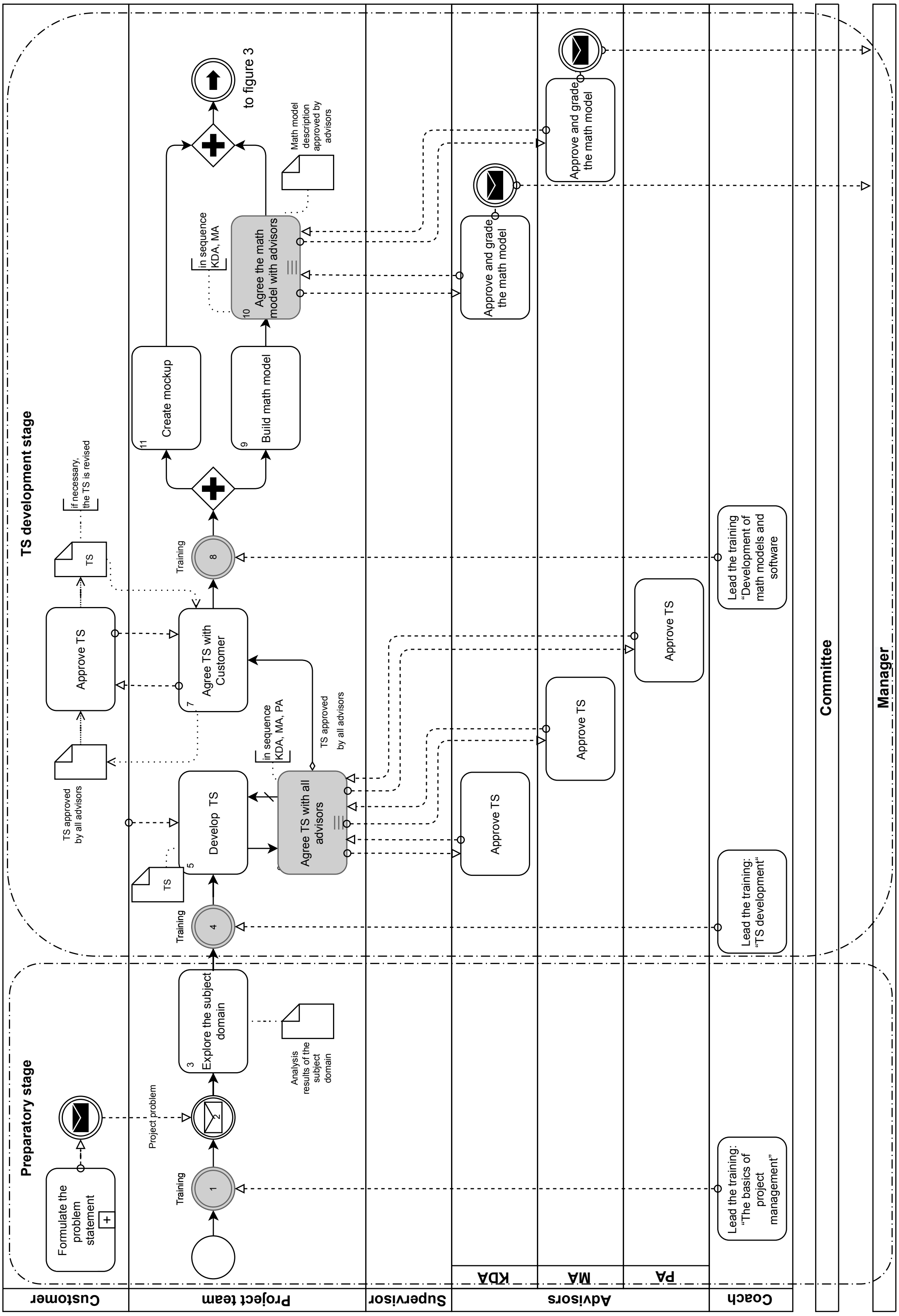

Figure 2. BPMN diagram of the process of working on the project (Steps 1 – 11). Stages are indicated with rounded-edges dash-dotted rectangles.

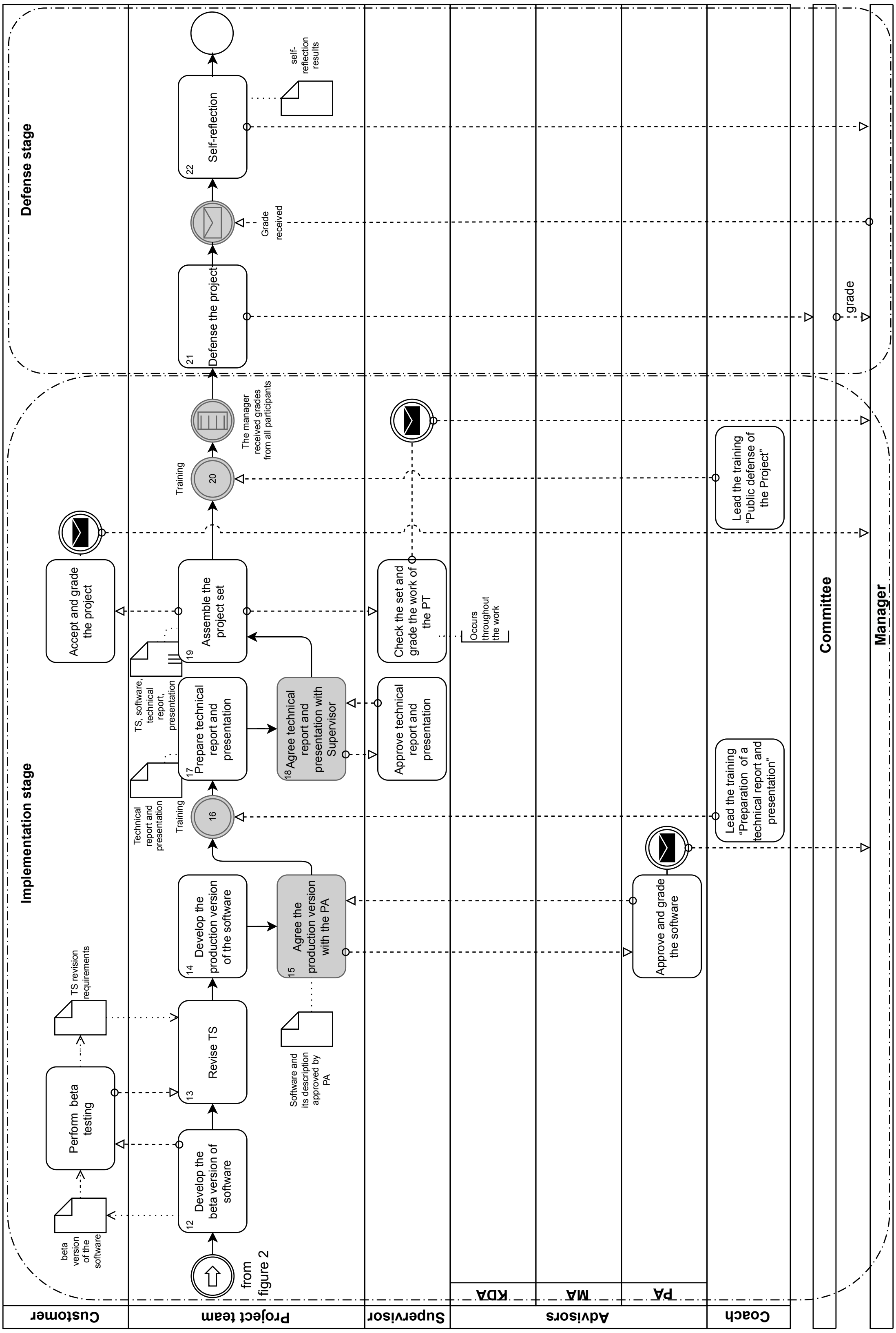

Figure 3. BPMN diagram of the process of working on the project (Steps 12 – 22). Stages are indicated with rounded-edges dash-dotted rectangles.

Control over the implementation of all PT actions in full and on time is carried out by the supervisor.

As a rule, several project teams work at the same time according to this scheme, so some events (for example, meetings of the trainer with the PTs, defenses of projects, etc.) can be carried out simultaneously for several PTs. The interaction of the PT with the advisors can occur at arbitrary times at the request of the PT.

The key issue that arises in the organization of any form of educational activity is the question of assessing the labor costs of teachers to perform the corresponding teaching load. Practice showed that project teams start working on projects approximately 3 weeks after the beginning of the semester since the start of the work of the teams is preceded by the preparatory work of teachers. It is advisable to complete the project no later than 2–3 weeks before the end of the semester, otherwise, it is difficult for students to prepare for tests and exams. Therefore, based on a 16-week semester, the optimal time to complete the project is 10 weeks. Then the total labor costs t of teachers (in hours) for providing n groups is:

$$t = 85 \times n + 20 \times \left[\frac{n}{5} + 1\right],$$

where $[\cdot]$ is integer part of the argument. In the first term, 85 is the total labor costs of the supervisor, customer, advisors, and manager for 1 team, and the second term takes into account the labor costs of the coach, who can simultaneously work with a maximum of five teams.

9. Conclusions

The paper describes the original methodology of project-based learning developed by the authors for junior students of the specialty 113 – "Applied Mathematics" of the educational program "Intellectual Data Analysis". This methodology is the result of many years of work by the staff of the Department of Computer Mathematics and Data Analysis of the National Technical University "Kharkiv Polytechnic Institute". During the creation of the methodology, the following were developed:

1) criteria to be met by the project problem statement;
2) detailed diagram of the work of the project team;
3) original methods of work of each participant in the process with PT and with each other;
4) original methodology for grading the results of the work of project team.

In the present paper, the general scheme of work on the project is presented in the form of a BPMN diagram, which guarantees the consistency of the process, its controllability at all stages, and transparency for each participant in the process, which allows them to clearly understand the goals and objectives at any given time throughout the entire work on the project. Thus, a ready-made tool for the implementation of PBL in the educational process is proposed, which can be used by teachers in the relevant field without any significant modifications.

The experience of using this methodology showed that it allows students to more effectively master the competencies laid down in the Standard of Higher Education than with the classical approach. In addition, within the framework of one project, it is possible to ensure that students master a significantly larger number of competencies than in the study of any standard discipline of an equivalent volume. The positive aspects of this methodology are noted by both students and teachers. Surveys of students show that, in their opinion, thanks to the projects, they:

- have seen more clearly the interrelationships between academic disciplines, which often look independent during the classical teaching;
- have learned to find the relationships between abstract mathematical concepts and real objects and phenomena, and build the corresponding mathematical models;

- have learned to formalize problems;
- have learned to reasonably choose and apply mathematical methods;
- have gained teamwork skills, learned to negotiate with team members, correctly distribute work stages, and delegate authority;
- etc.

Teachers, on the other hand, point out that

- students show higher motivation working on projects than studying standard courses;
- after working on the project, students have a deeper understanding of the essence of their future specialty, and they better master the subsequent disciplines.

In addition, it should be noted that in the course of project management, teachers also expand their horizons and improve their skills. The results of projects often become the basis for scientific and qualifying papers [20, 21].

Positive feedback on the results of the implementation of this methodology in the educational process also comes from IT companies (stakeholders), where specialists who graduated from our department work. They note that students with experience in project-based learning adapt more quickly to the conditions of real work in the IT industry. Moreover, PBL generally contributes to the emergence of new startups and, in general, the formation of links between the business and the department.

The implementation of project-based learning also has a marketing effect: public defenses, to which everyone is invited (which can be broadcast on YouTube and covered on social networks), are an important component of the department's marketing campaign. Furthermore, the involvement of third-party experts from various industries for public defense also contributes to the formation of a positive image of the department and the dissemination of information about it.

The proposed methodology can be quite easily adapted for use in related specialties and educational programs.

Acknowledgments

The authors wish to acknowledge the colleagues, who participate in the implementation of project-based learning. Without their many years of dedicated work, this work would not have been possible.

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References

[1] Quint J and Condliffe B 2018 Project-Based Learning: A Promising Approach to Improving Student Outcomes URL `https://eric.ed.gov/?id=ED580907`

[2] Larmer J, Mergendoller J and Boss S 2022 *Setting the Standard for Project Based Learning* (Alexandria, VA: ASCD) URL `https://www.pblworks.org`

[3] Lathram B, Lenz B and Vander Ark T 2016 Preparing students for a project-based world URL `https://www.gettingsmart.com/wp-content/uploads/2016/08/Preparing-Students-for-a-ProjectBasedWorld-FINAL.pdf`

[4] Hixson N K, Ravitz J and Whisman A 2012 *Extended Professional Development in Project-Based Learning: Impacts on 21st Century Skills Teaching and Student Achievement* (Charleston, WV: West Virginia Department of Education) URL https://files.eric.ed.gov/fulltext/ED565466.pdf

[5] Chyung S Y, Winiecki D J, Hunt G and Sevier C M 2017 *American Journal of Engineering Education* **8**(2) 61–82 URL https://doi.org/10.19030/ajee.v8i2.10065

[6] Jo I H 2011 *Asia Pacific Educ. Rev.* **12**(2) 301–310 URL https://doi.org/10.1007/s12564-010-9142-9

[7] Larmer J 2020 Gold standard PBL: Essential project design elements URL https://www.pblworks.org/blog/gold-standard-pbl-essential-project-design-elements

[8] Condliffe B 2017 *Project-Based Learning: A Literature Review* (New York, NY: MDRC) URL https://files.eric.ed.gov/fulltext/ED578933.pdf

[9] Monat J P and Gannon T F 2018 *Systems* **6**(3) 34 URL https://doi.org/10.3390/systems6030034

[10] Alves A, Sousa R, Moreira F, Carvalho M, Cardoso E, Pimenta P, Malheiro M, Brito I, Fernandes S and Mesquita D 2016 *J. Ind. Eng. Man.* **9**(3) 586–611 URL https://doi.org/10.3926/jiem.1816

[11] 2023 Worldwide CDIO Initiative URL http://www.cdio.org/

[12] Crawley E F, Malmqvist J, Lucas W A and Brodeur D R 2011 The CDIO syllabus v2.0: An updated statement of goals and engineering education *Proc. 7th Int. CDIO Conf.* (Copenhagen: Technical University of Denmark) pp 1–41 URL http://www.cdio.org/files/project/file/cdio_syllabus_v2.pdf

[13] Basjaruddin N C and Rakhman E 2016 *Int. J. Eval. Res. Educ.* **5**(4) 284–291 URL http://doi.org/10.11591/ijere.v5i4.5955

[14] Han S, Capraro R and Capraro M M 2015 *Int. J. Sci. Math. Educ.* **13**(5) 1089–1113 URL https://doi.org/10.1007/s10763-014-9526-0

[15] Fisher D, Kusumah Y S and Dahlan J A 2020 *J. Phys.: Conf. Ser.* **1657**(1) 012032 URL https://doi.org/10.1088/1742-6596/1657/1/012032

[16] Widodo S A, Istiqomah, Leonard, Nayazik A and Prahmana R C I 2019 *J. Phys.: Conf. Ser.* **1188**(1) 012087 URL https://doi.org/10.1088/1742-6596/1188/1/012087

[17] 2018 Standart vyshchoyi osvity Ukrayiny: pershyy (bakalavrs'kyy) riven', haluz' znan' 11 "Matematyka i statystyka", spetsial'nist' 113 "Prykladna matematyka" (in Ukrainian). URL https://mon.gov.ua/storage/app/media/vishcha-osvita/zatverdzeni%20standarty/12/21/113-prikladna-matematika.bakalavr-1.pdf

[18] Department of Computer Mathematics and Data Analysis of the National Technical University "Kharkiv Polytechnic Institute" 2023 Educational program "Intellectual Data Analysis" URL http://web.kpi.kharkov.ua/kmmm/uk/bakalavrat_ua/

[19] 2022 ISO/IEC 19510:2013, Information technology — Object Management Group Business Process Model and Notation. URL https://www.iso.org/standard/62652.html

[20] Savchenko A, Galuza A, Protsay N, Kolenov I, Tevyasheva O and Tonitsa O 2021 Construction of a linear food quality classifier based on their color analysis *2021 11th International Conference on Advanced Computer Information Technologies (ACIT)* pp 5–8 URL https://doi.org/10.1109/ACIT52158.2021.9548333

[21] Galuza A, Kostiuk O, Savchenko A, Boiko A, Harder S and Holotaistrova H 2021 Method for quantitative comparison of criteria for the color closeness of objects with given spectra *2021 11th International Conference on Advanced Computer Information Technologies (ACIT)* pp 1–4 URL https://doi.org/10.1109/ACIT52158.2021.9548568

Journal of Physics: Conference Series

PAPER • OPEN ACCESS

The use of immersive technologies in teaching mathematics to vocational students

To cite this article: T H Kramarenko and O S Kochina 2023 *J. Phys.: Conf. Ser.* **2611** 012006

The use of immersive technologies in teaching mathematics to vocational students

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Abstract. This study examines the use of immersive technologies in teaching mathematics to vocational students. The purpose of the research is to develop theoretical foundations and practical applications for the use of immersive technologies in mathematics education, and to measure the impact of these technologies on student motivation and learning outcomes. The study considers the scientific and theoretical underpinnings of immersive technologies in mathematics teaching, as well as methods for using the AR-Book application. A theoretical model, criteria, and methodological support for evaluating the use of immersive technologies are developed. A pedagogical experiment is conducted to evaluate the impact of these technologies on vocational students. Based on the results of the experiment and training materials, the study presents generalizations on the use of immersive technologies in mathematics education.

1. Introduction

Virtual reality technologies refer to immersive learning that creates the effect of presence using technical devices of virtual and augmented reality [1,2]. The range of application of virtual reality technologies is very wide [3, 4]. Technology can be used to teach students in both elementary and high school.

The importance of using immersive technologies has increased during the period of introduction of distance learning in schools. Due to the spread of the COVID-19 pandemic and the introduction of martial law in Ukraine, a significant number of educational institutions have switched to distance learning for an indefinite period [5]. These circumstances had a negative impact on the level of knowledge of students due to the difficulty of explaining topics in the conditions of distance learning [6]. Since mathematics is often a difficult discipline for students to master, the use of immersive technologies will help to increase the effectiveness of mathematics teaching.

2. Literature review

Today, various concepts of immersive technologies are known. The most cited set of technologies is VR (Virtual Reality) – fully simulated reality. In the latest developments, VR can include visualization in three-dimensional space, a 360-degree view. AR (Augmented Reality) is complemented by virtual elements that are modeled. It is a visual combination of initially independent environments – real and virtual; superimposition of programmed interactive virtual objects on a real image [7].

Immersive technologies is a collective name for all technologies that include user interaction with space, information, content [8]. They blur the lines between real and fictional worlds, allow you to interact and immerse yourself in information and product [9]. Augmented reality is an interactive technology that allows you to overlay digital content on real world objects. Overlaid digital content can be computer graphics, textual information, electronic links, videos and 3D objects. The superimposed virtual objects are read by digital devices, including smartphones, tablets, etc.

Various mobile applications with augmented reality in educational activities are used in teaching physics (AR Physics; Atom Visualizer), chemistry (Arloon Chemistry; Sparklab), space and astronomy (Spacecraft AR; Space 4D+), anatomy and medicine (FLARE Atma; Arloon Anatomy; Humanoid 4D+; AnatomyAR, Anatomy 4D), etc.

Today there are platforms that allow you to create your own applications in the format of augmented reality using ready-made components. Most of them are focused on creating AR applications for Android, iOS, Linux, Windows. Here are examples of such platforms: ARToolKit, Kudan ARSDK, AR SDK and others.

The article by Burov [10] finds that AR increases learning efficiency, encourages cognitive activity, improves learning, provokes interest in studying, promotes both research skills development and students subject competencies. The conceptual model of AR use in the educational process is substantiated and its four components (technical-technological, educational-scientific, formative-developmental, and qualitative-educational) are determined. The authors substantiate the principles (expediency, accessibility, cognition, integrity, educational orientation, mobility) and approaches (cognitive, systemic, activity-based, differentiational, personality-oriented, innovative), as well as describe pedagogical conditions and clarify the advantages and disadvantages of using AR technology in education.

Nechypurenko et al. [11] considered the problems of supporting educational and research activities in chemistry using augmented reality. The researchers concluded that: introduction of the augmented reality technology in the training process at higher technical educational institutions increases learning efficiency, facilitates students' training and cognitive activities, improves the quality of knowledge acquisition, provokes interest in a subject, promotes development of research skills and a future specialist's competent personality.

Gayevska and Kravtsov [12] emphasize that an appropriate learning environment should be created to meet the educational needs of students. It is concluded that augmented reality tools provide a new paradigm of teaching materials, which has a positive impact on the formation of basic and professional competencies of future Japanese language teachers; it can be effective when used in blended learning that combines distance, online, traditional, and self-directed learning of Oriental languages.

In teaching geometry with augmented reality, you can use applications for mobile phones Arloon Geometry [13], GeoGebra [14], AR-Book [15]. Students can be offered 3D models of many geometric shapes for consideration.

The subject of the study Rashevska ar al. [16] is the use of augmented reality tools in teaching geometry to students in grades 7-9. Analyses displayed two augmented reality tools: Arloon Geometry [13] and Geometry AR. In order to gain geometry instruction's academic success for the students, these tools can be used by teachers to visualize training material and create a problematic situation. It also provided support to reduce fear and anxiety attitudes towards geometry classes. The emotional component of learning creates the conditions for better memorization of the educational material, promotes their mathematical interest, realizes their creative potential, creates the conditions for finding different ways of solving geometric problems.

Arloon Geometry is only supported in English and Spanish. Of particular interest was the research work of España-Leyton [17] on the use of Arloon Geometry [13]. This research work, presents the implementation of an educational strategy to that the students of sixth grade, to develop spatial thinking, through the identification and differentiation of elements and properties of geometric bodies, with the support of the mobile application based on augmented reality Arloon Geometry. The results allowed to show the degree of motivation and the migration of students between levels, which were at level 1 of visualization, and after the implementation of the educational strategy they advanced to levels 2 and 3 of analysis and classification, developing spatial thinking, therefore in the end they were able to visualize, analyze and classify the constituent elements of geometric bodies, learning a new vocabulary and developing a higher level of geometric thinking.

Kramarenko et al. [18] review the peculiarities of the mobile application 3D Calculator of Dynamic Mathematics GeoGebra system with Augmented reality, improves the methodology of teaching Mathematics using cloud technologies and augmented reality.

Kuzmich et al. [19] consider the methodology of studying the geometric properties of metric spaces. To build a geometric interpretation of rectilinear and flat placement of points of metric space, it is proposed to build the appropriate analogues in two-dimensional and three-dimensional arithmetic Euclidean spaces. To visualize these concepts, it is proposed to use a dynamic geometric environment GeoGebra 3D.

Many researchers, in particular Kolomoiets and Kassim [20], highlight the following advantages of using AR technology for educational purposes as the ability to learn from any digital device; conciseness and clarity of educational content; transition from information and informative learning to interactive interaction with educational content in real time; individual learning; practice-oriented learning; increasing motivation and interest of students, etc.

Publications [21–23] are evaluates the limitations in the use of AR technologies for educational purposes. For example, due to the lack of modern mobile phones and tablets that support the latest technologies; insufficient number of educational applications with augmented reality; not all disciplines can choose the appropriate augmented reality application, etc. It is worth noting the methodological unpreparedness of teachers to use AR technology in education. Today, both students and teachers do not have enough experience with AR projects.

As noted in [24–26], the principle of immersiveness contributes to the implementation of the principle of visibility of education, expands and supplements it, taking into account modern trends and technical capabilities. Immersive technologies in education contribute to strengthening the role of visualization in the process of knowledge acquisition by the student through deep immersion in the virtual environment. The principle of complexity in the immersive approach involves the impact on all human senses to the perception of educational material. Therefore, it is important to introduce new pedagogical technologies, create promising integrated educational systems in which immersive technologies will play an important role.

3. Purpose and objectives of the article

There is not enough research on the effectiveness of using immersive technologies in teaching mathematics to students. Many teachers are not sufficiently prepared to implement new methods, technologies, which include immersive approach. Therefore, the results of this study are relevant. The authors of the article present the methodology of using the Ukrainian language application AR-Book in teaching mathematics to students. The results of the pedagogical experiment show the effectiveness of the application AR-Book to increase the level of motivation of students in the process of learning mathematics and their level of academic achievement.

The purpose of our study was to theoretically substantiate and develop directions for the use of immersive technologies in teaching mathematics to students. We measured the impact of immersive technologies on the level of motivation and learning outcomes of vocational students. To achieve the purpose of the study, the scientific and theoretical foundations of the problem of using immersive technologies in teaching mathematics; methods of using the AR-Book application in teaching mathematics to students are considered.

4. Results and discussion

The use of immersive technologies in teaching mathematics to students is based on the organization of mobile learning, optimization of the work mode of teachers and students; loyalty to knowledge control, etc. The listed items can be considered as conditions for the effective use of the immersive approach.

Learning with immersive technologies is carried out at a higher level due to immersion in the environment and the inclusion of sensory mechanisms in contextual learning. This approach is considered the most effective at the stage of organizing practical activities of students using e-learning or distance technologies. At the same time, personalized feedback is provided, unique opportunities for organizing work at home are created, and training scenarios are managed in remote work.

All these conditions are satisfied by a new way of learning through augmented reality, which is still gaining popularity in Ukrainian realities. The use of virtual simulators in the education system has a number of features.

We consider the methodology of using the AR-Book application in teaching mathematics to students. The AR-Book application from Ukrainian developers allows students to conduct safe cognitive experiments at home using AR technology [15]. The mobile application is designed to increase the efficiency of home learning. The application is relevant in a pandemic, and currently in the context of hostilities. This mobile application is a virtual laboratory in which every student can conduct school experiments anywhere and anytime. The application for learning mathematics corresponds to the school curriculum of the "standard" level.

We introduced the AR-Book application to future mathematics teachers during laboratory work on the methods of teaching mathematics, as well as to mathematics teachers during in-service training courses. Intuitive interface, meaningful visuals make the virtual simulator attractive both for training courses and for self-study.

The use of virtual simulator by students should be based on a certain amount of theoretical knowledge. We took into account the results of some studies. Therefore, before using the AR-Book application, it is advisable to provide the teacher with explanations of theoretical information, checking the student's basic skills in working with computers.

When teaching mathematics to students of vocational schools using immersive technologies, the curriculum for 10-11 grades and its coverage in modern textbooks were followed. Textbooks of the standard level were used in the training, in particular by Merzlyak et al. [27].

In figure 1 shows examples of visualizations from the AR-Book application. Namely, the presentation of theoretical information about parallel lines in the AR-Book application.

In figure 2 shows an example of the task and the correct answer in the task of finding the volume of a cylinder in the AR-Book application.

The correct answer is highlighted in green, and the possible answers are highlighted in yellow. If the student could not answer the questions correctly the first time, he has a new chance to succeed. In the textbook, theoretical information about parallel lines is presented in the form of rules, and in the AR-Book application – in the form of three-dimensional drawings with voice explanation. The quality of pupils' perception of educational material significantly depends on what type of information perception they have more developed (auditory or visual). It is advisable to compare the tasks for the topic "Cylinder" in the textbook for grade 11 and in the AR-Book application. In the textbook, the task formulation is given in the form of text. There are few three-dimensional drawings in the textbook. In the AR-Book app, all tasks are accompanied by a three-dimensional image that the student can see better by zooming in or changing the viewing angle of the figure. The use of augmented reality technology can also develop spatial thinking in students and contribute to a more harmonious development of the individual.

Having compared the design of tasks in the textbook and in the AR-Book application, we can

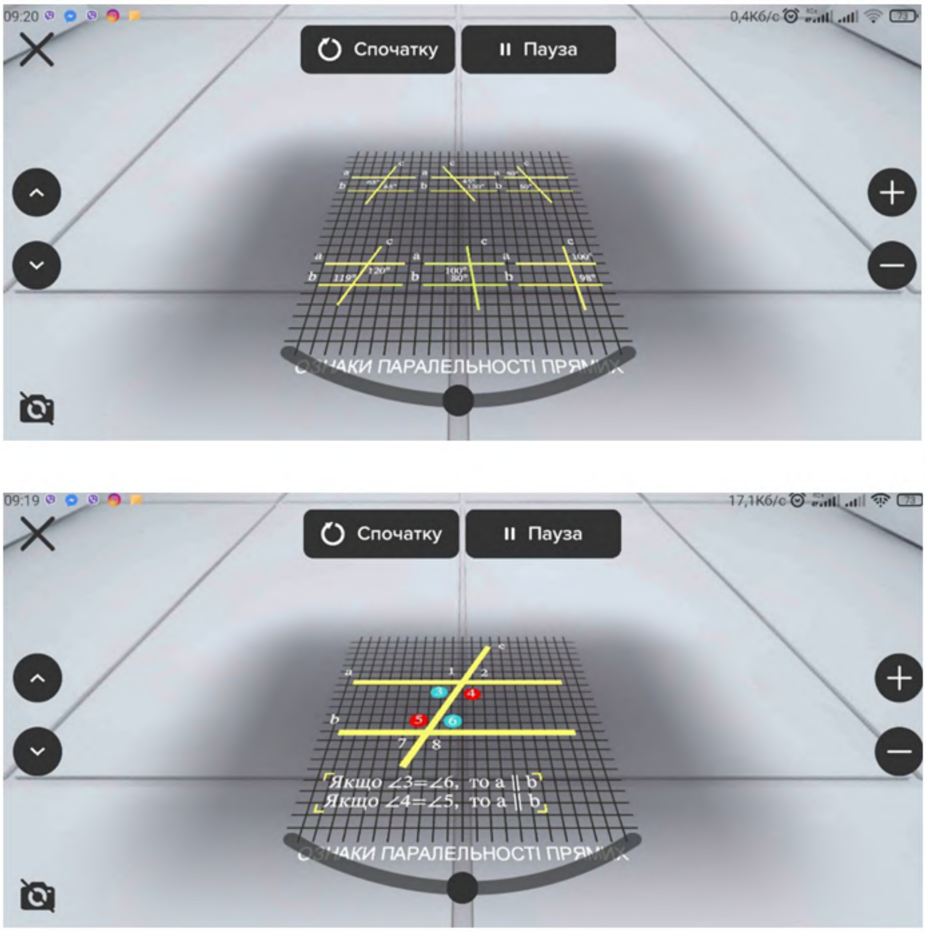

Figure 1. Presentation of theoretical information about parallel lines in the AR-Book application.

hope to increase the visibility of the presentation of theoretical material using AR-Book. The results of the survey of students show that the tasks from the application are more attractive for them. At the same time, high efficiency of mathematics teaching can be achieved by combining traditional and innovative teaching methods. In particular, using immersive technologies in teaching.

Educational communication is the main means of interaction between the teacher and students in the context of the use of AR-teaching tools. Using the means of educational communication, the teacher sets the parameters of learning, determines the conditions for performing the educational task, adjusts the course of students' activities, provides meaningful orientation and creates conditions for students to realize the results of their activities in the virtual reality environment.

Consider how to use the AR-Book application. The teacher offers to get acquainted with theoretical information, and then complete the task on the selected topic. If the student has difficulties with the task, the teacher gives recommendations on how to work with the application or further explains unclear points on the topic being studied. Or the student can listen to the lesson again.

For example, when studying the topic "Regular polyhedra", the teacher first provides students with theoretical information on the topic. The next step is to give an example of a task on the

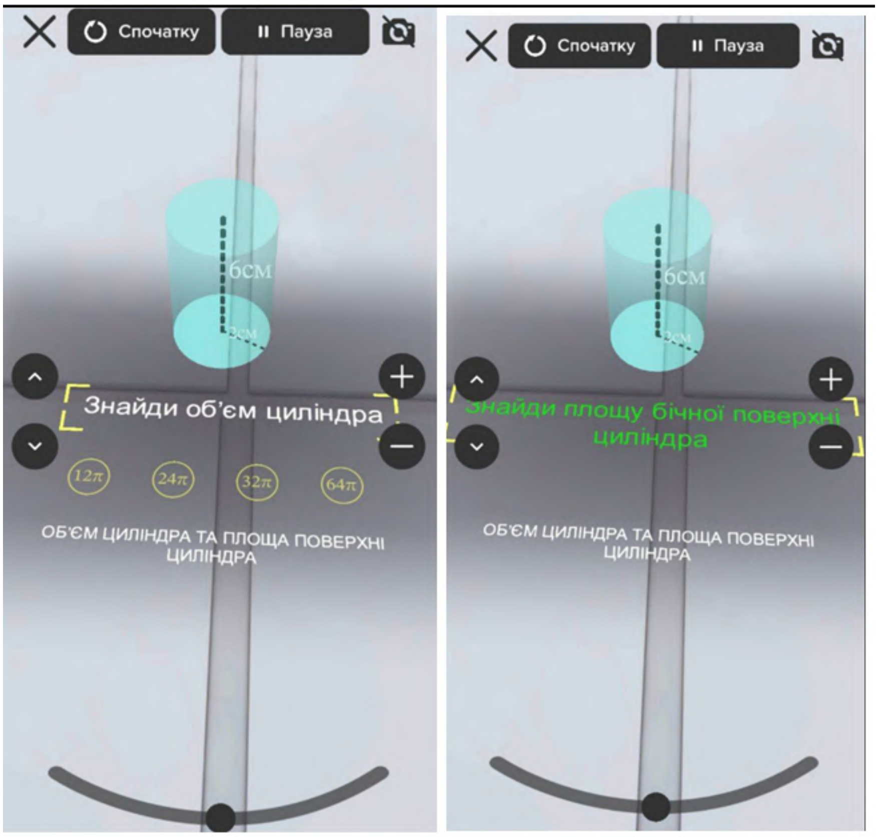

Figure 2. Presentation of theoretical information about parallel lines in the AR-Book application.

topic “Regular polyhedra”. Then the teacher invites students to complete a practical task using the AR-Book application. When completing the task, the student can choose two options: virtual environment and augmented reality, which differ in the visual display when the student performs tasks. Everyone chooses the option that is more convenient for him.

In the AR-Book application, some of the practical tasks are called experiments. There are also tests for the topic, which include a list of questions and answers to them. When a student starts a practical task, he/she is offered basic information on the topic. Then you need to solve problems of medium complexity and answer simple questions. For example, to determine the number of vertices, the number of faces.

When the student moves from studying the tetrahedron to the hexahedron, the questions are repeated. Questions are asked about three shapes: tetrahedron, octahedron and hexahedron. The student can zoom in on the octahedron model in the app, rotate it and examine it. If the student is unable to logically answer a question about the number of vertices or edges, they can turn the model around and count. If the student chooses the wrong answer, he/she can correct the mistake and succeed. Considering each of these polyhedra, students are offered a summary table. It provides information on the number of vertices, faces, and the number of edges extending from one vertex for each of the regular polyhedra, including the dodecahedron and icosahedron.

In the course of the study, a theoretical model of the use of immersive technologies in teaching mathematics to students of vocational schools was developed and tested. The target block of the system of forming students' mathematical competence is represented by the unity of the goal and tasks, the complex solution of which ensures its achievement. One of the goals was to increase the motivation of students to study mathematics and improve the assimilation of educational material.

To achieve the goal, professional mathematical tasks were identified based on such competencies as readiness to learn; work with modern teaching technologies; use systematic theoretical and practical knowledge in the process of teaching mathematics and others. This model (figure 3) reflects the general didactic and professional principles of learning. In particular, the general didactic principles include the principles of scientificity, systematicity, visibility, strength of assimilation, consistency, continuity, activity and consciousness of learning. To professional we include the principles of integration and differentiation of mathematical knowledge and creative activity.

The didactic block includes structural and functional components of the content and technology of vocational training with the use of immersive technologies. It presents forms, methods and means of training.

We attach special importance in teaching mathematics to the method of scientific research using modern information and communication tools. Observations have shown that the development of independent activity allows students to use ICT to obtain the necessary amount and quality of knowledge, to use immersive technologies independently.

It should be noted that the achievement of the intended goal is impossible without appropriate pedagogical conditions. The general pedagogical conditions include the formation of students' positive motivation for independent work in the process of studying mathematical disciplines; the formation of professional culture. The organizational and pedagogical condition is the provision of didactic material that forms the readiness of students to use information technology. The technological conditions include the establishment of interdisciplinary links with the disciplines of natural and professional cycles on the basis of modular learning; timely and efficient filling of the information educational environment with educational content.

The evaluation and result block is represented by criteria and indicators corresponding to each of them. In particular, the motivational criterion is the motivational readiness for effective professional activity. The volume and quality of acquired knowledge in accordance with the requirements of the curriculum of mathematical disciplines is considered as a cognitive criterion. The personal criterion is the application of mathematical knowledge in solving professionally oriented knowledge, performing mathematical processing of statistical data, etc. Reflective and creative criterion is the ability to choose acceptable immersive technologies in the process of finding solutions to a specific problem, in the process of mastering heuristic operations in the course of solving professional problems.

Thus, the theoretical model of using immersive technologies in teaching mathematics to students of vocational schools consists of a target block, didactic block and diagnostic block. The purpose is to increase the motivation of students to study mathematics and increase the assimilation of educational material through the use of immersive technologies.

The development of psychological criteria for the formation of motivation to acquire knowledge in mathematics of students of vocational schools as content-activity, motivational-value and personal will contribute to the development of teaching mathematical disciplines to students of vocational schools. Students will receive sufficient knowledge, they will form a high level of motivation to learn.

Psychodiagnostic methods (questionnaires, testing) were used in the empirical study. To evaluate the formation of motivation to acquire knowledge in mathematics of students of vocational schools in the learning process, the questionnaire "determining the level of aspirations" by Magun and Engovatov [28] was chosen to determine the orientation of students to acquire knowledge; the method "Motivation of learning activity" by Rean and Yakunin [29] to determine the motivation of pupils to learn mathematics; methodology of Kučera and Smékal

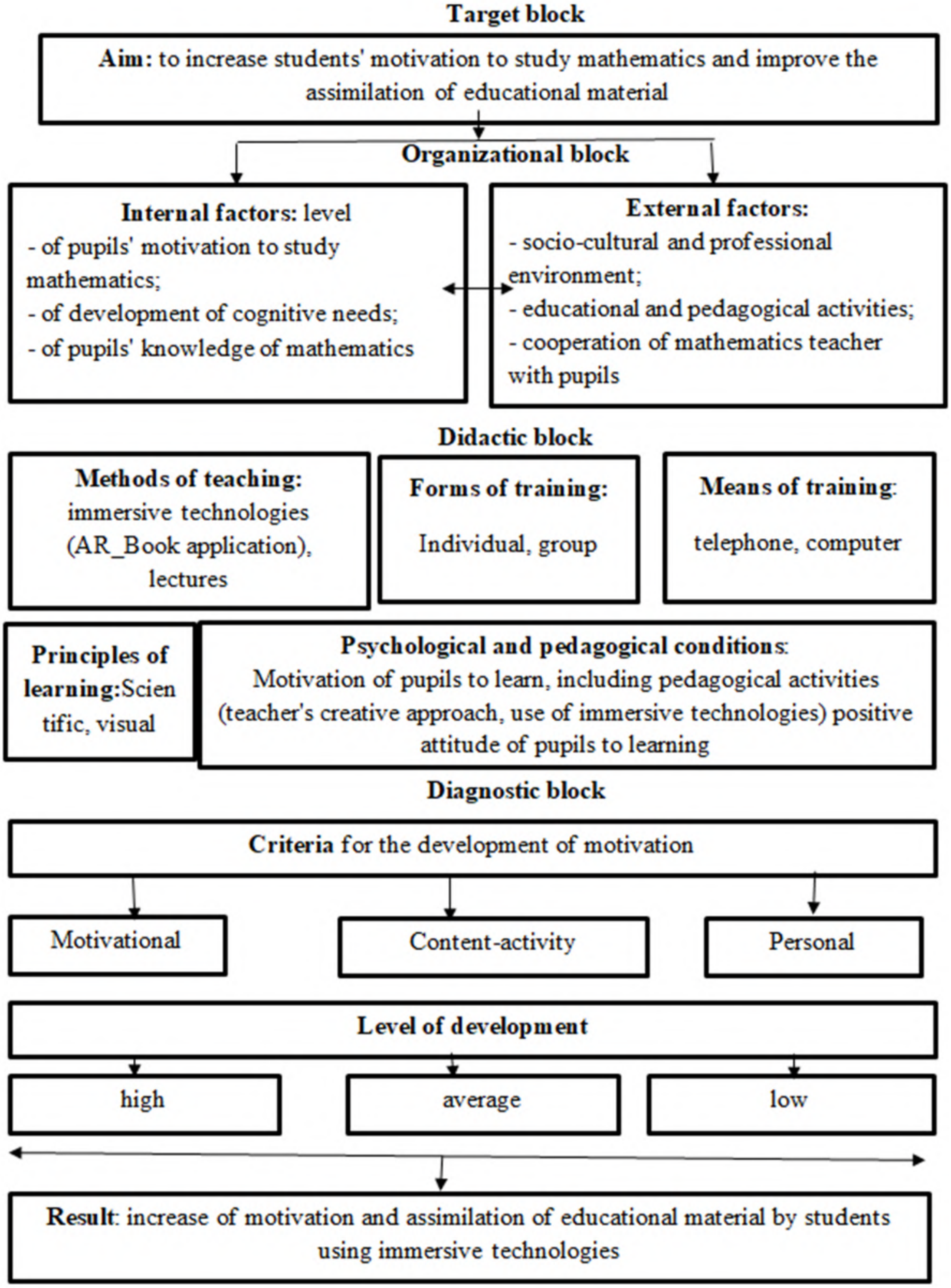

Figure 3. Theoretical model of using immersive technologies in teaching mathematics to students of vocational schools.

"Study of personality orientation" [30]; methodology "Value orientations" of Rokeach [31]; cut-off written testing. A pedagogical experiment was conducted for two months. Mathematics classes were held with the use of immersive technologies – AR-Book application. With the help of the educational mobile application AR-Book, students were offered to pass test tasks in mathematics. The list of topics is coordinated with the secondary school curriculum (which is also suitable for vocational school students). As already mentioned, the educational process was based on the use of curricula for 10-11 grades and the material was taught to students using modern mathematics textbooks.

AR-Book application was used as an additional tool for teaching mathematics to vocational school students. The tasks are accompanied by the teacher's explanation of certain aspects of the topic, formula, and after reviewing the educational material it is possible to pass a test task. For better learning of the topic, the student can take the test tasks the required number of times, because these applications are aimed at helping to learn the topic, not to control knowledge. To control knowledge, the teacher conducts traditional tests and cross-sectional independent work during the school semester.

After the pedagogical experiment, a repeated study of students' motivation to study mathematics and their level of knowledge after using the AR-Book application for two months was conducted.

The results of the study of the level of pupils' claims according to the methodology "Determination of the level of claims" by Magun and Engovatov after the experiment are presented in table 1. We tested the statistical hypothesis of differences in the frequency distribution for the pre- and post-experiment data using the chi-square test. We found that the alternative hypothesis of differences in frequency distributions was true. The significance level is 0.05 %, the critical value is 5.99; the empirical value is 12.00. This confirms the hypothesis of an increase in the level of motivation.

Table 1. Results of the study of the level of pupils' expectations according to the methodology "Determination of the level of expectations" by Magun and Engovatov after the experiment.

The level of claims	Before the experiment	After the experiment
Low	10 (36 %)	4 (16 %)
Medium	9 (36 %)	9 (36 %)
High	6 (24 %)	12 (48 %)
Total	25 (100 %)	25 (100 %)

We compared the proportions of high motivation before and after the experiment using the Fisher's Angle Transform criterion.

It was found that the alternative hypothesis about the differences in the proportions of high-level motivation was true. The significance level is 0.05 %, the critical value is 1.64; the empirical value is 1.71. The result confirms the hypothesis of an increase in the high level of motivation. Similarly, the sums of the shares of high and medium levels were compared. At the 0.05 % significance level, the alternative hypothesis for the post-experiment data was confirmed (critical value 1.64; empirical value 1.84).

As a result of the study of students' aspirations, it was found that the number of highly motivated students increased by 24% and low motivated students decreased by almost the same percentage. This allows us to draw conclusions about the high efficiency of using the AR-Book application to interest students in learning.

Table 2. Results of the study of the level of motivation of students' learning activities according to the method of Rean and Yakunin after the experiment.

Motivation factors	Before the experiment	After the experiment
to continue studying at a higher education institution	3 (12 %)	4 (16 %)
to get a diploma	5 (20 %)	1 (4 %)
to study to become a qualified specialist	8 (32 %)	9 (36 %)
to ensure the success of future career	6 (24 %)	5 (20 %)
to gain knowledge in the specialty	3 (12 %)	6 (24 %)
Total	25 (100 %)	25 (100 %)

The results of diagnostics of students' motivation for learning activities according to the methodology of Rean and Yakunin after the experiment are presented in table 2.

As we can see, the level of motivation to acquire knowledge in the specialty has increased, as evidenced by the factor of motivation to learn before the experiment, 12 % of students, and after the experiment, 24 % of students.

We compared the shares of the Fisher's Angle Transformation criterion before and after the experiment. It was found that the alternative hypothesis about the differences in shares was true. The significance level is 0.05 %, the critical value is 1.64; the empirical value is 4.07. The result confirms the hypothesis of an increase in motivation to acquire knowledge in the specialty.

The results of the study of the level of knowledge in mathematics after the experiment are shown in table 3.

Table 3. Results of the study of the level of knowledge in mathematics after the experiment.

The level of claims	Before the experiment	After the experiment
Low	12 (48 %)	5 (20 %)
Average	10 (40 %)	13 (52 %)
High	3 (12 %)	7 (28 %)
Total	25 (100 %)	25 (100 %)

We tested the statistical hypothesis about differences in frequency distributions for the pre- and post-experiment data using the chi-square test. We found that the alternative hypothesis about differences in frequency distributions was true. The significance level is 0.05 %, the critical value is 5.99; the empirical value is 12.78. This confirms the hypothesis that the level of math knowledge is increasing.

We compared the proportions of high motivation before and after the experiment using the Fisher's Angle Transform criterion.

It was found that the null hypothesis, i.e., for a high level of differences in the shares, has not yet been confirmed. The significance level is 0.05 %, the critical value is 1.64; the empirical value is 1.37.

Similarly, the sums of the shares of high and medium levels were compared. At the significance level of 0.05 %, the alternative hypothesis for the post-experiment data was confirmed (critical value 1.64; empirical value 2.03). That is, in total, the share of medium and high levels of knowledge is significantly higher after the experiment.

It was found that the level of knowledge in mathematics among pupils has also improved. The number of pupils with low level of knowledge decreased by 28%. The number of students with an average level of knowledge increased by 12%. The number of students with high level of knowledge increased by 16 AR-Book application was used as an additional tool for teaching mathematics to vocational school students. The tasks are accompanied by the teacher's explanation of certain aspects of the topic, formula, and after reviewing the educational material it is possible to pass a test task. For better learning of the topic, the student can take the test tasks the required number of times, because these applications are aimed at helping to learn the topic, not to control knowledge. To control knowledge, the teacher conducts traditional tests and cross-sectional independent work during the school semester.

After the pedagogical experiment, a repeated study of students' motivation to study mathematics and their level of knowledge after using the AR-Book application for two months was conducted.

As a result of the study of students' aspirations, it was found that the number of highly motivated students increased by 24 %, and low motivated students decreased by almost the same percentage. This allows us to draw conclusions about the high efficiency of using the AR-Book application to interest students in learning. The results of the study of the level of knowledge in mathematics after the experiment were analyzed. It was found that the level of knowledge in mathematics among pupils has also improved. The number of pupils with low level of knowledge decreased by 28 %. The number of students with an average level of knowledge increased by 12 %. The number of students with high level of knowledge increased by 16 %.

The statistical hypothesis was tested according to the criterion of differences in the distribution of values of the attribute. According to the Fisher's angular transformation, the alternative hypothesis of a decrease in the share of low level and an increase in the share of high level of pupils' motivation and learning achievements was confirmed.

5. Conclusions

Taking into account the results of the pedagogical experiment, we can conclude that the use of the AR-Book mobile application for teaching mathematics to students of vocational schools is appropriate. The systematic use of the application by students has brought a positive result in the form of increasing students' motivation and improving their level of knowledge.

Among the advantages of using immersive technologies in teaching mathematics to students are: full immersion in the learning process, "presence effect"; visibility and brightness of sensations; interactivity; facilitation of understanding and simplification of perception; use of visual and auditory channels of perception; the ability to simplify the perception of complex objects; the ability to scale, rotate, assemble and disassemble complex objects into their constituent elements; the possibility of gamification of education; the possibility of repeated repetition of information and training skills.

To use immersive technologies in teaching, it is necessary to create psychological and pedagogical conditions. The key requirements for the system of building interactive learning tools are: ease of use and versatility. By means of educational communication, the teacher sets the parameters of learning, determines the conditions for completing the learning task, adjusts the course of students' activities, provides meaningful orientation and creates conditions for students to realize the results of their activities in the virtual or augmented reality environment.

The theoretical model of using immersive technologies in teaching mathematics to students of vocational schools consists of a target block, didactic block and diagnostic block. The aim is to increase the motivation of students to study mathematics and increase the assimilation of educational material through the use of immersive technologies. Pupils will receive sufficient knowledge, they have a high level of motivation to learn.

Prospects for further research are the development of ways to solve the problems of using augmented reality technology in education and their implementation in practice.

References

[1] Mintii I S and Soloviev V N 2018 Augmented Reality: Ukrainian Present Business and Future Education *Proceedings of the 1st International Workshop on Augmented Reality in Education, Kryvyi Rih, Ukraine, October 2, 2018* (*CEUR Workshop Proceedings* vol 2257) ed Kiv A E and Soloviev V N (CEUR-WS.org) pp 227–231 URL `https://ceur-ws.org/Vol-2257/paper22.pdf`

[2] Semerikov S O, Mintii M M and Mintii I S 2021 Review of the course "Development of Virtual and Augmented Reality Software" for STEM teachers: implementation results and improvement potentials *Proceedings of the 4th International Workshop on Augmented Reality in Education (AREdu 2021), Kryvyi Rih, Ukraine, May 11, 2021* (*CEUR Workshop Proceedings* vol 2898) ed Lytvynova S H and Semerikov S O (CEUR-WS.org) pp 159–177 URL `https://ceur-ws.org/Vol-2898/paper09.pdf`

[3] Burov O Y and Pinchuk O P 2023 *Educational Technology Quarterly* **2023**(1) 58–68

[4] Klochko O V and Fedorets V M 2022 *Educational Technology Quarterly* **2022**(4) 276–306 URL `https://doi.org/10.55056/etq.431`

[5] Kovalchuk V I, Maslich S V and Movchan L H 2023 *Educational Technology Quarterly* **2023**(1) 1–17 URL `https://doi.org/10.55056/etq.49`

[6] Kalashnikova L, Hrabovets I, Chernous L, Chorna V and Kiv A 2022 *Educational Technology Quarterly* **2022**(2) 115–128 URL `https://doi.org/10.55056/etq.2`

[7] Lavrentieva O O, Arkhypov I O, Krupski O P, Velykodnyi D O and Filatov S V 2020 Methodology of using mobile apps with augmented reality in students' vocational preparation process for transport industry *Proceedings of the 3rd International Workshop on Augmented Reality in Education, Kryvyi Rih, Ukraine, May 13, 2020* (*CEUR Workshop Proceedings* vol 2731) ed Burov O Y and Kiv A E (CEUR-WS.org) pp 143–162 URL `https://ceur-ws.org/Vol-2731/paper07.pdf`

[8] Lytvynova S H, Semerikov S O, Striuk A M, Striuk M I, Kolgatina L S, Velychko V Y, Mintii I S, Kalinichenko O O and Tukalo S M 2021 AREdu 2021 - Immersive technology today *Proceedings of the 4th International Workshop on Augmented Reality in Education (AREdu 2021), Kryvyi Rih, Ukraine, May 11, 2021* (*CEUR Workshop Proceedings* vol 2898) ed Lytvynova S H and Semerikov S O (CEUR-WS.org) pp 1–40 URL `https://ceur-ws.org/Vol-2898/paper00.pdf`

[9] Semerikov S O, Vakaliuk T A, Mintii I S, Hamaniuk V A, Soloviev V N, Bondarenko O V, Nechypurenko P P, Shokaliuk S V, Moiseienko N V and Shepiliev D S 2022 Immersive E-Learning Resources: Design Methods *Digital Humanities Workshop* DHW 2021 (New York, NY, USA: Association for Computing Machinery) p 37–47 ISBN 9781450387361 URL `https://doi.org/10.1145/3526242.3526264`

[10] Burov O 2021 *Educational Technology Quarterly* **2021**(4) 689–700 URL `https://doi.org/10.55056/etq.43`

[11] Nechypurenko P P, Semerikov S O and Pokhliestova O Y 2023 *Educational Technology Quarterly* **2023**(1) 69–91 URL `https://doi.org/10.55056/etq.44`

[12] Gayevska O and Kravtsov H 2022 *Educational Technology Quarterly* **2022**(2) 105–114 URL `https://doi.org/10.55056/etq.7`

[13] Arloon 2022 Arloon Geometry URL `https://play.google.com/store/apps/details?id=com.Arloon.Geometry.AR&hl=en`

[14] GeoGebra Team German 2018 Learn GeoGebra 3D Calculator URL `https://www.geogebra.org/m/aWhYSpvy`

[15] FLEXREALITY 2023 AR_Book URL `https://arbook.info/`

[16] Rashevska N V, Semerikov S O, Zinonos N O, Tkachuk V V and Shyshkina M P 2020 Using augmented reality tools in the teaching of two-dimensional plane geometry *Proceedings of the 3rd International Workshop on Augmented Reality in Education, Kryvyi Rih, Ukraine, May 13, 2020* (*CEUR Workshop Proceedings* vol 2731) ed Burov O Y and Kiv A E (CEUR-WS.org) pp 79–90 URL `https://ceur-ws.org/Vol-2731/paper03.pdf`

[17] España-Leyton E O 2021 *Estrategia Educativa Para el Desarrollo del Pensamiento Espacial a Través de la Aplicación Móvil Arloon Geometry, en Estudiantes de Grado Sexto* Master's thesis Universidad de Santander URL `https://repositorio.udes.edu.co/handle/001/6886`

[18] Kramarenko T H, Pylypenko O S and Zaselskiy V I 2019 Prospects of using the augmented reality application in STEM-based Mathematics teaching *Proceedings of the 2nd International Workshop on Augmented Reality in Education, Kryvyi Rih, Ukraine, March 22, 2019* (*CEUR Workshop Proceedings* vol 2547) ed Kiv A E and Shyshkina M P (CEUR-WS.org) pp 130–144 URL `https://ceur-ws.org/Vol-2547/paper10.pdf`

[19] Kuzmich V, Kuzmich L, Savchenko A and Valko K 2022 *Journal of Physics: Conference Series* **2288**(1) 012024 URL https://doi.org/10.1088/1742-6596/2288/1/012024

[20] Kolomoiets T H and Kassim D A 2018 Using the Augmented Reality to Teach of Global Reading of Preschoolers with Autism Spectrum Disorders *Proceedings of the 1st International Workshop on Augmented Reality in Education, Kryvyi Rih, Ukraine, October 2, 2018* (*CEUR Workshop Proceedings* vol 2257) ed Kiv A E and Soloviev V N (CEUR-WS.org) pp 237–246 URL https://ceur-ws.org/Vol-2257/paper24.pdf

[21] Zinonos N O, Vihrova E V and Pikilnyak A V 2018 Prospects of Using the Augmented Reality for Training Foreign Students at the Preparatory Departments of Universities in Ukraine *Proceedings of the 1st International Workshop on Augmented Reality in Education, Kryvyi Rih, Ukraine, October 2, 2018* (*CEUR Workshop Proceedings* vol 2257) ed Kiv A E and Soloviev V N (CEUR-WS.org) pp 87–92 URL https://ceur-ws.org/Vol-2257/paper10.pdf

[22] Kiv A E, Shyshkina M P, Semerikov S O, Striuk A M and Yechkalo Y V 2019 AREdu 2019 - How augmented reality transforms to augmented learning *Proceedings of the 2nd International Workshop on Augmented Reality in Education, Kryvyi Rih, Ukraine, March 22, 2019* (*CEUR Workshop Proceedings* vol 2547) ed Kiv A E and Shyshkina M P (CEUR-WS.org) pp 1–12 URL https://ceur-ws.org/Vol-2547/paper00.pdf

[23] Burov O Y, Kiv A E, Semerikov S O, Striuk A M, Striuk M I, Kolgatina L S and Oliinyk I V 2020 AREdu 2020 - How augmented reality helps during the coronavirus pandemic *Proceedings of the 3rd International Workshop on Augmented Reality in Education, Kryvyi Rih, Ukraine, May 13, 2020* (*CEUR Workshop Proceedings* vol 2731) ed Burov O Y and Kiv A E (CEUR-WS.org) pp 1–46 URL https://ceur-ws.org/Vol-2731/paper00.pdf

[24] Vakaliuk T A and Pochtoviuk S I 2021 Analysis of tools for the development of augmented reality technologies *Proceedings of the 4th International Workshop on Augmented Reality in Education (AREdu 2021), Kryvyi Rih, Ukraine, May 11, 2021* (*CEUR Workshop Proceedings* vol 2898) ed Lytvynova S H and Semerikov S O (CEUR-WS.org) pp 119–130 URL https://ceur-ws.org/Vol-2898/paper06.pdf

[25] Petrovych O B, Vinnichuk A P, Krupka V P, Zelenenka I A and Voznyak A V 2021 The usage of augmented reality technologies in professional training of future teachers of Ukrainian language and literature *Proceedings of the 4th International Workshop on Augmented Reality in Education (AREdu 2021), Kryvyi Rih, Ukraine, May 11, 2021* (*CEUR Workshop Proceedings* vol 2898) ed Lytvynova S H and Semerikov S O (CEUR-WS.org) pp 315–333 URL https://ceur-ws.org/Vol-2898/paper17.pdf

[26] Tarasenko R O, Amelina S M, Semerikov S O and Shynkaruk V D 2021 *Journal of Physics: Conference Series* **1946**(1) 012023 URL https://doi.org/10.1088/1742-6596/1946/1/012023

[27] Merzliak A, Nomirovskyi D, Polonskyi V and Yakir M 2018 *Algebra and the beginnings of analysis and geometry. Standard level: textbook for 10th grade of general secondary education* (Kharkiv: Himnaziia)

[28] Magun V and Engovatov M 2004 *Sociology: Theory, Methods, Marketing* (3) 47–65 URL http://stmm.in.ua/archive/rus/2004-3/3.pdf

[29] Il'in E P 2002 *Motivacija i motivy* Mastera psihologii (SPb.: Piter)

[30] Kučera M and Smékal V 1976 *Test zrcadlového kreslení* (Bratislava: Psychodiagnostika)

[31] Rokeach M 1973 *The Nature of Human Values* (The Free Press) ISBN 9780029267509

Journal of Physics: Conference Series

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Measuring Earth’s mean density using BYOD technology

To cite this article: A V Zdeshchyts and V M Zdeshchyts 2023 *J. Phys.: Conf. Ser.* **2611** 012007

Measuring Earth's mean density using BYOD technology

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Abstract. BYOD (Bring your own devices) technologies are becoming more relevant in the educational process, when equipment that is "in the pocket" of a modern student is used in classes. BYOD technology becomes most effective if all students are provided with research equipments. But it is difficult to ensure such conditions in terms of distance learning during the war, the coronavirus pandemic, etc. In order to solve this problem, it is necessary to be able to develop laboratory installations that each student can make on his own. As an example of the implementation of this principle, the article considers a physical installation and a method of conducting laboratory work: "Measuring Earth's mean density using BYOD technology", which allows physics students, geodesists, surveyors to determine for themselves that the Earth has a heavy core. The purpose of this article is to show that a smartphone is a powerful measurement tool that, in combination with BYOD technology, increases student learning opportunities, namely: makes laboratory practice not too difficult; provides an opportunity to conduct experiments both in the laboratory and remotely. The main result of the work is proving the fact that the use of BYOD technology in combination with modern measuring tools – smartphones equipped with appropriate applications allows (to solve) the problem of distance learning of students. As it shown by the results of measuring the Earth's mass and density using BYOD technology, the values are consistent with the known ones obtained with more difficult to use and expensive technique. Along with the values of mass and density, the student receives other characteristics of the Earth: the value and slope of the induction vector of its magnetic field. Exceeding of the Earth's mean density, which is equal to 5676 kg/m^3 according to the results of experiments; the density of the main rock-forming minerals in the Earth's crust, which is in the range of 1900-3500 kg/m^3, leads the student-researcher to think about the internal structure of the Earth.

1. Introduction

It is known that students grasp scientific concepts more easily when they are directly involved in learning through laboratory experiments or other practical lessons. Practical or experiential learning also helps students to understand scientific theory [1]. Practice should be interesting, accurate, include fitting (data approximation) using the least square method, to determine measurement errors with its help.

One way to engage students in a classical physics course is to use smartphones to test or illustrate various concepts covered in lectures. Smartphones are increasingly used in higher education institutions during the study of mechanics [2–6], thermodynamics [7, 8], electromagnetism [9, 10], optics [11], as they provide a unique way of conducting a simple scientific experiment. Smartphone sensors allow us to measure acceleration, pressure, illumination, magnetic fields, surface inclination, noise level, and its spectrum. A smartphone can be used as a source of light and sound. In addition, smartphones have a "slow motion" option, which allows to record physical processes at a slower pace. For example, some smartphones have the ability to record physical processes at a speed of 960 frames per second.

In parallel with the rapid development of mobile applications for smartphones, BYOD (Bring your own devices) technologies are becoming more relevant in the educational process, when equipment that is "in the pocket" of a modern student is used in classes [12]. BYOD technology becomes most effective if all students are provided with research equipment. But it is difficult to ensure such conditions in terms of distance learning during the war, the coronavirus pandemic and so on [13]. In order to solve this problem, it is necessary to be able to develop laboratory installations that each student can make on his own. As an example of the implementation of this principle, the article considers a physical installation and a method of conducting laboratory work: "Measuring Earth's mean density using BYOD technology". There are three parameters determined in this work: 1) the acceleration of free fall, 2) the Earth's mass, and 3) the mean density of our planet, which will allow physics students, geodesists, surveyors etcetera to determine for themselves that the Earth has a heavy core.

The purpose of this article is to show that the smartphone is a powerful measurement tool that, in combination with BYOD technology, increases student learning opportunities, namely: makes laboratory practice not too difficult; provides an opportunity to conduct experiments both in the laboratory and remotely. This makes it possible to solve several important educational problems, in particular, the problem of providing educational institutions with modern measuring equipment, which, due to the constant development of mobile applications, significantly expands the boundaries of the educational process.

2. Related work

From the autumn of 1797 to the spring of 1798, Henry Cavendish conducted a series of experiments that were aimed at determining the Earth's density [14]. Adapting the torsion balance (and methodology) of his friend John Mitchell [15], Cavendish made the first truly accurate measurement of Earth's mean density: his result was within one percent of the currently accepted value of 5515.3 kg/m^3 [16].

The most important characteristic of a celestial body is its mass, which can be calculated by Kepler's third generalized law [17]. The mass of the Earth can also be calculated by measuring the force of gravity on its surface (gravimetric method) [18]. A student, for example, can determine the mass of the Earth using a mathematical pendulum.

A mathematical pendulum is an oscillator that is a mechanical system which consists of a mathematical point at the end of a weightless inextensible string or light rod that is in a uniform field of gravitational forces. The other end of the string is stationary.

A good approximation of this model is a small ball suspended on a thin, strong thread (thin steel wire, fishing line, etc.). When the pendulum is deflected to a small angle, it will carry out harmonic oscillations. The period of these oscillations is determined by the expression:

$$T = 2\pi\sqrt{l/g}. \tag{1}$$

From this equation it is possible to find the value of the free fall acceleration:

$$g = l * (2\pi/T)^2. \tag{2}$$

On the other hand, the acceleration of free fall can be found from the universal law of gravitation and Newton's second law:

$$ma = G\frac{mM}{(R+h)^2}, \tag{3}$$

where m is the mass of a body falling in the Earth's gravitational field, M is the Earth's mass, R is the Earth's radius, h is the height of the fall, G is the gravitational constant.

If h tends to zero, then from equation (3) we get that free fall acceleration:

$$a = G\frac{M}{R^2}. \tag{4}$$

This is the acceleration g in equation (2). Many works [19–21] are dedicated to the measurement of free fall acceleration using smartphone sensors. From equations (2) and (4) we get the formula for determining the Earth's mass:

$$M = \frac{l}{G} * \left(\frac{2\pi}{T}\right)^2. \tag{5}$$

Therefore, to determine the mass of the Earth M and its density ρ, we need to 1) make a mathematical pendulum by tying an inextensible thread to a ball, 2) measure the oscillation period, the length of the pendulum l (the distance from the suspension point to the center of the ball) and 3) know that the Earth's radius $R_{\oplus} = 6371$ km, gravitational constant G=6.67*10^{-11} N$\cdot$ m$^2\cdot$ kg^{-2}. Then the Earth's mass is determined as follows:

$$M = 24.24 \cdot 10^{24} \cdot \frac{l}{T^2},\ \text{kg}, \tag{6}$$

and the Earth's mean density:

$$\rho = \frac{M}{V} = 22378 \cdot \frac{l}{T^2}. \tag{7}$$

Let's ask the question: what tools does the student have for conducting this physical experiment, if he is at home? Modern smartphones have many sensors and there are a lot of corresponding mobile applications developed. The applications used to perform our laboratory work are Physics Toolbox Sensor Suite [22] and Phyphox [23]. These are very convenient applications that include the ability to measure parameters of physical fields using smartphone sensors: gyroscope, magnetometer, light sensor, accelerometer, provide the ability to record results, present them graphically, as well as save and share the results of experiments. Thus, the magnetometer sensor measures the strength of the magnetic field along the X, Y and Z axes, as well as the magnetic properties of materials. Such sensors can be used in studies of the magnetic field and fluctuations of its intensity. The light sensor can be used to study the light level.

Summarizing the above, we come to the conclusion that a mobile device should become an everyday tool for learning [24].

3. Research methods

The object of the study is the problems of students' education during their forced distance learning.

The subject of research is the symbiosis of BYOD technology and smart technology.

One of the methods used to obtain experimental data is the slow-motion recording of body movement against the background of a stopwatch, which registers time with an accuracy of 1 millisecond. The "Stopwatch" application might be used for that. In this method, a smartphone camera is used in "slow motion" mode to determine the period of oscillation of a mathematical pendulum.

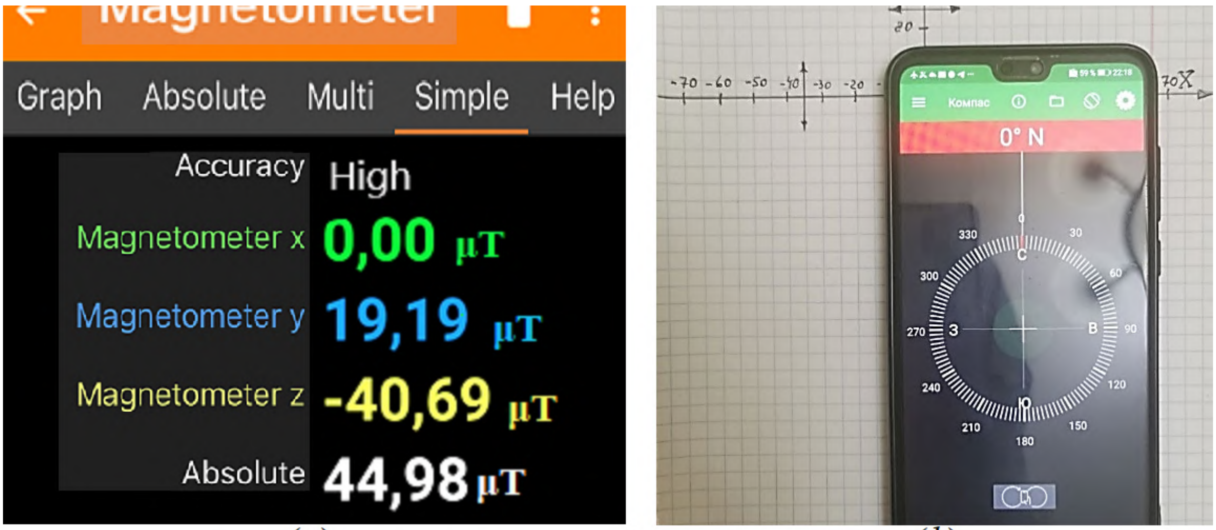
Other methods of determining the period of oscillation of a mathematical pendulum used the smartphone's magnetic sensor, accelerometer, light sensor, etc. in combination with applications that ensure the sensors operation.

4. Results

In order to determine the oscillation period of a mathematical pendulum using the magnetic sensor of a smartphone, we must first determine its location. To do this, you need a small magnet, a smartphone with the Phyphox or Physics Toolbox Sensor Suite application, a ruler, paper with a 5 mm grid. The position of the sensor is determined by using a technology that consists in bringing a small magnet closer to the phone's sensor from different directions (X, Y) and determining the maximum value of the magnetic field induction.

All measurements are very sensitive to the presence of metal around. Therefore, it is important to make sure that there are no other sources of magnetic interference in the working environment (iron, steel, for example, in the table; electrical cables, etc.). It is advisable to put the smartphone in flight mode. As smartphones contain non-magnetic data carriers, small magnets cannot damage the device in principle. Very strong magnetic fields can damage the mechanical parts of the smartphone (for example, loudspeakers). It may happen that the smartphone's magnetic field sensor would recalibrate if it measures an extremely strong field. If the measurement seems meaningless, you need to recalibrate the device by rocking it back and forth along the figure-of-eight trajectory.

Obtaining data is carried out the following way: 1) put the smartphone in flight mode and launch the "Magnetometer" program, 2) put the smartphone on a sheet of paper from a notebook. After turning the smartphone on the surface of the table together with the paper, align it in the Y direction to the north. The value of the X-component of the magnetometer is then equal to zero (figure 1, *a*). The direction of the Y axis is also determined using the Physics Toolbox application "Compass" (figure 1, *b*).

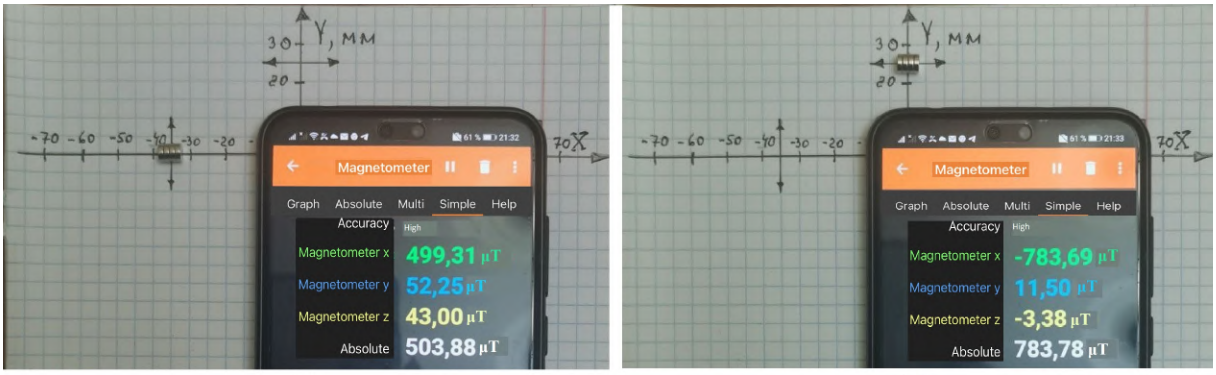


(*a*) (*b*)

Figure 1. Orientation of smartphone and coordinate grid using (*a*) magnetometer and (*b*) compass.

Determine the position of the magnetic field sensor in the smartphone. For this, the magnet is placed next to the smartphone (figure 2). If the maximum magnitude of magnetic field induction is displayed, then the magnet is exactly at the level of the sensor. The magnetic field sensor is now located at the intersection of the X and Y axes.

As seen in figure 1, (*a*), the indicators on the display make it possible to determine both the magnitude of the Earth's magnetic field ($B = 44.98$ μT), and calculate the angle of inclination of the magnetic field induction vector by components Y and Z. For example, according to the



(*a*) (*b*)

Figure 2. Photo of experiments: (a) a magnet aligned with the EW direction moves in the NS direction, (b) a magnet aligned with the EW direction moves in the EW direction.

magnetic field measurements shown in figure 1, (a): $tg\alpha = B_Z/B_Y = 40.69/19.19 = 2.12$, i. e, $\alpha = 64.75°$.

So, the important part is that during the performing of this laboratory work, the student independently acquires the knowledge about the Earth's magnetic field.

The iron ball of the pendulum most often stays at the state of rest and is magnetized under the influence of the Earth's magnetic field. The magnetization of the ball in this lab is used to measure the period of oscillation of a mathematical pendulum.

An iron ball with a diameter of 52 mm on a thread with a length of 710 mm was attached to the table top with a binder clip. The length of the pendulum $l_{pendulum} = 0.736$ m, which corresponded to the theoretically calculated oscillation period $T_{theor} = 1.721$ s. The magnetic sensor of the Huawei P20 Pro smartphone was used as a sensor, which was placed under the pendulum ball at the zero mark. The measurement of the change in the magnetic field near the sensor during the oscillation of the ball was carried out using the mobile application "Magnetometer" Phyphox. The view of the display during the experiments is shown in figure 3. The actual measured oscillation period was $T_{fact} = 1.71$ s.

Another method of determining the oscillation period of a mathematical pendulum is the video registration of the movement of the pendulum ball in the "slow motion" mode with simultaneous time registration (figure 4).

Slow motion is a function of the main camera of modern smartphones, which allows us to shoot videos with a high frame rate. In general, there is a standard in cinema - 24 frames per second. Slow motion allows to record an event with a frequency of 60-240, or even 960 frames per second. Such a video is launched with the usual frequency for mobile phones of 30 frames per second, allowing to show the video slowed down by 2-32 times. So the processes that were previously invisible to the human eye are open for measurement now. And it is more convenient to do this if there is a time fixation of the event. The stopwatch mobile application was used as such a clock with a time measurement accuracy of 1 millisecond.

The algorithm for determining the oscillation period consisted in measuring the time interval t during which the mathematical pendulum made $N = 10$ oscillations. The oscillation period was determined by the formula $T = \frac{t}{N}$. The mean oscillation period of the mathematical pendulum for 10 experiments was equal to $\bar{T} = 1.725$ s.

Another method of determining the oscillation period of a mathematical pendulum is the method that uses the smartphone's light sensor. To do that select the "Illumination" option in the Physics Toolbox mobile application. The oscillogram of oscillations of a mathematical pendulum, recorded by a smartphone, is shown in figure 5.

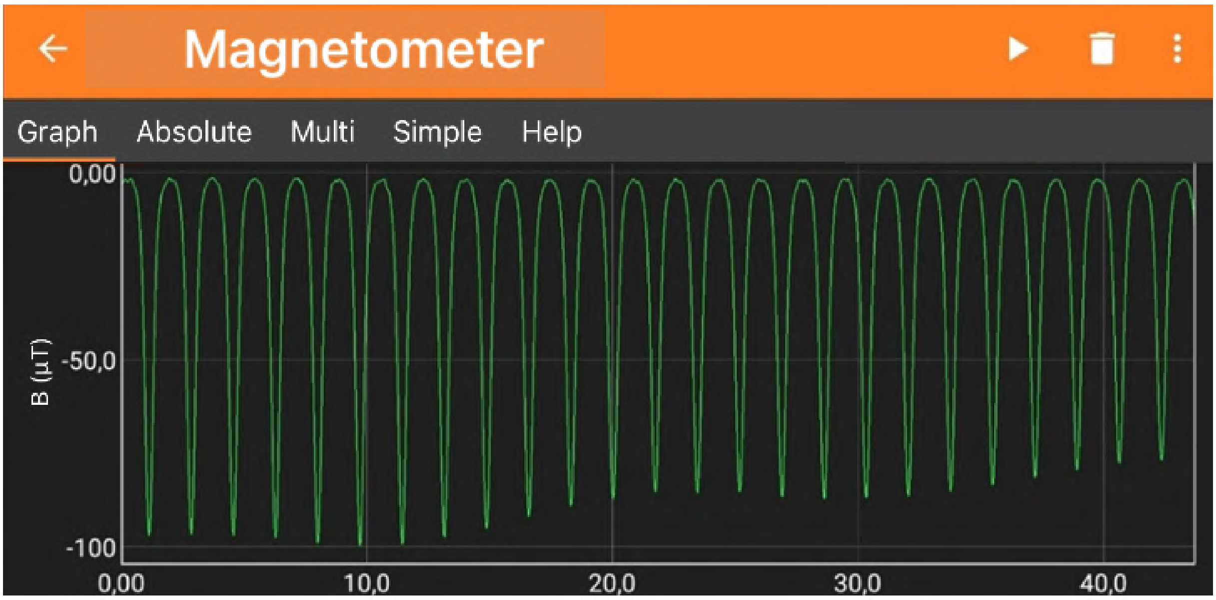


Figure 3. View of the display during the oscillation of the mathematical pendulum. Mobile application "Magnetometer" Phyphox.

Figure 4. Moments of time registration of reaching the oscillation amplitude.

The mean period of oscillations of the mathematical pendulum for this method for 10 experiments was $T = 1.750$ s.

So, the oscillation periods of the mathematical pendulum, determined using various methods and smartphone sensors, are as follows table 1.

Thus, there are 3 ways to measure the period of oscillation of a mathematical pendulum using a smartphone. The closest to the average value of $T = 1.731$ s is the method of determining the oscillation period of a mathematical pendulum using the magnetic sensor of a smartphone

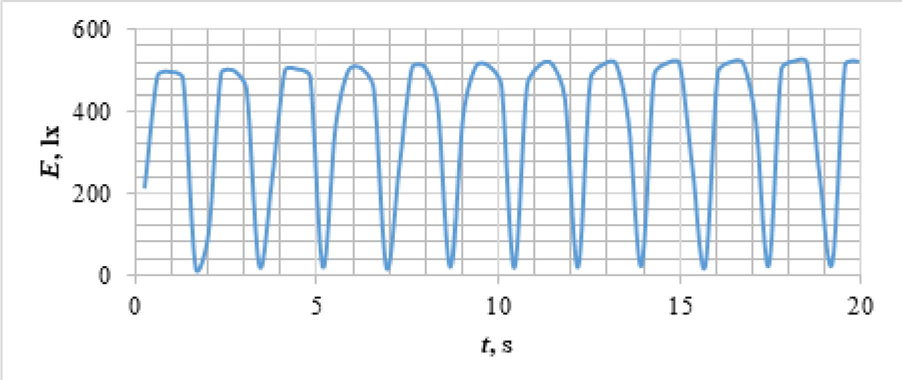


Figure 5. Oscillogram of oscillations (Physics Toolbox Sensor Suite).

Table 1. Results of measuring the oscillation period of the mathematical pendulum.

Sensor	Application	Period, s
Magnetic	Physics Toolbox	1,732
Magnetic	Phyphox	1,717
Camera	Stopwatch + slow motion	1,725
Light sensor	Physics Toolbox “Illumination”	1,750

* The data presented in the article are the averaged data of the results of measuring the Earth’s density by a group of physics students of a pedagogical university in distance mode. All students coped with this task on time and without difficulties.

with the Physics Toolbox application. According to the determined period (see equation (6)) the mass of the Earth is equal to:

$$M = 24.24 \cdot 10^{24} \cdot \frac{0.76}{(1.731)^2} = 6.15 \cdot 10^{24} \text{ kg},$$

which is close to the table value $M_{table} = 5.98 \cdot 10^{24}$ kg, whereas its density (see equation (7)):

$$\rho = (5676 \pm 64) \text{ kg/m}^3. \quad (8)$$

This is 2.9% more than the generally accepted value $\rho = 5515.3$ kg/m^3.

5. Conclusions

The main result of the work is proving the fact that the use of BYOD technology in combination with modern measuring tools – smartphones equipped with appropriate applications allows solving the problem of distance learning of physics students. As shown by the results of measuring the Earth’s mass and density using the BYOD technology, they are consistent with the known values obtained with the help of a more difficult to use and expensive technique. Along with the values of mass and density, the student receives other characteristics of the Earth: the value and slope of the induction vector of its magnetic field. Exceeding the mean density of the Earth, equal to 5676 kg/m^3 according to the results of experiments, the density of the main rock-forming minerals in the Earth’s crust, which is in the range of 1900-3500 kg/m^3, leads the student-researcher to think about the internal structure of the Earth.

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References
[1] Shapovalov Y, Shapovalov V, Tarasenko R, Bilyk Z, Shapovalova I, Paschke A and Andruszkiewicz F 2022 *Educational Technology Quarterly* **2022**(3) 216–231 URL https://doi.org/10.55056/etq.40
[2] Vogt P and Kuhn J 2012 *The Physics Teacher* **50**(3) 182–183 URL https://doi.org/10.1119/1.3685123
[3] Vogt P and Kuhn J 2012 *The Physics Teacher* **50**(7) 439–440 URL https://doi.org/10.1119/1.4752056
[4] Puttharugsa C, Wicharn S, Plaipichit S and Khemmani S 2021 *The Physics Teacher* **59**(6) 504–505 URL https://doi.org/10.1119/10.0006145
[5] Kaps A and Stallmach F 2020 *The Physics Teacher* **58**(3) 216–217 URL https://doi.org/10.1119/1.5145423
[6] Martyniuk O O, Martyniuk O S, Pankevych S and Muzyka I 2021 *Educational Technology Quarterly* **2021**(3) 347–359 URL https://doi.org/10.55056/etq.39
[7] Goy N A, Denis Z, Lavaud M, Grolleau A, Dufour N, Deblais A and Delabre U 2017 *The Physics Teacher* **55**(8) 498–499 URL https://doi.org/10.1119/1.5008349
[8] Silva M R, Martín-Ramos P and da Silva P P 2018 *The Physics Teacher* **56**(1) 53–55 ISSN 0031-921X URL https://doi.org/10.1119/1.5018696
[9] Girot A, Goy N A, Vilquin A and Delabre U 2020 *The Physics Teacher* **58**(2) 133–135 URL https://doi.org/10.1119/1.5144800
[10] Kanivets O V, Kanivets I M and Gorda T M 2022 *Educational Technology Quarterly* **2022**(4) 347–365 URL https://doi.org/10.55056/etq.429
[11] Wannous J and Horvath P 2023 *The Physics Teacher* **61**(1) 36–39 URL https://doi.org/10.1119/5.0033597
[12] Bilyk Z I, Shapovalov Y B, Shapovalov V B, Megalinska A P, Zhadan S O, Andruszkiewicz F, Dołhańczuk-Śródka A and Antonenko P D 2022 *Educational Technology Quarterly* **2022**(4) 328–346 URL https://doi.org/10.55056/etq.433
[13] Kovalchuk V I, Maslich S V and Movchan L H 2023 *Educational Technology Quarterly* **2023**(1) 1–17 URL https://doi.org/10.55056/etq.49
[14] Cavendish H 1798 *Philosophical Transactions of the Royal Society of London* **88** 469–526 URL https://doi.org/10.1098/rstl.1798.0022
[15] Michell J 1784 *Philosophical Transactions of the Royal Society of London* **74** 35–57 URL https://doi.org/10.1098/rstl.1784.0008
[16] Lally S P 1999 *The Physics Teacher* **37**(1) 34–37 URL https://doi.org/10.1119/1.880145
[17] Hevelius J 1674 *Philosophical Transactions of the Royal Society of London* **9**(102) 27–31 URL https://doi.org/10.1098/rstl.1674.0014
[18] Pryshlyak M 2019 *Astronomy for the 11th grade of general secondary education institutions (standard level, according to the curriculum of the author's team under the leadership of Yatskiv Ya. S.)* (Harkiv: Ranok) ISBN 0130850845 URL https://lib.imzo.gov.ua
[19] Berrada M, Littleton J A and Secco R A 2020 *The Physics Teacher* **58**(7) 470–472 URL https://doi.org/10.1119/10.0002063
[20] Berrada M, Littleton J A and Secco R 2020 *The Physics Teacher* **58**(7) 473–476 URL https://doi.org/10.1119/10.0002064
[21] Pili U and Violanda R 2018 *Physics Education* **53**(4) 043001 URL https://dx.doi.org/10.1088/1361-6552/aaab9c
[22] Vieyra-Software 2022 Physics toolbox sensor suite URL https://www.vieyrasoftware.net/physics-toolbox-sensor-suite
[23] 2nd Institute of Physics of the RWTH Aachen University 2016 Phyphox URL https://phyphox.org/
[24] Zdeshchyts V and Zdeshchyts A 2022 *The use of BYOD technology in the educational process in the conditions of distance learning of physics students* (Kryvyi Rih: Literiya) URL http://elibrary.kdpu.edu.ua/xmlui/handle/123456789/6482

Journal of Physics: Conference Series

PAPER • OPEN ACCESS

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To cite this article: R P Kukharchuk *et al* 2023 *J. Phys.: Conf. Ser.* **2611** 012008

ICon-MaSTEd 2023 IOP Publishing
Journal of Physics: Conference Series **2611** (2023) 012008 doi:10.1088/1742-6596/2611/1/012008

Using open experimental data of the European Organization for Nuclear Research in the process of studying the physics of elementary particles

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Abstract. The article discusses the theoretical justification, and the process of developing, implementing, and experimentally verifying the methodology for training future physics teachers using open experimental data from the European Center for Nuclear Research in studying elementary particle physics. The main stages of the study of elementary particle physics are clarified, taking into account the modern achievements of CERN. In the work, the study of elementary particles was carried out based on data from the CMS detector (Compact Muon Solenoid). A description of the methods, techniques, and ways of using the proposed methodological tools for the workshop on the physics of the atomic nucleus and elementary particles is presented. The process of selection and preparation of tasks and instructions based on the open experimental data of the European Center for Nuclear Research, recommendations for working with software, and their approbation in the educational process is considered. An experimental verification, analysis, and generalization of the research results were carried out. Arguments are given regarding the effectiveness and practicality of using the open experimental data of CERN in the process of studying elementary particle physics.

1. Introduction

The Large Hadron Collider (LHC) is the world's largest particle accelerator built at the European Center for Nuclear Research (CERN) and the most technologically advanced device of the 20th century. A detailed study of elementary particles allows the discovery of new possibilities and the use of their energy in industry, astronautics, medicine, etc. [1–3].

CERN research can be divided into three scientific categories.

(i) *Origin of mass.* Research in this area is in search of the Higgs boson, a hypothetical elementary particle assumed by the Standard Model (SM) of particle physics. The Higgs particle belongs to a class of particles known as bosons and is considered a key element in understanding why particles have mass.

(ii) *Dark matter.* The behavior of galaxies will lead scientists to the idea that their mass is greater than observations suggest. Theorists assume that every particle that exists in the SM has a twin. These particles are called supersymmetries, they can form invisible dark matter.

(iii) *Big Bang.* What happened in the first moments of the existence of the universe? The development of the theory that the cosmos consisted of a hot dense mixture of quarks and gluons (quark-gluon plasma) will make it possible to reproduce these conditions and study the properties of such a plasma.

In one second, the LHC has 600 million collisions, which corresponds to 1 million gigabytes of raw information. With the help of special software, this data is converted into readable objects and stored for further analysis. More than 20 PB of new data are generated each year through ongoing experiments, helping CERN scientists advance science and answer questions about the fundamental laws of nature.

Data can reach the CERN Computing Center at up to 6 GB per second – that's two DVDs every three seconds. The challenge is to make this data available to the physics community. The data center's biggest challenge is to keep up with the volume and pace of data growth. According to the results of the competition held in 2007, CERN chose to manage the LHC registration complex, software based on Oracle DBMS using Real Application Clusters (RAC) technology, Netapp solution. Since then, the entire Oracle-based CERN infrastructure has been unified using Netapp technologies, and today, 99% of all data entering Oracle databases are stored on Netapp systems.

An important fact for our study is that the European Center for Nuclear Research reported the discovery of a huge amount of data obtained at the Large Hadron Collider (LHC). It is noted that some data are presented in raw form, which they are available to CERN researchers [4]. Other information is presented in a processed form, which makes it suitable for use, in particular for educational purposes [5].

Valuable scientific information is published in the public domain in two archives, one containing the initial data set in a format that can be read by special software, and the second archive containing data optimized for education by researchers. Scientists from the CMS collaboration have also made several programs available to the public that can be useful for studying experimental data from the archives. CERN explained that more than 100 terabytes of published information came from seven teraelectronvolt proton collisions performed at the Large Hadron Collider in 2011. According to them, these data have already fulfilled their scientific role and now may well become public. Both students can use valuable information and professional scientists involved in elementary particle physics. In this regard, the question arises of the effectiveness of using CERN open data in the process of conducting practical work in elementary particle physics as one of the methods for generating knowledge about experimental methods for studying modern elementary particle physics.

2. Theoretical background

In 2016, CERN released 300 TB data, the CERN 6 Linux virtual machine, and analysis tools to the public. It became an outstanding event for physicists from all over the world. Also, students and schoolchildren can download this data and use it for term papers and laboratory work. It is even possible to discover hidden correlations that have escaped the attention of CERN specialists. The data were obtained during experiments in 2011, mainly from the collision of protons with an energy of 7 teraelectronvolts. In such collisions, many rare elementary particles are generated, flying in different directions and registered by detectors. Links to all datasets and programs are collected on the CMS Open Data page [4]. There are raw data without processing in the AOD (Analysis Object Data) format, simulation data for experiments in 2011 in the AODIM format, and examples of simplified data sets for analysis. The last time CERN published data on experiments in the public domain was in November 2014: then posted 27 terabytes collected in 2010.

The accelerator runs in a tunnel (torus-shaped, 27 km in circumference) up to 175 meters (570 feet) underground on the French-Switzerland border, near Geneva, Switzerland. As the name suggests, it is designed to accelerate hadrons, in particular protons and heavy ions. The accelerator system consists of an injector J (linear accelerator), a booster (small accelerator), and a powerful linear synchrophasotron. The system forms a 14 TeV proton beam. The accelerator has two storage rings, in which slightly deformed circles 300 m in diameter intersect 8 times at an angle of 150. Protons are introduced into the rings alternately through channels 1 and 2 for 30 min until the current reaches 30 A. After that, the synchrophasotron is disconnected. The pressure was increased to 10-9 Pa. This makes it possible to preserve colliding proton beams for several days. The beams collided at the intersections of the rings, where the events are recorded. After modernization in 2015, it was possible to obtain energy of 6.5 TeV per beam (13 TeV total collision energy, a modern world record). At the end of 2018, the collider was turned off for further modernization of the accelerator and detectors. The restart of the collider took place in 2022. The LHC became operational again on 22 April 2022 with a new maximum beam energy of 6.8 TeV (13.6 TeV collision energy). On July 5, 2022, he officially began his 3rd season of physics research. This round is expected to continue until 2026. In addition to higher energy, the LHC is expected to reach a higher luminosity, which is expected to increase even more after upgrading to HL-LHC. The High-Luminosity LHC is a project to upgrade the LHC to a higher luminosity of up to $2 \times 10^{35} cm^{-2} s^{-1}$. The collision energy will remain the same. Work in this mode will not begin until 2026.

The collider has four main detectors: two large ones – ATLAS and CMS, and two medium ones – ALICE and LHCb. Two specialized detectors, TOTEM, and LHCf are also installed near the two large detectors.

In our work, we consider the study of elementary particles based on the data of the CMS detector. The CMS detector is one of the largest at CERN. The CMS collaboration consists of more than 3,000 scientists, engineers, technicians, and students from 180 institutes and universities in 40 countries. The detectors are made up of many layers of material that use the different properties of the particles to detect and measure the energy and momentum of each one. In the LHC, particles move in opposite directions along the central axis of the CMS cylinder and collide in the middle of the detector. The most essential element of the detector is a very strong magnet. The greater the momentum of a charged particle, the less its trajectory is curved in a magnetic field, so when we know the radius of curvature, we can measure the momentum. That is why a strong magnet is necessary to allow scientists to accurately control the impulse to wind muons. The pulse can be measured both inside the coil (using tracking devices) and outside the coil.

The solenoid of the coil is prepared for an over-the-wire dart, which creates a magnetic field if the electric stream passes through it; the solenoid may have a deep valley of 13 m and a diameter of 7 m, and the magnetic field, as if creating wine, is 100,000 times stronger, lower near the Earth. The largest magnet of this type, but, in general, is more compact, in line with detectors of a similar magnet.

The CMS detector is designed to detect muons. Muon (from the Greek letter μ, used for designation) (English muon, heavy electron, mu meson, German Myon) – in the standard model of elementary particle physics – an unstable elementary particle with a negative electric charge and spin of 1/2. Along with the electron, tau lepton, and neutrino, it is classified as part of the lepton family of fermions. Like all fundamental particles, the muon has an antiparticle with the opposite charge, but with the same mass and spin: the antimuon. The mass of the muon is 207 times the mass of the electron; for this reason, the muon can be considered the heaviest electron. Muons are denoted as $\mu-$, and anti-muons as $\mu+$. On Earth, muons are registered in cosmic rays; they arise as a result of the decay of charged pions. Pions are formed in the upper atmosphere by primary cosmic rays and have a very short decay time of a few nanoseconds. The lifetime of muons is also small – 2.2 microseconds. However, cosmic ray muons have velocities close to the speed of light, so due to the time dilation effect of special relativity, they are easy to detect near the Earth's surface.

As with other charged leptons, there is a neutrino muon that is associated with the muon. Muon neutrinos are denoted as ν. Muons almost always decay into an electron, an electron antineutrino, and a muon neutrino; there are also rarer types of decay when an additional photon or electron-positron pair is produced.

The most common is the decay of a charged pi-meson and K-meson into a muon and a muon antineutrino, sometimes with the formation of neutral particles:

$\pi^- \to \mu^- \widetilde{\nu}_\mu$ (99% of the decays)
$K^- \to \mu^- \widetilde{\nu}_\mu$ (64% of the decays)
$K^- \to \pi^0 \mu^- \widetilde{\nu}_\mu$ (3% of the decays)

These reactions are the main channels for the decay of these particles. Other charged mesons also actively decay with the formation of muons, although with a lower intensity, for example, in the decay of a D meson, a muon is formed only in 18% of cases. The decay of pions and kaons is the main source of muons in cosmic rays and accelerators. These reactions are the main channels for the decay of these particles. Other charged mesons also actively decay with the formation of muons, although with a lower intensity, for example, in the decay of a D meson, a muon is formed only in 18% of cases. The decay of pions and kaons is the main source of muons in cosmic rays and accelerators.

Since 2014, CERN's CMS experiment has released research-grade data on particle collisions at the Large Hadron Collider. Almost all the data from the first LHC run in 2010-2012 and the corresponding simulated samples are now publicly available, and several scientific studies have been published using these data [6].

Wessels et. al claims that the case of particle physics raises important questions about the relevance of data to open access and the assumed economics of long-term processing and storing data [7].

Wenninger points out the important educational value of the CERN initiative. Through CERN, scientific users have access to an open network of global expertise and technical skills, combining student education and training with truly international collaboration. Students learn about goal-oriented research project management based on motivation rather than hierarchical structure [8].

Ojasalo and Kaartti describe the development, organization, and implementation of the concept of a multidisciplinary study camp for master students. The concept of a learning camp is called CERN Bootcamp [9]. Nachman advocates that we recognize a new generation of high-energy physicists: "data physicists", who are best suited to analyze open data and develop and deploy new advanced data science tools so we can put valuable data to work to the fullest potential [10].

In the future, the processing of LHC data will be based on machine learning algorithms. Machine learning algorithms are increasingly important in high-energy physics, with applications in particle and event identification, physics analysis, detector reconstruction, simulation, and triggering. Currently, most data analysis tasks in LHC experiments benefit from the use of machine learning [11]. Regarding the recently restarted Large Hadron Collider (LHC) at CERN, Wiener et al. al attempted to facilitate the introduction of high energy physics into the classroom [12]. All physics schools offer courses at the intersection of DS, ML, and physics, often using courses developed by High Energy Physics (HEP) researchers, combined with open software and data used in HEP [13].

CERN carries out active educational activities. "The CERN@school project which lends the Timepix technology to schools has been developing for the last ten years with over 300 schools involved and thousands of students" [14].

CERN@school brings CERN's technology into the classroom to support the teaching of particle physics. It also aims to inspire the next generation of physicists and engineers, with participants being part of a national collaboration of students, teachers, and scholars to analyze data obtained from Earth and space probes to make new, curiosity-driven discoveries in schools [15]. These projects represent a secondary school program CERN@school, which provides a framework for the novel implementation of traditional classroom experiments using Timepix and allows students to contribute to large international scientific collaborations and develop their research project [16].

CERN makes data from other detectors freely available. Through the Hands-on-CERN project, it is possible to "participate" in modern particle physics experiments at the forefront of scientific research using scientific data transmitted via the Internet. The main goal is to demonstrate particle collisions from the frontiers of physics, stimulate interest in science and technology, and demonstrate the openness and internationality of basic research. Hands-on-CERN complements traditional physics courses, exposing students to contemporary physics and technology at the most basic level—detector technology and data transmission over the Internet [17].

Learning with ATLAS@CERN is a European educational project on CERN's LHC and ATLAS detectors. Within its framework, an autonomously run educational portal containing particle physics textbooks and masterclasses, seminars, and/or other events promoting an inquiry-based learning approach to teaching particle physics [18, 19]. Long noted that CERN is also using innovative software adapted by European particle physics researchers and made available on the Internet to introduce more innovative research methods for teaching particle physics concepts [20]. This allows students to get a "hands-on" experience in the classroom and see what real scientific research might look like [21].

Validation of the 2010 Compact Muon Solenoid (CMS) open data is through successful reconstruction of the J/ψ, Y, and Z decay channels [22] for comprehensive statistics. Although we cannot directly observe the particles formed in the collision, their decay products leave signals in the CMS sub-detectors.

Special software uses these signals to reconstruct the decay products, which scientists classify into different families and physicists call physical objects. It is important to note that these reconstructed "physical objects" are only interpretations of the signal recorded by the CMS, potentially with various sources of uncertainty (efficiency, error, etc.).

For example, figure 1 shows two events associated with muon accumulation. First impressions are recorded in muon chamber fragments, but not by real muons. On the other hand, the second event clearly shows how real muons pass through the CMS. Like a jigsaw puzzle, scientists had to gather every piece of information about the "physical objects" of each collision to form a picture of what happened during the collision. By analyzing trillions of collisions, scientists can find patterns in the data that could indicate undiscovered particles or phenomena, or make more precise measurements of known phenomena. In most cases, the standard collection of Physical Objects can be used without additional editing. However, "different types of analysis may require different combinations of "physical objects" and information about how they relate to each other. The difficulty is to balance the efficiency of data selection (samples containing many objects of a certain type) versus random data (probably false)" [22].

CERN has an open data portal [4]. The CERN Open Data Portal is an access point to

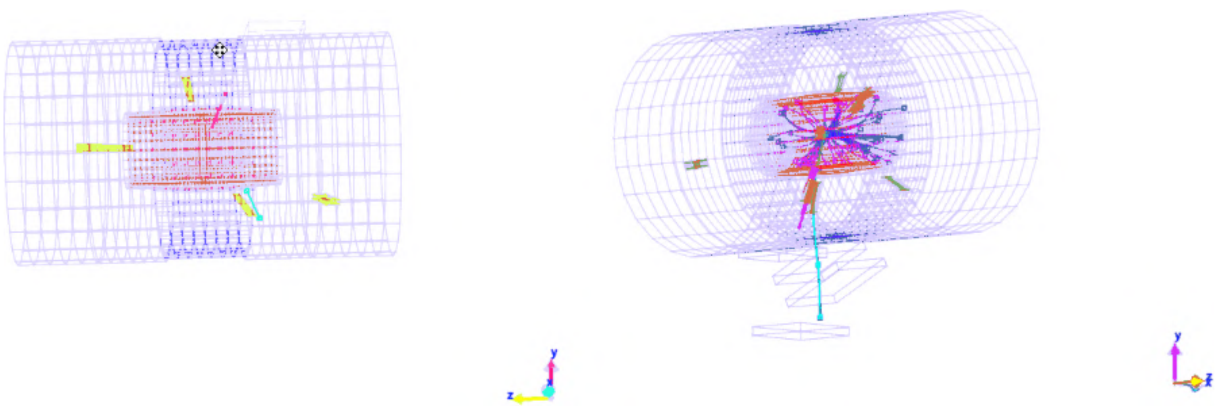

Figure 1. Two events from the muon collection.

a growing range of data generated through research conducted at CERN. It distributes saved results from various research activities, including the accompanying software and documentation that is needed to understand and analyze the data. The main page has links: education and research, as well as the site and search. By clicking on the link "about" the site opens a dialog box that prompts you to select: this site, CMS open data, ALICE open data, ATLAS open data, LHCb open data, glossary, and news. The portal adheres to established global standards in the field of data storage and Open Science: products are distributed under open licenses; they have digital object identifiers (DOIs) to make them citable objects in scientific discourse.

Through the portal, CERN provides the following data and software.

(i) Datasets for download (Downloadable datasets): primary datasets: complete reconstructions of collision data without any other samples (Primary datasets); simulation results (Simulation data); examples of simplified data sets obtained from primary data for use in various analysis programs (Examples of simplified datasets derived froth primary ones).

(ii) Software (Tools): a virtual machine (Virtual Machine (VM)) with CMS software that provides access to primary data sets, an example of data analysis from reading the primary data set and obtaining intermediate results to the final stages of analysis; mode, for example, for displaying images of events on the monitor and for plotting histograms, the source code of various software products that are available in the collection of CMS tools (Source code).

(iii) Primary datasets are provided in AOD (Analysis Object Data) format and simulation results are provided in AODIM format. AOD/AODSIM files contain the information needed to analyze: high-level physical objects such as muons, and electrons; tracks with corresponding collisions; calorimetric clusters with corresponding collisions; information about event samples (triggers), data necessary for further selection and identification of criteria for physical objects of physics.

These files are not the final interpretation of events with a simple list of particles. They contain several instances of the same physical object, that is, reconstructions that were carried out according to different algorithms. On the main page, it is proposed to go to two sections: education and research. The Education section invites you to visualize events, test reconstructed data, run analysis tools, or create your own. In the Exploration section, we have the opportunity to get real working environments, virtual machines, and datasets to start our exploration. Each section describes in detail each experiment and the amount of data obtained during its implementation.

CMS Learning Resources is a collection that includes learning resources that use public CMS data. The items in this collection are suitable for educational purposes. For training purposes, complex raw data is processed in the format of simple event visualization programs, histograms, and training resources. To work with the programs, you must have constant access to the Internet. Visualization of events takes place in a specially created environment, the event display, and for the convenience of work and familiarization with its main elements, there is a "Help" link. This link takes you to a page that explains how to use the event display. The CMS event display – iSpy – can be used to visualize collision data. Special type files with .ig extension can be opened with iSpy. Each .ig file is a collection containing numerous individual collision events. To create a histogram, the researcher is asked to select data in CSV format – comma-separated values. If you would like to create your CSV files based on datasets, it is suggested to use the sample code on GitHub [23].

For research purposes and analysis of primary data, it is necessary to use special software environments and software tools. First, you should install a virtual machine for analyzing the data already obtained in the CMS Open Data experiments. To analyze CMS data collected in 2011, you will need version 5.3.32 of CMS SW, which is supported in Scientific Linux 6. If the student is new to Linux, they are offered an introductory short introduction to Linux or try to work through the interactive command line.

3. Results

CERN hosted CMS International Masterclasses – international CMS master classes, which introduce students from more than 52 countries to the methods of elementary particle research. Students have the opportunity to work with real experimental data from the CMS LHC. The basic provisions of the master classes are: 1) the study of particle physics requires the use of circumstantial evidence to confirm the results; 2) the Standard Model is the current theoretical basis for our understanding of matter; 3) the behavior of particles is governed by the laws of conservation and the transformation of mass and energy. In our study, we used the experience of master classes as the basis for the methodology for using open experimental data from the European Center for Nuclear Research in the process of studying elementary particle physics.

In the first lessons, students get acquainted with the device and the principle of operation of the muon detector. Main measurement tool is computer program – event display iSpy (figure 2).

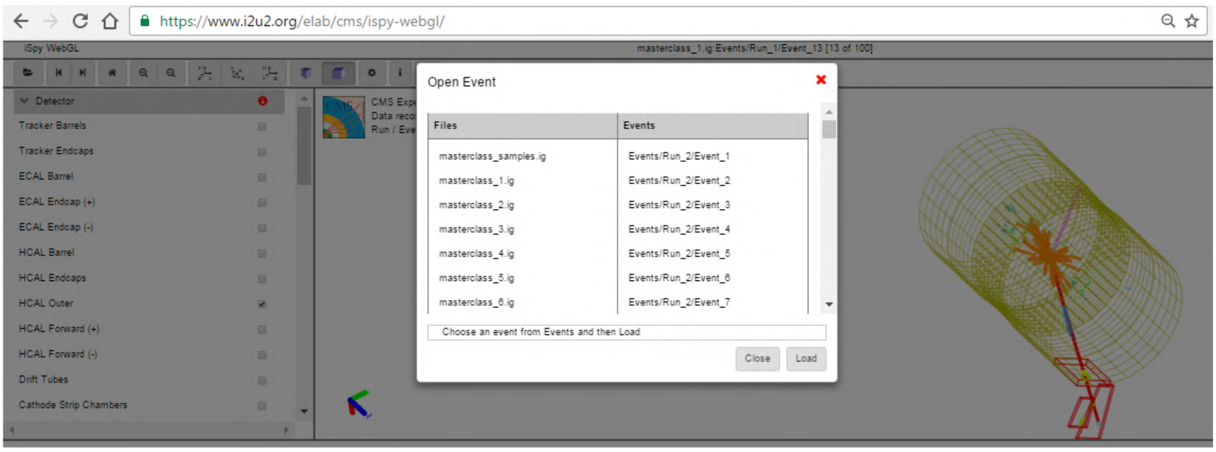

Figure 2. Interface iSpy.

Let's consider the work with iSpy on the example of studying the decay of the J/ψ-meson. J/ψ-meson is a subatomic particle, neutral, with spin 1, in the quark model it consists of a magic quark and a magic antiquark. The J/ψ-meson is its own antiparticle. The J/ψ-meson has a double name because it was discovered at the same time in two different laboratories, and even the announcement of the discovery was made on the same day – November 11, 1974, but named differently.

Characteristics of the J/ψ-meson: 1) composition: $c\bar{c}$; 2) Statistics: boson; 3) Family: mesons; 4) interactions: all; 5) antiparticle: self; 6) status: open; 7) discovered by: Richter and Ting, 1974; 8) symbol: J/ψ; 9) some types: 1; 10) mass: 3.096916 GeV/c^2; 11) lifetime: 7.2×10^{-21}s; 12) electric charge: 0 e; 13) spin: 1.

Students are to examine decays involving muon pairs and determine which events are J/ψ meson candidates, and then construct a histogram of mass counts for events that pass the "pupil trigger". In the process of decay, the J/ψ particle usually gives birth to a pair of muons. The decay of $J/\psi \rightarrow \mu + \mu-$ occurs without a change in the total flavor, since the J/ψ meson (quark structure c – anti-c) consists of a quark and an antiquark, and their flavors are compensated. Therefore, the decay does not require the participation of the weak interaction but can occur due to the annihilation of quarks $c\bar{c}$.

This can be either an annihilation into three gluons or one virtual photon. In the first case, the process is described by a strong interaction, and in the second, by an electromagnetic one. Three gluons then turn into colorless hadrons, the end products of the J/ψ decay. Such a J/ψ decay is shown in figure 3. This type of decay is the main one for the J/ψ particle. It accounts for about 59% of all J/ψ decays. Trigluon annihilation should occur at relatively short distances, since the virtual quark, which acts as an intermediary in such an annihilation, can only exist for a short period due to its large virtuality. The characteristic distances at which particle annihilation occurs are approximately equal to the radius of the forces that ensure this annihilation, i.e. at distances of the order of the Compton wavelength c and b-quarks, the magnitude of which is 0.1 fm.

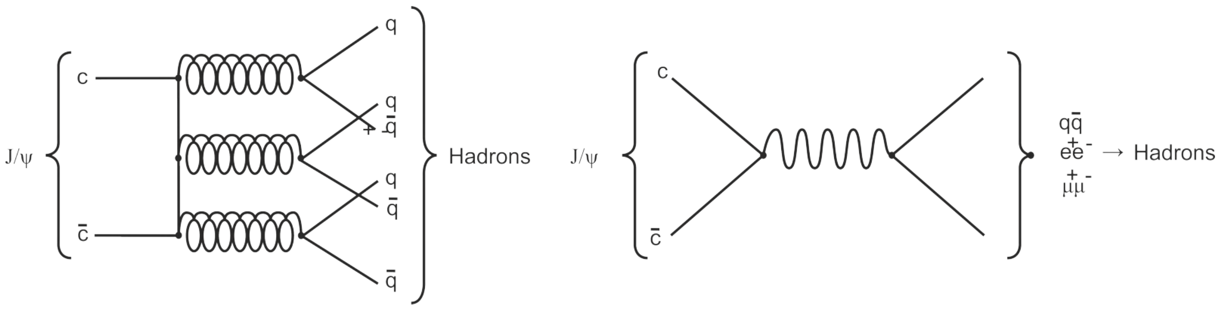

Figure 3. Quark diagrams of J/ψ decay to hadrons and through a virtual photon due to the strong interaction.

Annihilation through a virtual photon is exclusively electromagnetic, inferior in probability to gluon decay, but it accounts for 29% of all J/ψ decays. The student is invited to study two snapshots of events. Do they have evidence of the presence of muon pairs? Is the candidate for J/ψ? How confident can you be about this? An event must pass two tests before it can be considered a J/ψ candidate. To assess the degree of confidence in their conclusions, teachers of SMS master classes use a rating system. The student and partner analyze 100 events. After consulting with mentors and teachers, students decide how to rate each of the solutions. Estimates are entered in the table.

Consider examples of tests offered to students in the course of practical work.

Test 1: Opposite charges.

To be a candidate for J/ψ, an event must have two muon tracks of opposite electric charge. If two tracks deviate in the same direction inside the solenoid (located inside the hadron

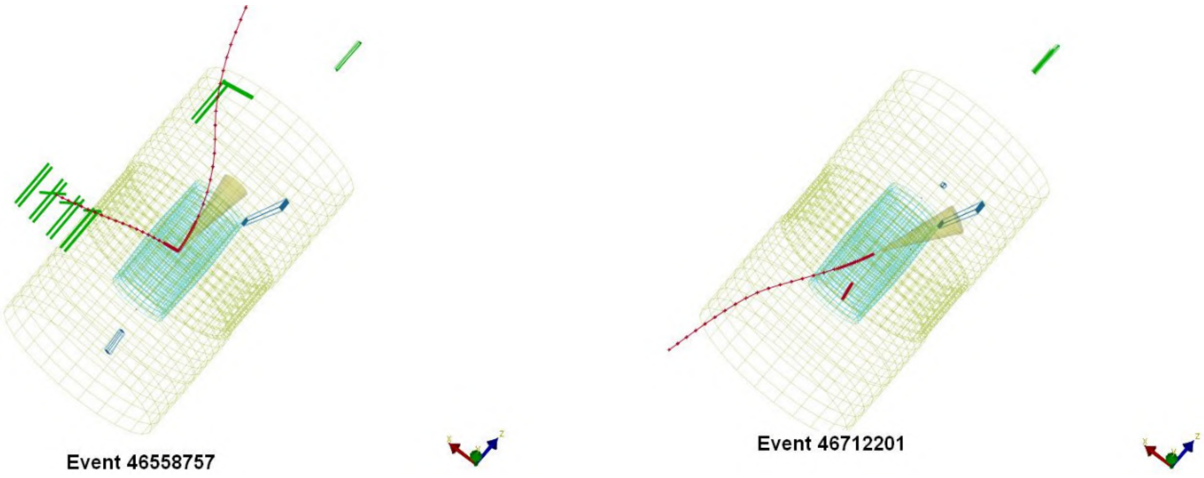

Figure 4. Events at which the appearance of J/ψ is possible.

calorimeter), they have the same sign, therefore, they are not created as a result of the J/ψ decay (Figure 5). Given this, what should be the charge J/ψ? The projection in the x-y plane accurately reflects the charge of the particle, other views can be misleading. If an event fails the "charge test", it is almost certainly not a J/ψ decay: score "0".

Figure 5. Test "Opposite charges".

Test 2: Quality of the muon track.

If 2 muons pass the charge test, analyze the J/ψ probability by evaluating each muon track. If there are more than two tracks, rate the two most successful with the opposite charge. Each muon is depicted as a "global muon" track. The terms "tracking muon" and "outer muon" refer to muon tracks in different parts of the CMS, while "global muon" is a track that describes the entire path of the muon if it can be accurately reproduced. Each muon track shows multiple measurements in drift tubes (DT), resistive plate chambers (RPC), or cathode strip chambers (CSC). These are all elements of the CMS muon detector; tracks outside the superconducting magnet are calculated based on the signals in these systems.

The track is not directly connected to the particle jet (which looks like a cone in the event display). Note to students that they will need to manipulate the display by adding or subtracting individual components, such as CSC measurements, to best analyze the muon tracks. To do

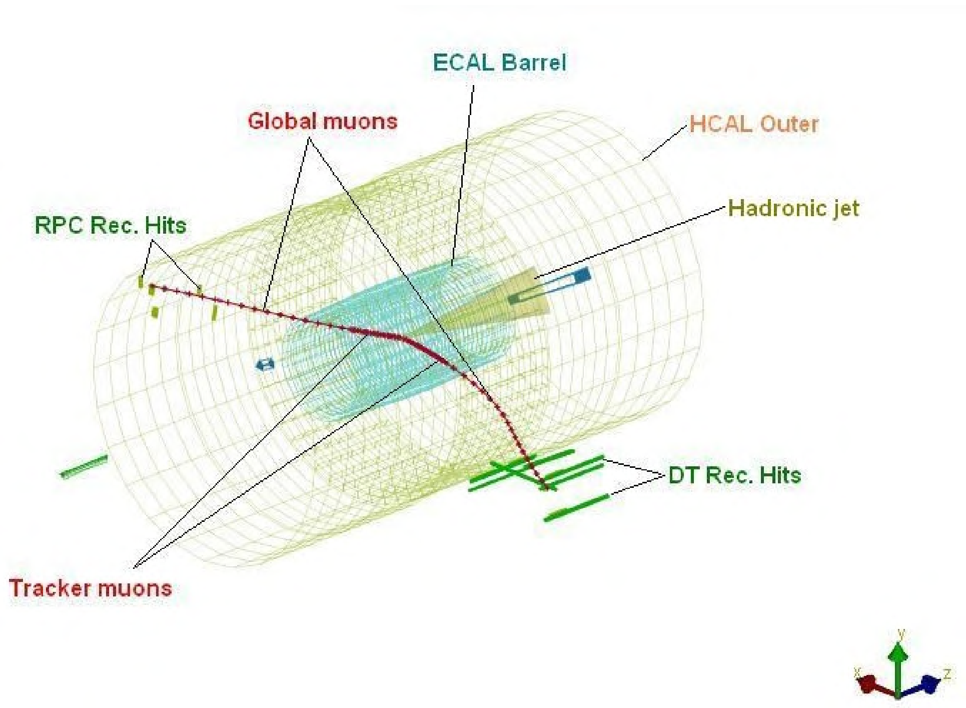

Figure 6. Elements of an event – a candidate for J/ψ.

this, we suggest opening the window and Spy Online wide enough to see the buttons on the left panel. We declare the problem: evaluate candidate events for J/ψ decays. Use the principles described above to evaluate events. Be consistent and careful. Rate the candidate J/ψ on a scale of 0 to 3, based on the study of muons in the event display: 0 – no chance; 1 – so-so; 2 – useful; 3 is excellent.

Record the score for each event in the datasheet (figure 7). Calculation of the mass (completion of the second part of the master class) will become possible only after the evaluation of muons. If you encounter unusual or difficult-to-assess events, consult with other students, faculty, and mentors to make the most accurate and consistent analysis possible. Next, the student is advised to count how many events in her set received the same scores. Compare the results with other groups (students). If the numbers differ significantly, discuss your scoring criteria and see if the scores need to be adjusted.

If you finish processing all 100 events, start with a new set. It is better to choose a set that no one has processed yet. The student has 2000 events at his disposal, and the more he can analyze, the better the final results will be. The whole group performs this part of the CMS data processing under the guidance of the instructor. It is necessary to decide which scores to include in the invariant mass distribution plot, for example, only events rated "3", or events rated 2 or 3, etc.

As a result, we propose to use the data table to obtain data on the masses calculated for the selected events. Plot the masses of the selected candidates in the form of a histogram. Save the mass plot for particle J/ψ. Discuss the interpretation of the final result, as well as the contribution of each group.

A similar technique is used to study the decays of W, Z, and H-bosons. When a W or Z boson decays, it creates two particles, leptons.

Higgs boson can decay in many ways. The two possible decays that students can see are the decay of the Higgs boson into two Z bosons and the decay of the Higgs boson into two

E3 =IF(D3=0;"";SQRT(((G3+L3)^2-(((H3+M3)^2)+((I3+N3)^2)+((J3+O3)^2))))

	A	B	C	D	E	G	H	I	J	L	M	N	O
1				Rating (0-3)	Mass	Muon Track #1				Muon Track #2			
2	MCNo	RunNo	EvNo	default=0	(GeV)	E	px	py	pz	E	px	py	pz
3	1	140124	1007912007	0		13,7061	4,88649	-2,5086	12,5569	3,67389	-0,68325	0,529614	3,56917
4	2	140124	1007957044	0		9,09052	-2,16135	-2,96392	-8,31686	3,80945	0,787428	-0,77583	-3,644
5	3	140124	1008000431	0		6,81754	5,76035	3,23987	-1,67015	19,1486	12,8875	12,3887	-6,86217
6	4	140124	1008032300	0		31,8853	-5,85709	2,78331	-31,2188	4,26886	-1,50179	-0,48697	-3,96478
7	5	140124	1008075983	0		13,5527	1,18694	-2,35966	-13,2924	4,36207	1,19082	0,142888	-4,19262
8	6	140124	1008203315	0		7,98636	1,41051	1,49141	7,71732	5,83304	-0,76009	1,22497	5,6511
9	7	140124	1008209356	0		8,4759	0,778887	1,81616	8,24164	4,36099	1,60931	0,0627	4,05133
10	8	140124	1008225333	0		10,3318	1,00769	2,58479	9,95179	6,43402	1,43627	0,03499	6,27068
11	9	140124	1008234146	0		7,6356	-1,32042	1,37354	7,39331	3,63523	-1,23253	-0,80557	3,322
12	10	140124	1008257850	0		9,08621	-1,92841	0,835437	8,83919	3,68113	0,273585	1,7503	3,22508
13	11	140124	1008262278	0		7,55158	1,41924	0,266467	7,41148	4,81347	-1,54717	-0,67497	4,50655
14	12	140124	1008289349	0		12,9147	-4,65907	-0,54563	-12,0321	3,70193	-0,41843	1,00964	-3,53535
15	13	140124	1008315074	0		10,7599	-2,99026	-0,31443	10,3307	8,58578	-1,79347	-1,97114	8,16104
16	14	140124	1008359945	0		10,1877	-0,93162	-3,02517	9,68287	4,58675	-1,62879	-0,14059	4,2842
17	15	140124	1008421464	0		8,15766	0,58943	-2,16005	7,84366	4,43274	1,91828	-1,699	3,61547
18	16	140124	1008461960	0		5,54986	0,702483	2,7066	4,79277	5,68172	-0,89181	1,5977	5,378
19	17	140124	1008477500	0		10,5807	1,23298	3,47886	9,91551	3,03217	-0,46632	-1,08312	2,79147
20	18	140124	1008524496	0		17,6481	-4,51342	-1,31655	-17,01	3,36175	0,842363	0,309338	-3,23805
21	19	140124	1008524805	0		9,1962	-3,56662	0,827198	8,43528	5,97017	-0,19314	-1,42278	5,79398
22	20	140124	1008602059	0		5,71933	2,33776	0,918908	-5,13713	3,73981	-0,52136	0,64587	-3,645
23	21	140124	1008641940	0		12,637	0,605848	4,4148	-11,8247	4,23532	-1,10013	-0,21288	-4,08303
24	22	140124	1008666475	0		21,0644	-3,05143	-2,86835	-20,6436	8,53169	-0,41929	-2,18543	-8,23569
25	23	140124	1008667143	0		8,9901	2,28989	-0,67301	8,66685	26,0104	2,75204	-3,61233	25,6107
26	24	140124	1008699102	0		6,13549	0,376432	-2,32089	-5,66611	2,96216	0,753553	0,211548	-2,85494

dimuon 2-5GeV

Figure 7. Datasheet.

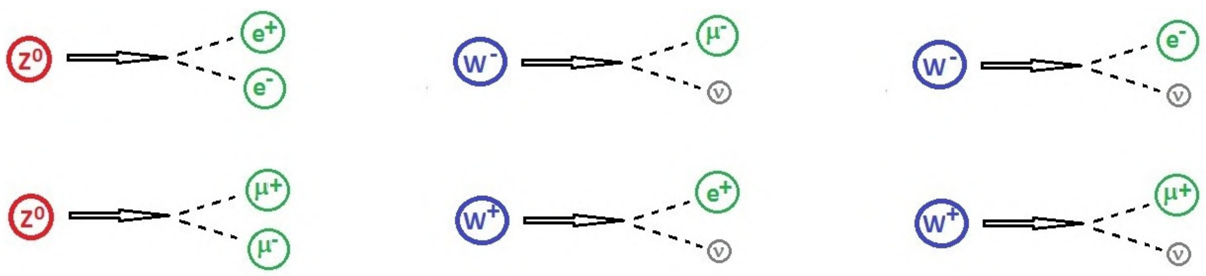

Figure 8. Decays of W and Z bosons.

photons (figure 8). But in these CMS, the following actions are very rare. When W+ or W- is produced in a proton collision inside the CMS, W quickly decays. The two leptons formed as a result of the collision (an electron or a muon and a neutrino) leave the decay point and go beyond the beamline, falling into the CMS detector. Electrons and muons appear as tracks in the inner sensor. Particles are deflected in a strong magnetic field in the CMS: clockwise for positively charged, and counterclockwise for negatively charged (when viewed from the x-y projection on the event display). Neutrinos do not turn out to be detectors, but the lack of momentum (usually attributed to neutrinos) in the system is depicted as a yellow arrow.

Students must determine where the decay of Z into muons is most likely depicted? Z to electrons? Where is event W depicted? How to distinguish a candidate for W from a candidate for Z, which may have missing energy? (figure 10). There are several options for the decay of the Higgs boson. We'll look at two. 1) Higgs decay into two Z-bosons. Z-particles decay into leptons, as above, so we get four tracks of leptons: two pairs of muons ($2\mu - \mu +$), two pairs of

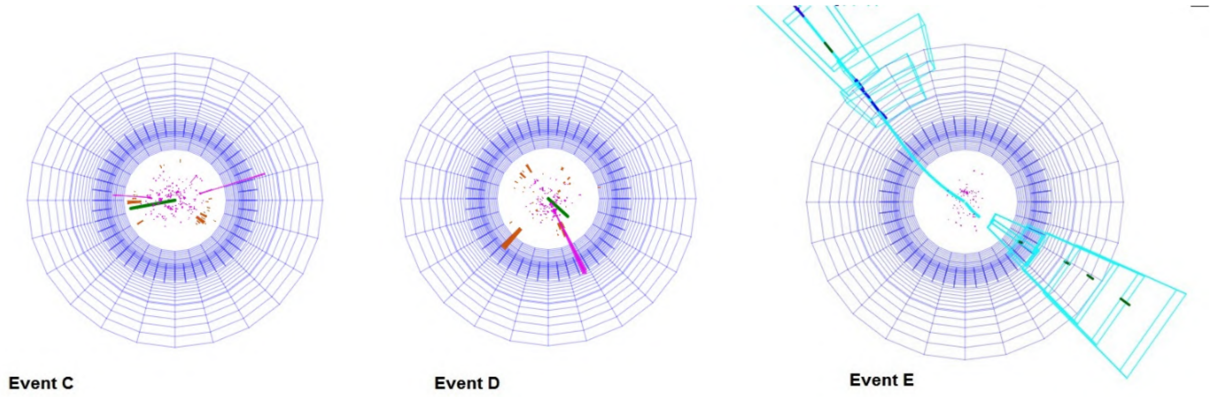

Figure 9. Decays of W and Z bosons.

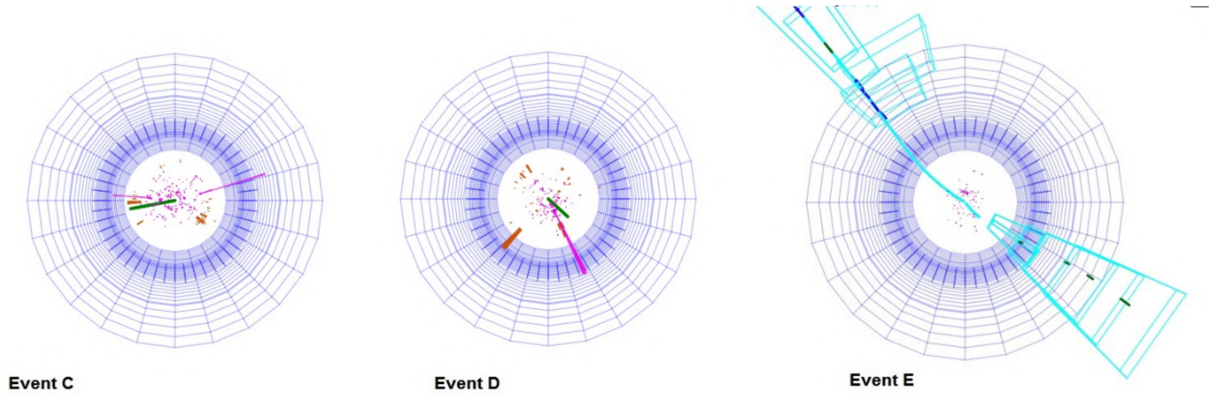

Figure 10. Candidate events for Z-bozon.

electrons ($2e^-e^+$), or one pair of muons and one pair of electrons ($\mu^-\mu^+e^-e^+$); 2) Higgs decay into two photons. Photons have no charge, so they are visible in the tracker. Instead, they leave traces (energy) in an electromagnetic calorimeter (ECAL).

Both events in figure 11 are Higgs boson candidates. One of the events shows 2 photons (2 green bars of energy from the electromagnetic calorimeter (ECal) with no corresponding tracks). The other shows the possible decay of Higgs into two Z bosons (in this case, each Z rapidly decays into two electrons). We ask students: what do you think, what is what?

As with muons, students study the event screen, interpret the results, and record them on a spreadsheet to document their observations.

At the stage of ascertaining experience, there was a study of methodological approaches to practical work in elementary particle physics. In particular, the work of students in studying the methods of experimental particle physics was studied.

At the research stage, a starting experiment, training, and control were carried out. In the process of experimental verification of the results of the study, the following methods were used: 1) observation; 2) testing; 3) teaching using experimental methods and materials. The processing of research data was carried out using methods of mathematical statistics. The effectiveness of the developed approach was evaluated based on the calculation of the coefficient of efficiency of

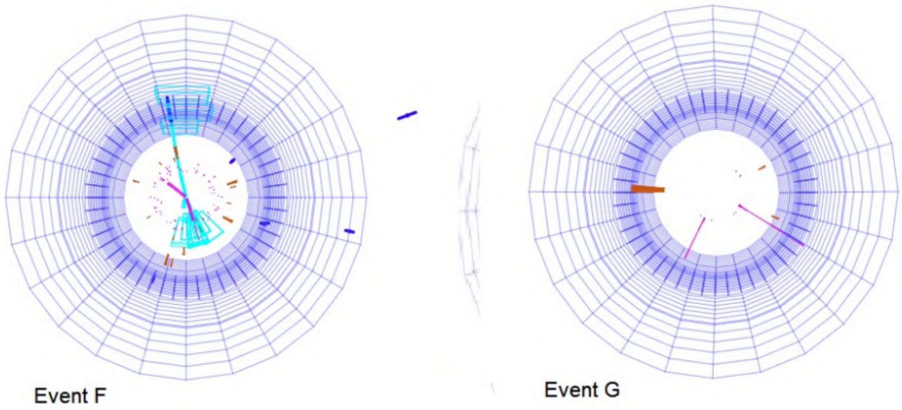

Figure 11. Candidate events for Higgs boson.

mastering physical knowledge, determined by the formula:

$$\gamma = \frac{K_e}{K_k}, \tag{1}$$

where γ is the coefficient of efficiency of mastering knowledge in elementary particle physics; K_e – is the coefficient of assimilation of physical knowledge for the experimental group; K_k is the coefficient of assimilation of physical knowledge for the control group.

The main goal of the formative stage was to test the effectiveness of the proposed developments for the workshop on elementary particle physics. At this stage, the influence of the developed methodology on increasing the level of the efficiency coefficient of mastering physical knowledge was determined. Formative experiment, in which 5 students of the 36F group of the Faculty of Natural Science and Physics and Mathematics Education (control group) and 5 students of the same 36F group (experimental group) participated.

By the structure of student learning outcomes, the non-parametric Mann-Whitney U-test was used to assess the difference between two small samples in terms of the level of the attribute. The Mann-Whitney U-test is a non-parametric alternative to the independent-sample t-test. Its advantage is that we abandon the assumption that the distribution is normal and the variances are uniform. Data needs to be measured at least on an ordinal scale (ranked). The Mann–Whitney U-test is used to compare 2 samples with a size of n_1 or $n_2 < 11$, i.e. the sample size constraint is met.

Each sample must contain at least three observations; if there were two observations in one sample, then in the second of them there should be at least five. Each sample should contain no more than 60 observations, but even with 20 or more observations, ranking is rather laborious. Data should be presented on at least an ordinal scale.

The empirical value U is calculated using the formula

$$U_{emp} = n_1 n_2 + \frac{n_1(n_1+1)}{2} - S_1, \tag{2}$$

where is the sample size 1 and 2, respectively; S_1 is the sum of the ranks of sample 1.

Using the Mann-Whitney U-test table of critical values, we determine the critical values $U_{0.01}$ and $U_{0.05}$ for given n_1 and n_2. If $U_{emp} \leqslant U_{0.01}$, hypothesis H0 should be rejected; if $U_{emp} > U_{0.05}$, it should be accepted. If $U_{0.01} < U_{emp} \leqslant U_{0.05}$, the H0 hypothesis is rejected at a significance level of 0.05 (or 5%), although in practice this significance level for the Mann-Whitney U-test is considered unacceptable. The assimilation coefficient was measured on a 100-point scale by the criteria for evaluating the curriculum of the discipline "General Physics: elementary particle physics".

Table 1. Coefficient of efficiency of assimilation of physical knowledge.

	Control group			Experimental group		
№	Student code	Trait level	Rank	Student code	Trait level	Rank
1	Y4	35	1	Q8	70	7
2	P9	41	2	G23	56	4
3	S6	42	3	S11	76	9.5
4	W8	65	5	T1	76	9.5
5	H4	69	6	I5	71	8
	Sum of ranks		17	Sum of ranks		38
	U emperical	2				

From table 1 it can be seen that there is a larger rank amount in the experimental selection, which is considered by selection 1, and a smaller amount – in selection 2.

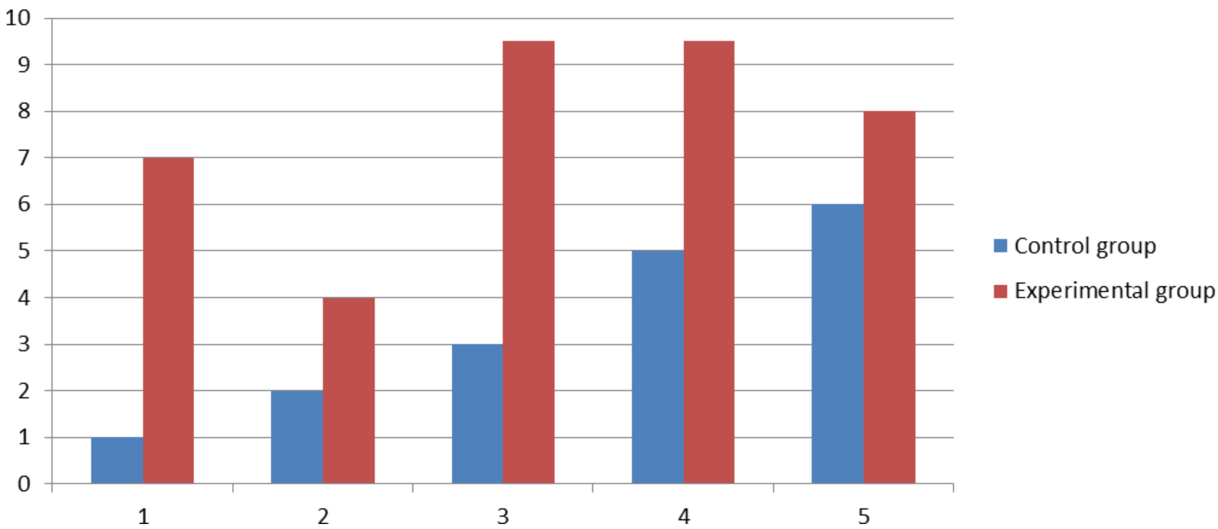

Figure 12. Ranks of students in the control and experimental groups.

We formulate hypotheses. H0: students of selection 2 (control group) do not pass to students of selection 2 (experimental group) for the coefficient of efficiency in acquiring physical knowledge. H1: the students of the control group are given to the students of the experimental group for the coefficient of efficiency in acquiring physical knowledge.

According to the table of critical values of the Mann-Whitney criterion, the critical values $U_{0.01}$ and $U_{0.05}$ for the given $n_1 = 5$ and $n_2 = 5$ are equal to $U_{0.01} = 1$ and $U_{0.05} = 4$. Since $U_{emp} < U_{0.05}$, hypothesis H0 should be rejected, and accept hypothesis H1, i.e. students of the control group are inferior to students of the experimental group in terms of the coefficient of efficiency of assimilation of physical knowledge of elementary particle physics.

4. Conclusions

The article considers new approaches to the use of open experimental CERN data in the process of studying the physics of elementary particles; developed instructions to do with site services, tasks for practical work, and methodical recommendations. The pedagogical expediency of the effective impact of the developed methodological support on improving the quality of knowledge acquisition, increasing learning motivation, and developing students' cognitive interest has been proven.

Our research showed that there are opportunities to study the operation of the most technological device in the world – the Large Hadron Collider due to the opening of access to a huge array of data obtained at the Large Hadron Collider and the development of information and communication technologies.

The exploratory and experimental verification of the research results proved the expediency of the practical implementation of the developed methodology for the use of CERN services and data in the process of studying the physics of elementary particles. Further research is expected to be conducted in the direction of studying how to work with data that is presented in the raw form in which it is available to CERN researchers.

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References

[1] Solovev V N 1984 *physica status solidi (a)* **83** 553–559 ISSN 00318965 URL https://doi.org/10.1002/pssa.2210830216
[2] Pokutnyi S I and Efremov N A 1991 *physica status solidi (b)* **165** 109–118 ISSN 03701972 URL https://doi.org/10.1002/pssb.2221650108
[3] Pokutnyi S I and Efremov N A 1992 *physica status solidi (b)* **172** 573–582 ISSN 03701972 URL https://doi.org/10.1002/pssb.2221720208
[4] CERN 2023 Open Data Portal URL http://opendata.cern.ch
[5] CERN 2023 The cms detector | CMS Experiment URL https://cms.cern/
[6] Lassila-Perini, Kati, Lange, Clemens, Carrera Jarrin, Edgar and Bellis, Matthew 2021 *EPJ Web Conf.* **251** 01004 URL https://doi.org/10.1051/epjconf/202125101004
[7] Wessels B, Finn R L, Wadhwa K, Sveinsdottir T, Bigagli L, Nativi S and Noorman M 2017 Front Matter *Open Data and the Knowledge Society* (Amsterdam University Press) pp 1–4 ISBN 9789462980181 URL https://doi.org/10.5117/9789462980181
[8] Wenninger H 2000 Technology Transfer and Education in Particle Physics at CERN URL http://wenku.baidu.com/view/ccd7683131126edb6f1a10e7.html
[9] Ojasalo J and Kaartti V 2019 Intensive Multidisciplinary Learning Concept in Higher Education: Case CERN Bootcamp *AICBMM-AICSSE 2019 December (Cambridge) Conference Proceedings, Academic International Conference on Social Sciences and Education* (UK: Cambridge) pp 20–29 URL https://www.theseus.fi/bitstream/handle/10024/333178/Ojasalo_Kaartti.pdf
[10] Nachman B 2022 *Computing and Software for Big Science* **6** URL https://doi.org/10.1007/s41781-022-00090-6
[11] Andrews M, Burkle B, Chaudhari S, Di Croce D, Gleyzer S, Heintz U, Narain M, Paulini M and Usai E 2021 *EPJ Web Conf.* **251** 03057 URL https://doi.org/10.1051/epjconf/202125103057
[12] Wiener G J, Woithe J, Brown A and Jende K 2016 *Physics Education* **51** 035001 URL https://doi.org/10.1088/0031-9120/51/3/035001
[13] Benelli G, Chen T Y, Duarte J, Feickert M, Graham M, Gray L, Hackett D, Harris P, Hsu S C, Kasieczka G, Khoda E E, Komm M, Liu M, Neubauer M S, Norberg S, Perloff A, Rieger M, Savard C, Terao K,

Thais S, Roy A, Vlimant J R and Chachamis G 2022 Data Science and Machine Learning in Education URL https://doi.org/10.48550/ARXIV.2207.09060

[14] Parker B, Thomas L, Rushton E and Hatfield P 2019 *Radiation Measurements* **127** 106090 ISSN 1350-4487 URL https://doi.org/10.1016/j.radmeas.2019.03.008

[15] Whyntie T, Cook J, Coupe A, Fickling R L, Parker B and Shearer N 2016 *Nuclear and Particle Physics Proceedings* **273-275** 1265–1270 ISSN 2405-6014 37th International Conference on High Energy Physics (ICHEP) URL https://doi.org/10.1016/j.nuclphysbps.2015.09.202

[16] Hatfield P, Furnell W, Shenoy A, Fox E, Parker R and Thomas L 2018 *Journal of Instrumentation* **13**(10) C10004 URL https://doi.org/10.1088/1748-0221/13/10/C10004

[17] Johansson K E 2001 *International Journal of Modern Physics C* **12** 443–449 URL https://doi.org/10.1142/S0129183101002103

[18] Kourkoumelis C 2010 Learning with ATLAS@ CERN *Inspiring Science Learning. Proceedings of the "Learning with ATLAS@CERN" Workshops* (Greece: The University of Crete campus at Rethymno) pp 19–25 URL http://eprints.lincoln.ac.uk/id/eprint/24604/1/24604%20InspireScienceLearning_low.pdf

[19] Froehlich G and Bogner F 2010 Learning with ATLAS@ CERN: Quality Assurance & Validation *Inspiring Science Learning. Proceedings of the "Learning with ATLAS@CERN" Workshops* (Greece: The University of Crete campus at Rethymno) pp 25–33 URL http://eprints.lincoln.ac.uk/id/eprint/24604/1/24604%20InspireScienceLearning_low.pdf

[20] Long L 2011 *Physics Education* **46**(3) 270 URL https://doi.org/10.1088/0031-9120/46/3/003

[21] Velychko V, Fedorenko E, Kaidan N and Kaidan V 2021 *Educational Technology Quarterly* **2021** 662–672 URL https://doi.org/10.55056/etq.38

[22] Thulasidharan L 2018 J/ψ,Y and Z studies with CERN Open Data URL https://doi.org/10.13140/RG.2.2.20146.66245

[23] McCauley T 2013 Dimuon-filter that selects events from the Mu primary dataset from the CMS open data release URL https://github.com/tpmccauley/dimuon-filter

Journal of Physics: Conference Series

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Design and fabrication of an improvised Young’s Modulus Apparatus

To cite this article: J L Patero 2023 *J. Phys.: Conf. Ser.* **2611** 012009

Design and fabrication of an improvised Young's Modulus Apparatus

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Abstract. In elasticity of matter, the behaviour of elastic materials are described in terms of elongation, external force applied to elastic materials, stress, strain, and elastic moduli such as Young's modulus, Shear modulus, and Bulk modulus. Demonstration of this elastic modulus, particularly Young's modulus in the classroom is a usual problem because acquiring an apparatus for this purpose is expensive. In this paper, improvised Young's modulus apparatus is fabricated. The improvised Young's modulus apparatus is tested using pure copper wire, and two other metallic wires of stainless steel and galvanized iron wires: the copper wire of diameter 0.42 mm has a Young's modulus of 10.04×10^{10} N/m$^2 \pm 6.783$ N/m^2 which is 8.7% than the known Young's modulus of pure copper wire. On the other hand, the Young's modulus of GI wire of diameter 0.555 mm and stainless steel wire of diameter 0.42 mm are 17.92×10^{10} N/m^2 and 18.021×10^{10} N/m^2, respectively. The improvised apparatus is functional and can be used for classroom experiments and demonstration.

1. Introduction

Young's modulus is a fundamental concept in physics [1–3]. Teaching laboratory physics needs apparatus that allows students to perform actual experiments rather than reading. This could enhance student's curiosity and eventually improves their class performance. However, acquiring laboratory apparatus for this purpose remains a challenge around the globe in the basic education level and even in the higher education specially to countries like Philippines. It has a high initial cost and are very expensive like the ones distributed eg. by Fisher Scientific and PASCO Scientific. In the Philippines, it takes months and even years to acquire such apparatus due to the state procurement procedure that we have especially since such instruments can be purchased from outside of the country.

To help aid the challenge of unavailable and expensive laboratory apparatus, particularly in elasticity of matter, fabrication of such apparatus was conducted. This paper presents the design and fabrication of an inexpensive improvised apparatus used to determine Young's modulus of selected metallic wires.

2. Methodology

2.1. Materials and devices used in the fabrication of the apparatus

One (1) 32 cm × 10 cm long flat board, improvised spring balance, micrometer caliper, metal screw, machine bolt, plain/flat washer, acrylic plastic, lighter (with LED, battery), wood screw, rubber footing, wing nut, GI wire, stainless wire, copper wire, sandpaper, and paint were the materials used in this project. Drill press, air compressor, hacksaw, steel tape, hammer, electric plainer, drill bit, cross-cut saw, bench vise, electrical sander, and screw driver were the devices used in this project.

2.2. Salient features of the apparatus
Different apparatus for similar purpose may differ from design. This paper ensures that the fabricated Young's modulus apparatus is functional in comparison with those existing in the market. The following are the salient features of this apparatus.

- Easy Storage – The improvised apparatus can be place anywhere in a secure physics stockroom.
- Accurate Data – The data accuracy for all measurements is ± 0.05 mm.
- Colour – For vivid demonstration.
- Easy to Use – Ensures consistency with quality procedures.
- Inexpensive – Made of locally available materials.
- Easy Set-up – The details are in the procedure provided.
- Low Friction – Means lab results closely match the theory.
- Rugged, Lightweight Construction – Have extruded wood bodies with high-impact, composite acrylic plastic.
- Durable – The base is a tough wood extrusion.
- Easy Measurement – A measuring device calibrated in millimetre is permanently mounted on the base.
- Versatile – Portable and easy to dismantle. Compact design requires minimal bench space and fits on lab bench or counter top.

2.3. Specifications
- Dimension: 132 cm x 10 cm
- Power Supply: 3.6 V

2.4. Components of the apparatus
The sensor assembly shown in figure 1(b) is consist of sensor contact that serves as an extension to the pulling arm of the spring balance, contact/sensor indicator that lights on if the sensor contact touches on the timble of the micrometre and a micrometre calliper where you can read directly the elongation.

The tensioner assembly shown in Figure 1(c) is consist of improvised spring balance that provides load to the Young's modulus apparatus and spring balance holder, that can be adjust according to the desired load.

2.5. Construction and fabrication procedure
The micrometre caliper is fastened to an acrylic plastic with a thumbscrew. The acrylic plastic is then screwed and mounted into the base of the apparatus exactly 1.0m from the wire anchor, located at the left end of the base. The base is held by four rubber footings. In the micrometre caliper, sensor contact is placed connecting the spring balance and the specimen. The testwire is placed in the wire anchor by clamping it between two flat washers and is tightened with a wing nut.

The sensor contact is connected to the positive terminal of the sensor indicator through an electrical wire and the micrometre caliper is also connected to the negative terminal of the

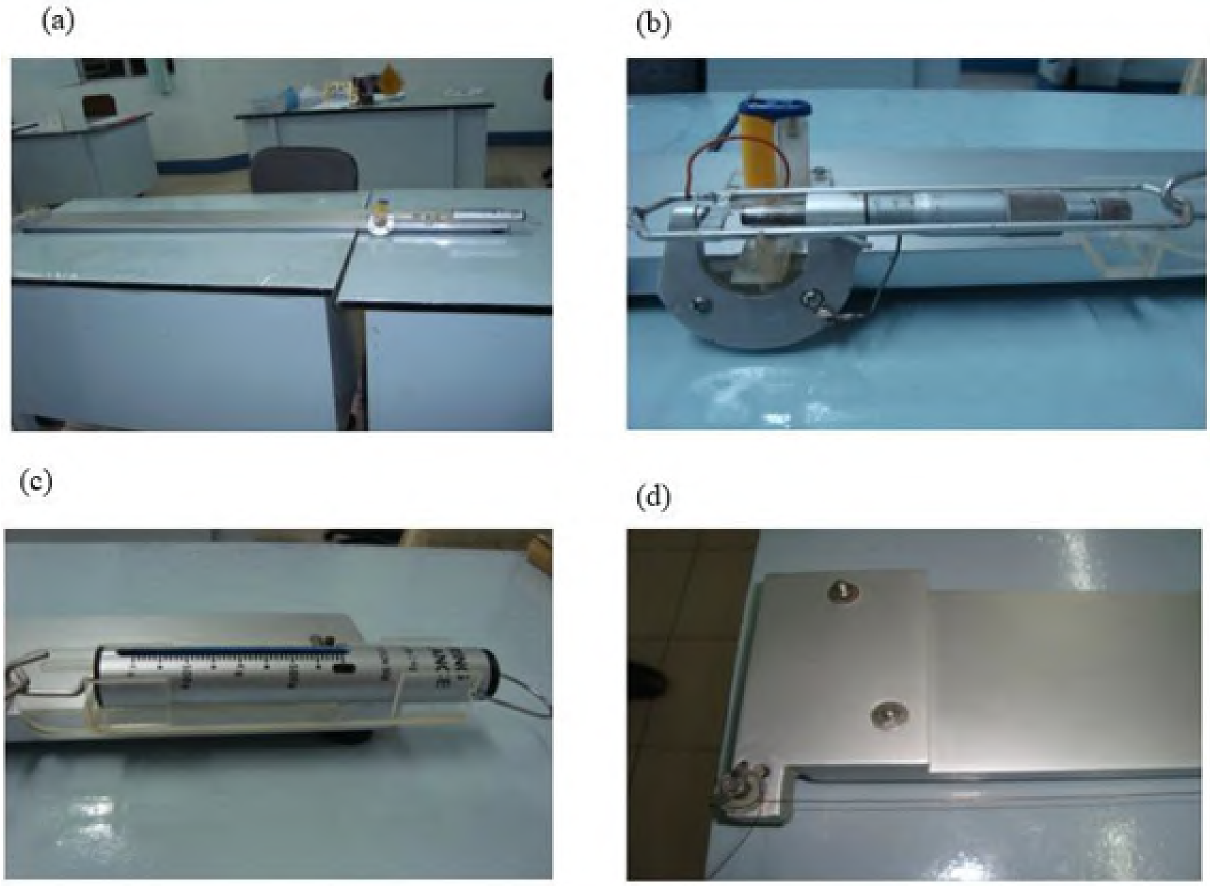

Figure 1. (a) The apparatus assembly. The (b) sensor and (c) tensioner assembly. (d) The test wire anchor.

sensor indicator through an electrical wire. If the sensor contact touches with the micrometre, the sensor indicator lights on. Thus, measurement of the elongation can now be obtained directly. The spring balance is attached to the sensor contact. The spring balance is placed in a spring balance holder which is also made from acrylic plastic. The holder is mounted into the base of the apparatus by tightening it with a wing nut. The holder is adjustable according to the desired load.

Note that the apparatus components are mounted on a hardwood base.

3. Results and discussion

After the apparatus has been constructed and fabricated, it was then tested. Readings were recorded and analyzed. It gives a quantitative relationship between elongation and the load provided by the spring balance. Although the specimen used in this paper was different from those existing models, but the behaviour of the specimen was the same.

Testing was done in a normal classroom condition, with no control over the humidity of the air. The apparatus is not temperature – sensitive. The apparatus was operated manually for a less time. Since the measurements can be directly seen in the micrometer caliper. The elongations were measured in millimeter. The data accuracy for all the measurements is ±0.05 mm.

3.1. Determination of Young's modulus

To determine the Young's modulus of a wire, first, one end of the specimen was tied to the sensor contact and the other end on the wire anchor. The distance from the wire anchor to the sensor contact is exactly 1.0 m which is also equal to the original length, Lo of the wire. With the spring balance, desired load was given. The spring balance holder was adjusted. Definitely there was an increase in the length of the specimen. The increase in length can be read directly in the micrometre caliper. We make sure that the sensor/contact indicator lights on when we took the readings. This indicates that the tip of the timble of the micrometre caliper touches enough the sensor contact. Graphs below show the linearity of the relationship.

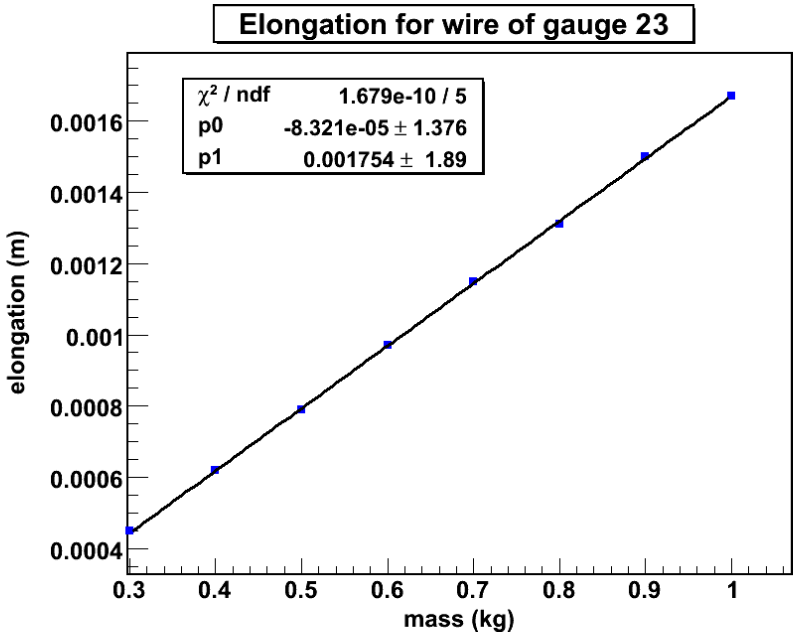

Figure 2. Elongation versus load for Copper wire with $d = 0.42$ mm.

Seventy (70) readings were performed and calculated the mean values for every specimen. The spread of the data was estimated by standard deviation.

As we see from the graphs above, there is a linear relationship between the load and the elongation in figure 2 and figure 4. This shows that the two quantities are directly proportional with each other. In figure 3, the graph is linear only up to a load of 800g with an elongation reaches to 0.70 mm. This part is elastic deformation, while from 800g to 1000g, there is an inelastic deformation.

3.2. Data analysis and sample computation

As to functional, we determine experimentally value of the Young's Modulus of the selected metallic wires for each of the specimen using the Principle of Least Squares and compare it with the standard value. The experimental value of the Young's modulus can be expressed as

$$\Delta L = \frac{12.5}{d^2}\frac{1}{Y}m, \tag{1}$$

where $\frac{12.5}{d^2}\frac{1}{Y}m$ is the slope of ΔL and m (load).

Thus, plotting ΔL versus m (load) in a graph will have the slope of

$$slope = \frac{12.5}{d^2}\frac{1}{Y} \tag{2}$$

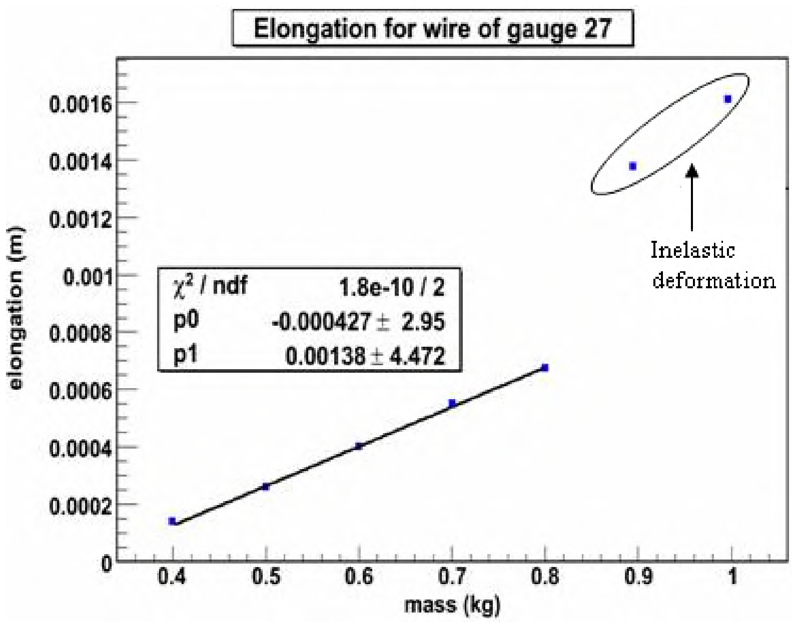

Figure 3. Elongation versus load for stainless wire with $d = 0.42$ mm.

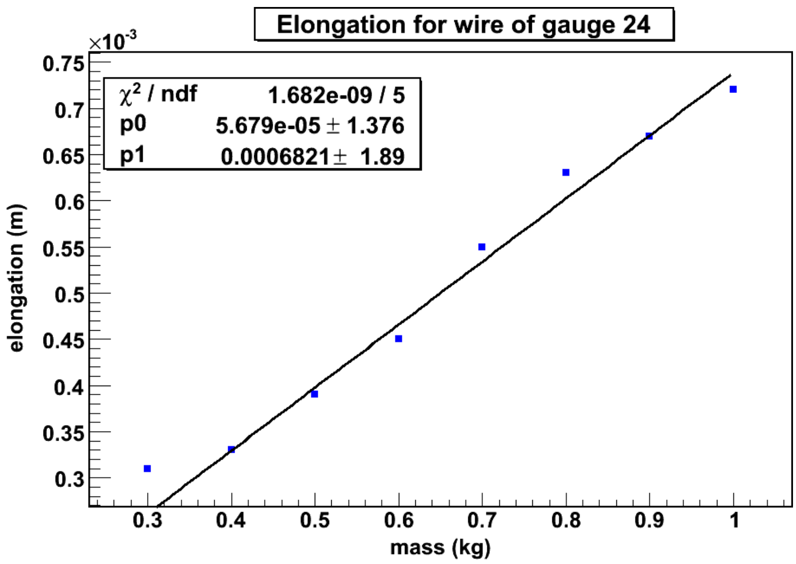

Figure 4. Elongation versus load for GI wire with $d = 0.555$ mm.

where the Young's modulus Y can be calculated as

$$Y = \frac{1}{\textbf{slope}} \frac{12.5}{d^2} \tag{3}$$

Here, the experimental value, we use the principle of least square. Thus,

$$Y = \frac{N \sum_{i=0}^{N} X_i Y_i - \sum_{i=1}^{N} X_i \sum_{i=1}^{N} Y_i}{N \sum_{i=1}^{N} X_i^2 - \left(\sum_{i=1}^{N} X_i \right)^2} \tag{4}$$

Using the above equation for the calculation of Young's modulus, the values are summarized in the table below.

Table 1. Experimental values of Young's Modulus of the three metallic wires.

Specimen / Metallic wires	Standard value (Pa)	Experimental value (Pa)	% Difference
Copper	11×10^{10}	10.040×10^{10}	8.73 %
Stainless Steel	20×10^{10} (steel)	18.021×10^{10}	9.895 %
Galvanized Iron	20×10^{10} (iron)	17.920×10^{10}	10.04 %

The experimental value of the Young's modulus is then compared to the standard value using percentage difference,

$$\text{Percentage Difference of Y} = \left| \frac{\text{Standard Value} - \text{Experimental Value}}{\text{Standard Value}} \right| \times 100 \qquad (5)$$

4. Conclusion

The fabricated simple and inexpensive Young's Modulus apparatus to determine experimentally the value of Young's modulus of copper, GI, and Stainless wires is simple and consists of relatively inexpensive off-the-shelf material. It also helps minimizes the computations that in many instances proves to be deterrent in the understanding of the concept [4]. It is versatile and easy to build. And it is excellent even for high school student. Experiment is simple and feasible; students were able to obtain all of the necessary data in an hour laboratory period. Best for classroom demonstration. This apparatus can be used also in introductory physics laboratory experiment.

Data proves that elongation is directly proportional to the load. Analytically proves that the proportionality of stress and strain is the Young's Modulus.

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References

[1] Young H and Freedman R 2019 *University Physics with Modern Physics* 15th ed (Pearson)
[2] Heuvelen A V 1986 *Physics: A General Introduction* 2nd ed (Little Brown and Company)
[3] Williams H 2022 *Physics Education* **57**(2) 025016 URL `https://wrap.warwick.ac.uk/161905/1/WRAP-measuring-Young%E2%80%99s-modulus-tensile-tester-Williams-2022.pdf`
[4] Niculescu A and Shumaker R 2003 *Physics Teacher* **41**(6) 364–367 URL `https://doi.org/10.1119/1.1607808`
[5] Greenslade Jr T B and Wilcox R 1993 *Physics Teacher* **31** 116–117

Journal of Physics: Conference Series

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Effects of Physics Alphabet Model on the mean achievement of student’s performance

To cite this article: E C Samson *et al* 2023 *J. Phys.: Conf. Ser.* **2611** 012010

Effects of Physics Alphabet Model on the mean achievement of student's performance

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Abstract. This study focuses on the development and assessment of an instructional tool known as the "Physics Alphabet Model" for Grade 10 students at Cantilan National High School. The research employs a descriptive design and post-test scores to measure the tool's effectiveness. Each group, consisting of 30 students, is divided into a control group and an experimental group, where the experimental group is exposed to the Physics Alphabet Model as an instructional aid. The teaching method employed for both groups is the Conventional Method, and the integration of the Physics Alphabet Model occurs within the respective classrooms of the participants. After collecting and analyzing the test scores from both groups, it becomes evident that there is a notable improvement in mean scores between the pre-test and post-test assessments for both methods. Statistical analysis, specifically the T-test, indicates a significant difference when comparing the means of pre-test and post-test scores for both the control and experimental groups. Furthermore, it is noteworthy that the post-test mean score and the associated significance value obtained when integrating the Physics Alphabet Model are significantly higher than those achieved through the Conventional Method alone. Consequently, this study concludes that the incorporation of the Physics Alphabet Model as an instructional resource in the study of physics leads to a substantial enhancement in students' mean achievement scores.

1. Introduction

In the realm of physics, the utilization of diverse models serves as a valuable tool for comprehending intricate physical scenarios [1]. This underscores the importance of employing instructional learning materials in the pursuit of mastering physics concepts. The absence of such learning materials when teaching physics is bound to yield subpar performance among students. Even a highly skilled and well-trained science teacher would face limitations in translating their expertise into tangible educational experiences if the educational environment lacks the necessary equipment and materials [2].

Worldwide, secondary-level physics education continues to encounter hurdles, despite some encouraging reports. Numerous research endeavors have indicated that students at this educational level exhibit limited interest in the field of science [3]. For instance, a study highlighted the generally lackluster performance of Nigerian students in ordinary-level physics [4]. Similarly, in the Philippines, the academic landscape is characterized by persistent challenges, notably the scarcity of instructional materials and technologies, as well as inadequate laboratory facilities [5].

To help address the above mentioned challenges, a physics alphabet was developed. As of now, various kinds of alphabet model existed. There are Greek, Latin, English and others in which it contains different kinds of format, style and design as well as the scope of its content. Meanwhile, the level of education is now upgrading, therefore there is new to be explored.

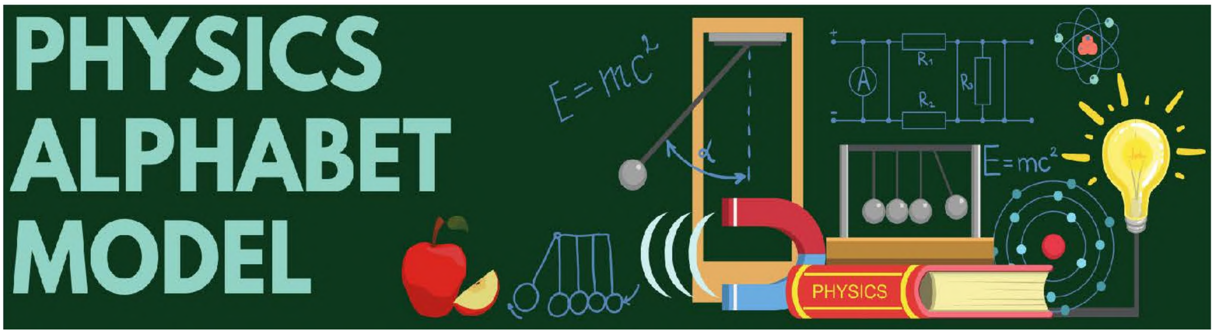
Therefore, the researchers adopted and modified alphabet model in Physics, and test it measuring the significance of having the model or not can affect the performance of students in studying Physics.

2. Methodology

2.1. The Physics Alphabet Model

This model is designed to provide an environment for interactive student engagement and enhance systems skills abilities. Particularly it provides less confusion and less difficult for the students to identify and familiarize the notation of the quantity to its symbol and units. Table 1 below is the Physics Alphabet Model (PAM).

Table 1: The Physics Alphabet Model.



Greek letters and their names	**Alphabet Letters Symbol**	**Physical Quantity / Coefficient / Constants**	**S.I. measurement Units**	**Unit Symbol**
A α **Alpha**	A	Area	Square meter	m^2
		Amplitude	Meter	m
		Magnetic vector potential	Tesla meter	$T \cdot m$
	a	Acceleration	Meter per second squared	ms^2
	α	Angular acceleration	Radian per second squared	rad/s^2
B β **Beta**	**B**	Magnetic field / Magnetic flux density	Tesla	T
	B	Bulk modulus	Pascal	Pa
	β	Coefficient of volume expansion	Inverse Kelvin	K^{-1}
	C	Capacitance	Farad	F
		Circumference	Meter	m
	c	Specific heat capacity	Joule per kilogram degree Celsius	J/(kg °C)
		Speed of light	Meter per second	m/s (3×10^8)
		Viscous damping coefficient	Kilogram per second	Kg/s

Continued on next page

Continued from table 1

Greek letters and their names	Alphabet Letters Symbol	Physical Quantity / Coefficient / Constants	S.I. measurement Units	Unit Symbol
Δ δ **Delta**	D	Density	Kilogram per cubic meter	kg/m^3
		Diameter	Meter	m
	d	Distance	Meter	m
		Moment arm	Meter	m
	d	Displacement	Meter	m
E ε **Epsilon**	**E**	Electric field	Newton per Coulomb or Volt per meter	N/C or V/m
	E	Energy	Joule or Newton/meter	J or N/m
		Light Intensity or Illumination	Lux	cd/m^2
		Young's Elastic Modulus	Pascal (Newton per square meter)	Pa (N/m^2)
	e	Electron charge	Coulomb	C
	F	Force	Newton	N
		Faraday constant	Coulombs per mole	$C{\cdot}mol^{-1}$
	f	Focal length	Meter	m
		Frequency	Hertz	Hz
		Friction force	Newton	N
Γ γ **Gamma**	G	Universal gravitational constant	Newton-meter squared per kilogram square	$N{\cdot}m^2/kg^2$
		Shear modulus	Newton per square meter or Pascal	N/m^2 (Pa)
	g	Acceleration due to gravity	Meters per second squared	m/s^2
	γ	Surface tension	Newton per meter	N/m
		Shear strain	1, or radian	rad
		Heat capacity ratio	1	
H η **Eta**	H	Radiation dose	Sievert	Sv
		Magnetic field strength / Magnetic field intensity	Ampere per meter	A/m
		Enthalpy	Joule per mole	J/mol
	h	Height, depth	Meter	m
		Planck constant	Joule second	J·s or $kg{\cdot}m^2/s$
I ι **Iota**	**I**	Moment of inertia	Kilogram meter squared	$Kg{\cdot}m^2$
		Sound intensity	Watt per square meter	W/m^2
		Electric current	Ampere	A
		Luminous intensity	Candela	Cd
	I	Light intensity	Watt per square meter	W/m^2
	J	Current density	Ampere per square meter	A/m^2
		Impulse	Newton seconds	N·s
K κ **Kappa**	K	Modulus of compression	Pascal	Pa
		Heat flow rate	Watt	W
		Kinetic energy	Joule	J

Continued on next page

Continued from table 1

Greek letters and their names	**Alphabet Letters Symbol**	**Physical Quantity / Coefficient / Constants**	**S.I. measurement Units**	**Unit Symbol**
	k	Spring constant	Newton meter	N·m
		Wave vector	Radians per meter	m^{-1}
		Boltzmann constant	Joule per Kelvin	J/K
		Stiffness	Newtons per meter	N/m
Λ λ **Lambda**	**L**	Angular momentum	Kilogram-meter squared per second	$kg{\cdot}m^2/s$
		Length	Meter	m
	L_f	Latent heat of fusion	Joule per kilogram	J/kg
	l	Inductance	Henry	H
		Sound level	Decibel	dB
	λ	Wavelength	Meter	m
		Linear charge density	Coulomb per meter	C/m
M μ **Mu**	**M**	Magnetization	Amperes per meter	A/m
		Moment of a force	Newton meter	N·m
	m	Mass	Kilogram	Kg
	μ	Magnetic moment	Newton meter per Tesla	N·m/T
		Viscosity	Kilogram per meter-second	Kg/(m·s)
		Magnetic Permeability	Henry per meter	H/m
N ν **Nu**	N	Number of particles		
		Number of turns		
		Number of turns per unit length, turns	inverse meter	m^{-1}
	n	Principal quantum number		
		Index of refraction		
O o Omicron	**O** **o**	NOT used for anything – it would too easily be confused with number zero		
Π π **Pi**	P	Power	Watt	W
		Power of a lens	Diopter	D
	p	Momentum	Kilogram-meter per second	kg·m/s
	p	Pressure	Pascal	Pa
	π	Pi		3.14159
	Q	Heat	Joule	J or $kg{\cdot}m^2/s^2$
	q	Electric charge	Coulomb	C
P ρ Rho	R	Electrical resistance	Ohm	Ω
	r	Internal electrical resistance	Ohm	Ω
	ρ	Mass density	Kilogram per cubic meter	kg/m^3
Σ **σ,ς** **Sigma**	S	Entropy	Joule per Kelvin	J/K
		Surface area	Square meter	m^2
	s	Displacement, distance, arch length	Meter	m
	σ	Electrical conductivity	Siemens per meter	S/m

Continued on next page

Continued from table 1

Greek letters and their names	Alphabet Letters Symbol	Physical Quantity / Coefficient / Constants	S.I. measurement Units	Unit Symbol
		Surface tension	Newton per meter	N/m
		Surface area charge density	Coulomb per square meter	C/m^2
T τ **Tau**	**T**	Torque	Newton meter	N·m
	T	Period	Seconds	s
		Temperature	Kelvin or Celsius	K or C
	t	Time	Seconds	s
Υ υ **Upsilon**	U	Potential energy	Joule	J
		Internal energy	Joule	J
	u	Relativistic mass	Kilogram	Kg
		Energy density	Joule per cubic meter	J/m^3
	V	Voltage or electric potential difference	Volt	V
		Volume	Cubic meter	m^3
		Shear force	Newton	N
	v	Velocity	Meter per second	m/s
	W	Weight	Newton	N
	W	Work	Newton meter (Joule)	J
	w	Width	Meter	m
Ξ ξ **Xi**	X	Electrical reactance	Ohm	Ω
	x	Position vector, Displacement	Meter	m
	Y	Electrical admittance	Siemens	S
Z ζ **Zeta**	Z	Electrical impedance	Ohm	Ω
		Atomic number	Atomic Mass Unit	amu

2.2. Research design

In this study, the researchers employed a quasi-experimental design. The quasi-experimental design entails the deliberate selection of groups for testing a variable, without employing random pre-selection procedures. Following this selection, the experiment proceeds similarly to conventional experiments, with a variable being compared across different groups. This research design was implemented among a specific group of Grade 10 students at Cantilan National High School. The primary objective of this study is to assess the notable disparity in mean academic achievements between students who had access to the Physics Alphabet Model while studying the subject of physics and those who did not.

2.3. Respondents of the study

A heterogenous group of students in Grade 10 under Basic Education Curriculum (BEC), a regular curriculum under the K-12 program, were the respondents of the study. They were chosen equally because to ensure diversity of ideas and opportunities among respondents and were identified as least in the performance of Physics subjects. Thirty (30) of the 52 students from Grade 10-Gold, and thirty (30) of 55 students in Grade 10 Silver were randomly sampled based on their grading in 2nd Quarter performance. Sections Gold and Silver are just name of the sections and are of same level of performance. The 30 students from the two sections were assigned and divided to as experimental group and control group.

2.4. Research instrument
In this study, a researcher-designed questionnaire was employed as the primary research tool. The questionnaire comprised 20 items, each offering respondents a choice of three options. The formulation of each item is based on the topic discussed before and after the test. The researcher-made instrument was validated by the experts. The instrument was personally administered by the researcher themselves, with the assistance of the respective adviser of the respondent students.

2.5. Research procedure
Prior to the selection and sampling of the respondents of the study, the researcher first modified a Physics Alphabet Model as a tool in administering the study. Where the information needed in making the model is gathered from varied Physics textbooks and related materials and internet sources. After making the finished instructional model and having an approval to conduct the study, the researchers selected two sections in the regular K-2 curriculum class. Those are Grade 10-(Silver); the control group, and the other one was the Grade 10 (Gold); experimental group, were in fact 30 of each section were randomly sampled based on their grades in the 2nd grading period. The next day, the pre-test was conducted in both groups utilizing the 20-item validated survey questionnaire. Then, after two days, the conduction of the prepared five lessons on various physics topics using the Physics Alphabet Model was demonstrated in the experimental group. To assist learning, the researcher employed the Conventional Method. Following the demonstration, the researchers conducted a post-test questionnaire to see if there was a difference in their scores before and after the model. Furthermore, similar to the experimental group, researchers conducted the post-test questionnaire to the control group section without including the model. And lastly, is the interpretation of the gathered data.

2.6. Data analysis
To analyze the data, we employed various statistical measures including the mean and standard deviation. Additionally, a t-test statistical analysis was utilized to compare scores between different groups and assess the hypotheses. The chosen significance level for the analysis was set at $p = 0.05$, serving as the criterion for either accepting or rejecting each of the hypotheses under investigation.

2.7. Research setting
The researchers conducted the survey at Cantilan National High School, located in Magasang, Cantilan, Surigao del Sur. The development of creating a Physics Alphabet model was done at Science Building, North Eastern Mindanao State University, Cantilan Campus.

2.8. Statistical tools
The researcher's uses Match Paired T-Test in an unequal variance where it was statistically analyzed through the use of SPSS software.

3. Results and discussion
To assess the performance of both the experimental and control groups, both groups were subjected to pretests and posttests. The assessment tool utilized was a 50-item multiple-choice Physics Test (PTP), and each student was allotted 30 minutes to complete the test. The

objective of this test was to evaluate the impact of the Physics Alphabet Model on the mean achievement scores of students at CNHS.

Table 2. Paired sample statistics result: mean achievements scores of students in Physics with and without Physics Alphabet Model.

Variable			Mean	N	Standard Deviation	Standard Error Mean
Pair 1	Experimental Group (with Model)	Pre-test	9.5333	30	1.56983	0.28661
		Post-test	15.4000	30	1.56690	0.28608
Pair 2	Control Group (without Model)	Pre-test	8.3000	30	1.62205	0.29614
		Post-test	10.9667	30	1.77110	0.32336
				$\sum$ N = 60		

The results presented in table 2 display the scores obtained by both the experimental and control groups. The experimental group exhibited a mean achievement score of 9.53 in the pretest, which increased to 15.40 in the posttest. This increase indicates a noticeable improvement in students' performance with the incorporation of the Physics Alphabet Model as an instructional aid.

This observation underscores the idea that traditional teaching methods may be less effective for today's tech-dependent students. While some educators still prefer a traditional approach, modern technological advances have enabled the creation of materials and tools that can alleviate the burden on teachers and enhance information assimilation, making the learning process more engaging.

As technology continues to advance, teaching methods and instructional materials must evolve to meet students' expectations for effective learning. This study aims to modify a new model that facilitates effective learning in Physics, and the significant difference in mean achievement scores among students supports its efficacy. The use of the Physics Alphabet Model (PAM) in the learning process proves to be an effective instructional aid for students at CNHS.

These findings align with Onasanya's research [3], which highlights the historical reliance on excessive verbal communication, often referred to as the "chalk-talk method", in the teaching-learning process.

As described by Onasanya et al [6], graphics encompass a variety of visual elements such as charts, posters, sketches, cartoons, graphs, and drawings. Graphics effectively convey information and concepts by combining illustrations, text, and images. The integration of graphics into teaching materials enhances clarity and precision in the content under study. These visual aids assist in visualizing complex concepts and their interrelationships, promoting a deeper understanding of the subject matter.

The table 3 reflects the result of the mean achievement scores of the students without the aid of Physics Alphabet Model with 8.30 mean score in pre-test and 10.96 in posttest. Thus, it signifies that there's a different of scores on pre-test and post-test survey. This means that even though the Physics Alphabet Model was not utilized, there is still an increase in the mean scores of the group from pretest to posttest, however, the results do not suffice the significant results on the posttest achieved by the experimental group.

As shown in table 3, Pair 1 indicates a noteworthy difference at the 0.05 significance level between the mean scores of the pretest and posttest within the experimental group, with a t-value of approximately 19.411 and degrees of freedom (df) equal to 29. This finding signifies that there is a significant disparity between the pretest and posttest mean scores when the

Table 3. Paired sample t-test result (significant at 0.05 C = 2.045).

Pairs		Mean	Standard Deviation	Standard Error	95% Confidence Interval of Difference		t-value	DF
Pair 1	Experimental (Posttest-Pretest)	5.8666	1.65536	0.30223	6.48479	5.24854	19.411	29
Pair 2	Control (Posttest-Pretest)	2.6666	1.82574	0.33333	3.43841	1.98492	8.000	29
Pair 3	Experimental-Control (Posttest Experimental) - (Posttest Control)	4.4000	2.45792	0.44875	3.48220	5.31780	9.805	29

Physics Alphabet Model is employed in conjunction with conventional teaching methods in the experimental group. It suggests that the integration of the Physics Alphabet Model has a substantial positive impact on students' performance in physics, as evidenced by a significant increase in their scores. Similarly, Pair 2 demonstrates a t-test value of 8.0 with df = 29 and $p > 0.05$, indicating that the pretest mean scores significantly differ from the posttest mean scores in the context of conventional teaching. Furthermore, table 3 also provides insights into Pair 3, underscoring the significant distinction in mean performance on the posttest between the experimental and control groups.

Table 4. Interpretation of data gathered.

Variable	Mean difference	t-value	Decision	Interpretation
Experimental	5.9	19.411	H_0 Rejected	Significant
Control	2.7	8.000	H_0 Rejected	Significant
Experimental – Control	4.4	9.805	H_0 Rejected	Significant

Table 4 showcases the data depicting the variations in average mean scores from pre-test to post-test for the Experimental Group, Control Group, and the Experimental-Control difference. Significantly, the observed p-value is 0.05, with a calculated critical value of C = 2.045. This outcome points to a substantial distinction among the three variables.

Given that the obtained t-values for all variables exceed the threshold of $p > 0.05$, it necessitates the rejection of the null hypothesis. Consequently, the researchers embrace the alternative hypothesis, asserting a notable divergence in student mean achievement scores in physics between the Experimental Group employing the Physics Alphabet Model and the Control Group without its utilization as an instructional aid.

A closer examination of the t-values reveals that the result from the Experimental Group demonstrates a significantly higher level of rejection of H_0 compared to the Control Group. Moreover, when comparing the posttest results between the two groups, a substantial difference is also evident. This signifies that the integration of the Physics Alphabet Model as an instructional material yields positive effects on the performance of students at Cantilan National High School, ultimately leading to an improvement in their mean achievement scores in physics.

4. Conclusion

Based on the comprehensive analysis of the study's results, the researchers have arrived at a compelling conclusion: the adapted Physics Alphabet Model serves as an effective instructional material, contributing to a noteworthy enhancement in students' mean achievement scores in the field of physics. The study unequivocally demonstrates a significant divergence in student performance (scores) when comparing the experimental group, which utilized the Physics Alphabet Model, with the control group that did not incorporate this model as an instructional aid. It is noteworthy that the experimental group's outcomes exhibit a significantly higher level of rejection of the null hypothesis (H_0) when contrasted with the control group's results. This underscores the substantial positive impact of the Physics Alphabet Model on students' academic achievements in the realm of physics.

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References

[1] Peierls R 1980 *Contemporary Physics* **21** 3–17 URL `https://doi.org/10.1080/00107518008210938`
[2] Adalikwu S A and Iorkpilgh I T 2013 *Global Journal of Educational Research* **12**(1) 39–45 URL `https://doi.org/10.4314/gjedr.v12i1.6`
[3] Onasanya S A and Omosewo E O 2011 *Singapore Journal of Scientific Research* **1**(1) 68–76 URL `https://scialert.net/abstract/?doi=sjsres.2011.68.76`
[4] Owolabi T 2004 *Educational Perspectives* **7** 15–20
[5] Orleans A V 2007 *The Australian Educational Researcher* **34** 33–54 ISSN 2210-5328 URL `https://doi.org/10.1007/BF03216849`
[6] Onasanya S A, Shehu R A, Iwokwagh N S and Soetan A 2010 *Information Technology Journal* **9**(1) 89–97 URL `https://doi.org/10.3923/itj.2010.89.97`

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Laboratory equipment for practice learning in the framework of educational course “Molecular Physics and Thermodynamics”

To cite this article: O I Pursky *et al* 2023 *J. Phys.: Conf. Ser.* **2611** 012011

Laboratory equipment for practice learning in the framework of educational course “Molecular Physics and Thermodynamics”

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Abstract. This article presents laboratory equipment for practice learning of physics specialties students in the framework of educational course “Molecular Physics and Thermodynamics”. The presented laboratory equipment allows measuring the temperature dependence of the thermal conductivity coefficient of molecular liquids under atmospheric pressure and saturated vapors pressure in the temperature range from 150K to 400K. A general scheme of the developed experimental setup for measuring the thermal conductivity of liquids by the steady-state method under isobaric condition has been described. The created laboratory setup uses general design solutions of the coaxial cylinder method, preserving its features and measurement precision in general. The measurements are carried out on coaxial-geometry cell under atmospheric pressure. A modified heat potentiometer method with one thermometer was used, which allowed us to minimize the error in the estimation of the thermal conductivity coefficient due to the uncontrollable heat flows and different calibration of thermometers. The total systematic error in the measurement of the molecular liquids thermal conductivity does not exceed 3%. The procedures for direct measurement and calculation of the thermal conductivity coefficient of molecular liquids using the developed laboratory equipment are described.

1. Introduction

In physics education, an extremely important factor that determines the learning quality is the process of forming students’ practical skills through experimental research [1–3]. At the performing laboratory work, students learn to use physical devices as means of experimental research, which together with theoretical learning provides a basis for full understanding of physical process or phenomenon [2, 4, 5].

The problem of developing the intellectual thinking of students cannot be associated only with the acquisition of mental actions by students, since the student’s ability to think theoretically about a certain research does not yet ensure the ability to perform the same actions in practice [6, 7]. An important stage in the development of intellectual education-scientifically abilities of students is not only the study of theory, but also the implementation of this theory in practical activities [1, 7]. Therefore, modern methods of teaching physics foresees the involvement of students in such types of educational activities that allow to use the acquired theoretical knowledge in practice, in particular, to perform laboratory work by students [2, 8, 9].

The modern course of "Molecular Physics and Thermodynamics" presents rather complex theories that require experimental verification for a better understanding by students, in particular, transfer processes and kinetic phenomena in liquids, phase transitions, isochoric, isobaric, adiabatic and other thermophysical processes [10–13].

In this work presented the developed laboratory equipment for practical training, in particular experimental research of the temperature dependence of heat transfer processes in molecular liquids under isobaric conditions in the temperature range from 150K to 400K and described the procedures for its use.

2. Review on measuring methods of thermal conductivity

Temperature dependences of thermal conductivity are investigated, as a rule, along isobars and isochores. At the same time, it should be noted that various experimental methods were used to measure thermal conductivity coefficients, in particular linear-flow steady state method and radial-flow steady state method.

The main difficulties that arise at the implementation of the linear-flow steady state method are [14]: ensuring the passage of the entire heat flow directly through the sample under study; avoidance of uncontrolled heat loss through electrical connections and the environment; avoidance of thermal radiation from the surface of the sample under study. Heat transfer through the environment and along electrical connections can be made negligible by using heat sinks and making measurements under vacuum conditions. Heat losses due to thermal radiation are minimized by installing radiation screens, which reproduce the temperature field of the sample under study. Installing radiation screens also allows for significantly increasing the upper temperature limit for measuring the thermal conductivity coefficient. The best way to avoid heat loss through thermal radiation is to heat the sample internally so that all the heat passes through the sample.

In the steady-state radial flow method [14], heat is supplied to the inside of the sample and spreads radially from the heater to the outer surface of the sample, so thermal radiation does not affect the value of the steady-state temperature on the surface. In this method, the main problems are the occurrence of axial heat flows and uncontrolled heat losses through electrical connections and from the side surfaces of the internal heater. The occurrence of axial temperature gradients can be avoided by using materials with high thermal conductivity in the design of the measuring cell. Losses of thermal energy through electrical connections are blocked by heat sinks. As a rule, it is impossible to completely avoid losses of controlled power supplied to the internal heater through its side surfaces. But with the help of the design of the measuring cell, these losses can be minimized to values that practically do not affect the measured values of the thermal conductivity.

In the method of sample electric heating [15], heat is released in the sample, which is a conductor, if an electric current is passed through it. Among the disadvantages of this method, the following can be highlighted: in the case of a longitudinal heat flow option, in the case of a thin wire through which current is passed, the central part of the wire heats more than its ends; additional dependence of the resistance of the sample on pressure and temperature, which introduces an error in the determination of the thermal conductivity coefficient; the impossibility of using this method for measuring the thermal conductivity coefficient of dielectric substances.

To measure thermal conductivity, comparative methods are also used, which can be used in both described stationary methods of measuring the thermal conductivity coefficient [14]. In the linear-flow steady state method, the temperature gradients in the investigated and reference samples are compared, provided that the same heat flows pass through these samples. In the radial heat flow method, the reference and investigated samples should be located concentrically. The process of measuring the thermal conductivity coefficient by comparative methods is very simplified if the reference and investigated samples have the same geometric dimensions. The main disadvantages of comparative methods, regardless of the experimental method of measuring thermal conductivity, are significant complications in the measuring cell design and limitations in the use of this method in the low temperatures area for measuring substances with low values of the thermal conductivity coefficient.

In addition to the steady state methods of thermal conductivity coefficient measuring indicated here, there are also non-stationary methods in which the arbitrary temperature distribution in the sample changes with time [16]. In general, non-stationary methods are quite difficult to apply and cannot be used for all experimental conditions. As a rule, non-stationary methods contain constructive solutions that limit their use to a certain substances class and limited temperature range. The general characteristics of non-stationary methods for thermal conductivity research are given in [17].

According to the analysis of the characteristics of various methods for measuring thermal conductivity given in the literature, stationary methods are simpler and more reliable, since they are based on direct measurements of thermal conductivity.

One general conclusion can be drawn from the considered experimental methods of measuring the thermal conductivity coefficient: none of the existing methods of measuring the thermal conductivity can ensure a hundred percent distribution of the controlled heat flow through the sample, only due to its thermal conductivity. There are always processes that affect the measured values of the thermal conductivity coefficient, thus introducing significant errors in its value. Therefore, when choosing one or another measurement method, it is necessary to take into account the specifics of the scientific task, taking account: the temperature range of the study, the pressure range, and the characteristics of the substances under investigation. To study the isobaric thermal conductivity of liquids, among the stationary experimental methods, the most successful constructive solution from the point of view of minimizing the influence of additional factors on the process of measuring the thermal conductivity coefficient is the radial-flow steady state method with coaxial geometry of measuring cell.

3. General scheme of setup for measuring the thermal conductivity of molecular liquids

The modern molecular theory of fluids is mainly qualitative in nature and does not have dependencies that provide reliable methods for calculating heat transfer coefficients [18–22]. This circumstance, to some extent, explains the emergence of empirical and semi-empirical equations for calculating the thermal conductivity coefficient. As a rule, the field of such equations application limited to a small temperature interval or a certain group of liquids. In most cases, they give such errors that the reliability of their use raises serious doubts. In addition, many dependencies require knowledge of additional quantities for which there are no reliable experimental data [23–26]. The vast majority of existing experimental methods for determining the coefficient of thermal conductivity are based on the regularities of the Fourier law solution [27–29]. The peculiarities of the thermal conductivity measuring method for liquids put specific requirements both on conducting of the experiment and on the measuring equipment itself.

For this purpose, laboratory equipment was created for measuring the isobaric thermal conductivity of liquids. The general design scheme of the installation is shown in figure 1. The created experimental technique uses general design solutions of the coaxial cylinder method [30–32], preserving its features and measurement precision in general. The installation allows measuring the coefficient of thermal conductivity of liquids under atmospheric pressure and saturated vapors pressure in the temperature range from 150 to 400K. Cooling to below room temperature is carried out thanks to the use of a removable cooling conductor (figure 1a). When placing the cooling conductor in the transport dewar, its lower part is in contact with liquid nitrogen.

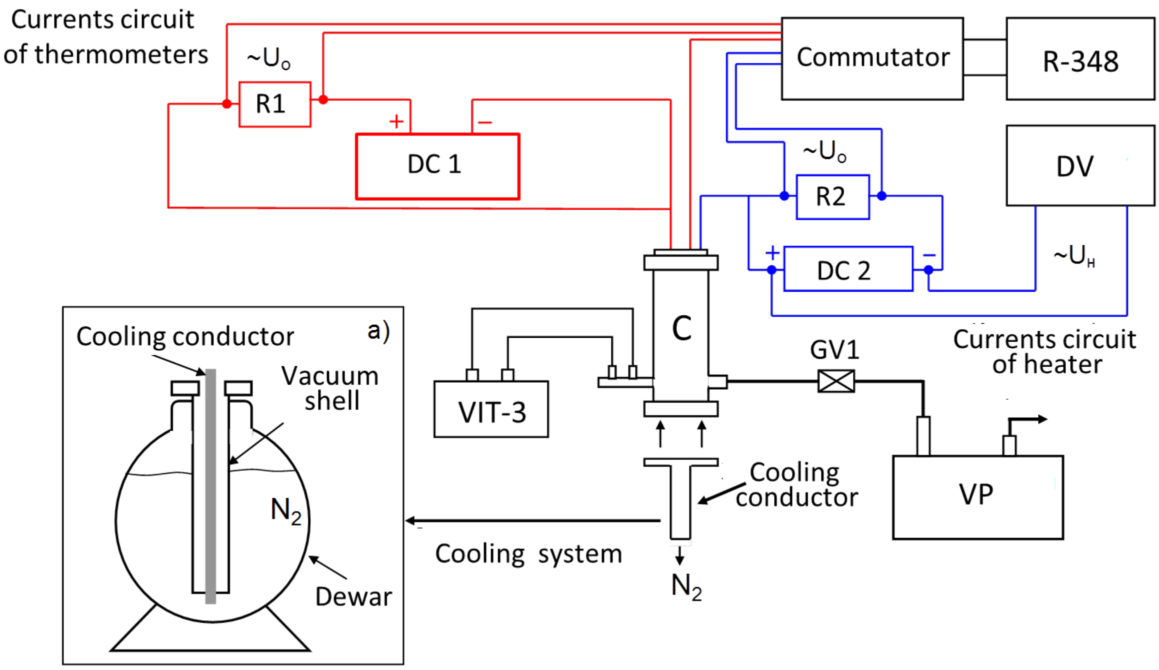

Figure 1. The general scheme of laboratory equipment for measuring the thermal conductivity of liquids by the steady-state method. a) Cryostat cooling system.

To create a constant heat flow that independent from the level of liquid nitrogen in the dewar, the rod of the cooling conductor was placed in a specially made vacuum shell, while the lower part of the cooling conductor rod went beyond the boundaries of the vacuum shell and was in constant contact with liquid nitrogen (figure 1a). The core of the cooling conductor is made of copper. A heater was placed in the upper part of the cooling conductor rod, which allows controlling the power of the heat flow through the cooling conductor. The cooling conductor is connected by a flange to cryostat C. The upper part of the copper cooling conductor rod was connected to the surface of the copper platform on which the measuring cell was placed (figure 2). Pumping out the internal volume of the cryostat and vacuum shell was carried out by rotary vane vacuum pump (VP) through channel with gate vacuum (GV1). The quality of the vacuum in the process of measuring the thermal conductivity coefficient was kept constant and monitored using thermocouple vacuum gage (VIT-3). The flange joints of the cryostat were sealed with gaskets made of vacuum-resistant rubber.

To obtain information about the temperature of the test sample, an electric current circuit of thermometers (figure 1) is used, which includes highly stabilized direct current source DC1 and two platinum resistance thermometers (figure 2). The exact values of the electric current in the thermometer circuit were determined by measuring the voltage drop U_0 on the exemplary resistance R1 (accuracy class 0.01).

The electric current circuit of the heater (figure 1) is used to supply and adjust the power of the inner cylinder heater of measuring cell (figure 2). A stabilized power supply DC2 is included in the circuit to ensure the supply of the necessary voltage (voltage fluctuations in the stabilized mode do not exceed ±0.001V). The electric current in the heater circuit was calculated by measuring the voltage drop U_H on the exemplary resistance R2. The measuring system is built according to the potentiometric scheme and consists of potentiometer R-348 (accuracy class 0.002) and comparator (accuracy class 0.005). With the help of potentiometer R-348, the voltage drop on platinum resistance thermometers (figure 2) and exemplary resistances R_0 was

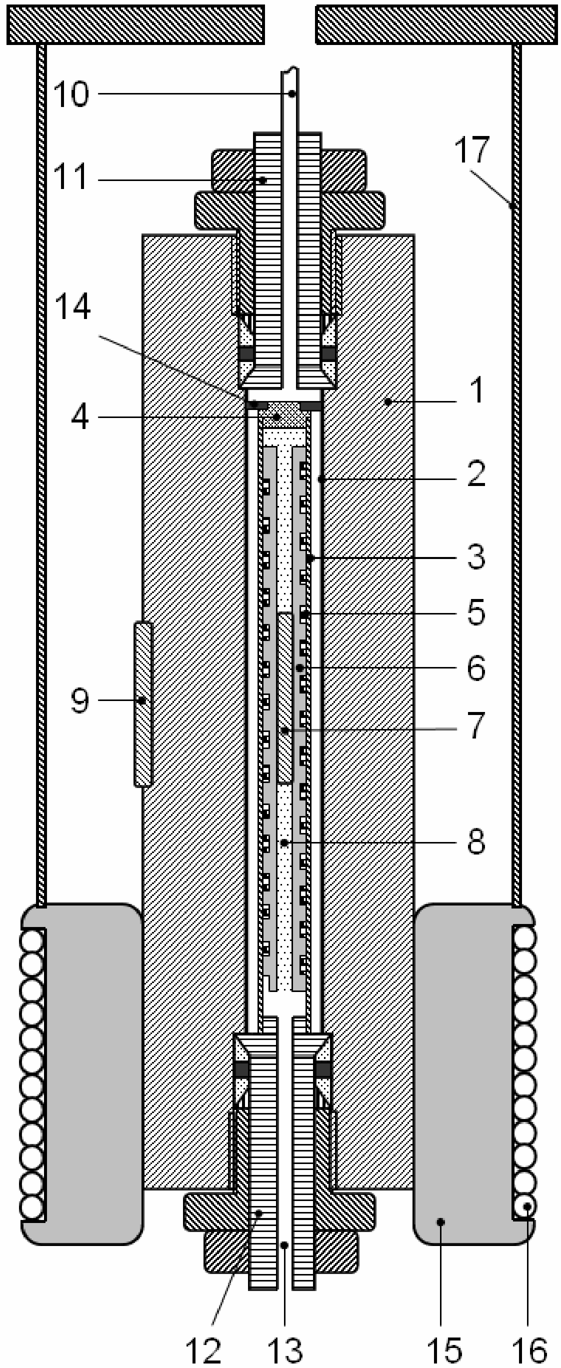

Figure 2. The schematic of the measuring cell: 1 – external copper cylinder; 2 – stainless steel tube pressed in copper cylinder; 3 – inner cylinder; 4 – inner cylinder plug; 5 – internal heater; 6 – internal heater copper base used to equalization of the axial heat flow; 7 – internal platinum thermometer (TR1); 8 – high-heat conducting powder; 9 – external platinum thermometer (TR2); 10 – feed channel of substance under pressure; 11, 12 – Bridgman seals; 13 — service duct; 14 – fluoroplastic centering ring; 15 – copper platform; 16 – copper platform heater; 17 – radiation screen.

determined. The high accuracy class of the R-348 potentiometer allowed measuring voltage drops with an accuracy of 10^{-8}V.

The commutator (figure 1) was used to switch pairs of potential conductors and speed up the process of measuring the thermal conductivity coefficient. Comparator DV is used in the installation for measuring the voltage applied to the inner cylinder heater to create controlled heat flow through the study liquid layer. The accuracy of the voltage measurement provided by comparator is no worse than 10^{-6}V. Its use made it possible to increase the accuracy of the thermal conductivity coefficient measurements, which, given the small values of the thermal conductivity of liquids, is a significant factor. All electrical conductors used in the installation to connect the cryostat with external devices are made of copper and shielded.

4. Measuring cell construction

The measuring cell construction is shown in figure 2. It consists of two coaxial-geometry cylinders between which the liquid under study is located. The measurement cell was produced from copper block with a length of 175 mm and an outer diameter of 46 mm. Along the axis of cylinder 1, a hole is drilled for a pressed-in thin-walled (0.5 mm) tube 2, made of stainless steel. Its inner diameter is 11 mm.

The liquid samples were between the outer 1 and the inner cylinder 3. Liquids have small thermal conductivity coefficients (two or three orders of lower than the thermal conductivity of metals). With such a construction of the measuring cell, the thermal resistance of the metal layer of the inner cylinder 3, which occurs between the liquid and the internal thermometer 7, and the boundary Kapitza thermal resistance on the outer 1 and inner 3 cylinders, in comparison with the thermal resistance of the liquid sample layer, can be ignored. The dimensions of the inner cylinder 3 were selected in accordance with the following requirements: a) prevention of the possible occurrence of convective heat exchange; b) fulfillment of the condition for the Rayleigh number $GrPr < 10^3$; c) the ratio of the length of the cylinder to its diameter is not less than 8; d) the thickness of the liquid sample layer should not exceed 0.8 mm; e) the possibility of placing a heater 5 and an internal thermometer 7 inside the inner cylinder 3. The inner cylinder 3 is stainless steel tube closed on one side by a plug 4 and soldered at the other end into the obturator of the Bridgman seals 12, with an outer diameter of 10 mm, a wall thickness of 1 mm, and a length of 100 mm. The inner cylinder heater 5 is wound bifilarly along the helical groove of the copper cylinder 6 pressed into the inner cylinder 3. The inner cylinder heater 5 is made of manganin wire with a resistance of 100 Ohm and a diameter of 0.18 mm. A platinum resistance thermometer 7 is placed inside the copper cylinder 6.

The free internal volume of the copper cylinder 6, that remaining after placing the thermometer 7, is filled with compacted heat-conducting powder 8. The external platinum thermometer 9 is placed on the surface of the external cylinder 1. The supply channel 10 for study liquid and the internal cylinder 3 are sealed with the help of Bridgman seals 11, 12. Bridgman seals are also used to maintain the pressure that occurs in study liquid samples with an increase in temperature in the case of measurements of the thermal conductivity of liquids under saturated vapors pressure. Through the channel 10, the gap between the coaxial cylinders 1 and 3 with a thickness of 0.5 mm is filled with the liquid under study. The electric current conductors of the inner cylinder 3 are led out through the opening 13 of the Bridgman seals 12. The same gap between the inner 3 and outer cylinders 3 along the entire length is ensured by the fluoroplastic centering ring 14. The measuring cell was placed inside the cryostat C (figure 1) on the copper platform 15. On the surface of copper platform the main heater 16 is placed. With the help of the heater 16, the required temperature of the measuring cell is set.

5. Measurement of thermal conductivity coefficient

Measurements of the liquids thermal conductivity coefficient are carried out as follows. First, the free volume between the outer 1 and inner cylinders 3 was filled by the liquid under study. During the cooling of the measuring cell, due to the decrease in the volume of liquid, a situation may arise when part of the gap between the coaxial cylinders will be unfilled with liquid. Therefore, the inlet channel 10 is also partially filled with the liquid under study. After the general assembly of the measuring cell and cryostat C and the connection to the cooling conductor, the internal volume of the cryostat and vacuum shell was pumped out with a forevacuum pump (VP). Cooling of the system was carried out by immersing the cooling conductor in a transport dewar with liquid nitrogen. Then the heater 16 was supplied with the voltage necessary to obtain the specified temperature of the measuring cell. Next, potentiometer R-348, comparator and the power supply DC1 of the electrical current circuit of thermometers were turned on. The system remained in this state until a stationary thermal regime was established, when the temperature of the thermometers stopped changing with time. As a rule, waiting to this mode took 3-5 hours. With the help of the R-348 potentiometer, the voltage drop was measured on platinum thermometers 7 and 9, and the temperature of the measuring cell T_1 was determined. This temperature was kept constant during the entire process of thermal conductivity measurement. Then the DC2 power source was turned on and the voltage required to create the desired heat flow through the liquid under study was applied to the heater of the inner cylinder 5. After a certain period of time (about 30 min.), a new stationary thermal regime was established (at the same temperature of the outer cylinder 1). Then the temperature of the internal thermometer T_2 was measured and the temperature gradient ΔT was determined. The heat Q released by the internal heater 5 when creating a temperature gradient is determined by the formula $Q = U_H/I_H$, where I_H is the current in the circuit of the internal heater, U_H is the voltage applied to the inner cylinder heater. The voltage value of the source DC2 is measured by the comparator DV. The current value in the internal heater electric circuit is calculated by the formula $I_H = U_0/R_0$. The voltage drop U_0 on the exemplary resistance R_0 is measured by potentiometer R-348. To avoid convective heat transfer and minimize heat transfer due to thermal radiation, all experiments should be carried out at ΔT <0.5K.

The use of one thermometer during temperature gradient measurements made it possible to avoid the influence of unaccounted heat flows and the difference in the calibration of thermometers on the value of the thermal conductivity coefficient. With this method of measuring thermal conductivity the maximum possible error in thermal conductivity values, associated with unaccounted power losses of the internal heater 5 due to thermal radiation, does not exceed 0.2% (with a temperature gradient of no more than 0.5 K). The reliability of the laboratory installation was determined from a series of preliminary experiments on measuring the thermal conductivity of exemplary liquids. Nonane, toluene, and ethyl alcohol (95.6%) were chosen as the exemplary liquids, which were studied in detail [24].

The main factors that depend on the correctness of the thermal conductivity coefficient measurement by the radial steady-state method [33–37] are the accuracy of the temperature gradient ΔT determining and stability of the measuring cell temperature during the measurement process. In this installation, platinum resistance thermometers with sensitivity to temperature changes ±0.0005K are used to measure the temperature and temperature gradient. The accuracy of maintaining a constant temperature of the measuring cell is no worse than ±0.005K/h. The measurement error of the liquids thermal conductivity coefficient does not exceed 3%. With the help of the created laboratory installation, it is also possible to measure the thermal conductivity coefficients in the temperature areas that correspond to pre-crystallization temperatures.

6. Experiment procedure

For experimental measurement of thermal conductivity, it is necessary:

1. Fill the measuring cell with the tested liquid.
2. Connect external devices to the measuring cell, close the thermostat.
3. Turn on the power source (DC2) of the potentiometer R-348.
4. Turn on the amplifier of the R-348 potentiometer.
5. Turn on the power source of the thermometer circuit (DC1).
6. Turn on the power source of the inner cylinder heater, set a voltage of 1.5-2V (at this voltage, the temperature gradient between the outer and inner cylinders does not exceed 0.5K, it is recommended to set a voltage equal to the value of the voltage applied to the inner cylinder heater during the calibration of the measuring cell).
7. Turn on the power sources of the copper platform heater and set the voltage required to obtain the required temperature of the measuring cell (in the case of measurements at room temperature, do not turn on the power sources).
8. Leave the system until the galvanometer arrow of the R-348 potentiometer stops on the divider with a value of 10^{-6}V (this means that a stationary (quasi-stationary) heat flow has been established in the system).
9. Adjust the R-348 potentiometer before taking measurements according to device passport.
10. With the help of the R-348 potentiometer, take the readings of the voltage drops on the internal resistance thermometer $U_T R1$, the external resistance thermometer $U_T R2$ (figure 2), the exemplary resistance of the current circuit of the thermometers $U_R 1$, the exemplary resistance of the current circuit of the internal heater $U_R 2$ (figure 2).
11. With the help of a digital voltmeter (DV), remove the readings of the external drop at the output of the power source (DC2) of the internal heater U_H (figure 1).
12. Enter the measured data in the table 1.
13. Using the commutator, adjust the R-348 potentiometer to measure the voltage drop on the internal resistance thermometer (reset the commutator terminals to the $U_R 1$ position).
14. Select the 10^{-6}V measurement mode.
15. Turn off the power supply of the internal heater DC2 and the voltmeter DV.
16. Wait for 15-30 minutes, until the galvanometer arrow of the R-348 potentiometer stops on the division with a value of 10^{-6}V.
17. With the help of potentiometer R-348, remove the readings of voltage drops on the internal resistance thermometer U_{RT1}, the external resistance thermometer U_{RT2}, the exemplary resistance of the current circuit of the thermometers U_{R1} - already without supplying power to the heater of the inner cylinder.
18. Enter the measured data in the table. 2.
19. Repeat steps 8-18 (it is recommended to measure it at least 3 times
20. To carry out measurements at other temperature, it is needed to increase the power supply of the copper platform heater voltage by 5-8 V (with such a voltage change, the returning the stationary thermal regime takes place in approximately 30-50 minutes).
21. Carry out points 8-20 in sequence.
22. After completing the measurements, turn off all devices.

7. Calculation of the thermal conductivity coefficient

The thermal conductivity coefficient calculated using the formula [14]:

$$\Lambda = Q\frac{\ln\left(r_2/r_1\right)}{2\pi L\Delta T}. \tag{1}$$

Table 1. The voltage drop values were obtained by measuring the coefficient of thermal conductivity of liquid nonane (as an example) with power supply to the inner cylinder heater.

No.	U_{TR1}, V	U_{TR2}, V	U_{R1}, V	U_H, V	U_{R2}, V
1	0.1066047	0.1063025	0.0186389	1.674	0.0068968
2	0.1066045	0.1063026	0.0186387	1.673	0.0068969
3	0.1066048	0.1063026	0.0186388	1.674	0.0068967

Table 2. The voltage drop values were obtained by measuring the coefficient of thermal conductivity of liquid nonane (as an example) without power supply to the inner cylinder heater.

No.	U_{TR1}, V	U_{TR2}, V	U_{R1}, V
1	0.1066095	0.1063653	0.0186365
2	0.1066094	0.1063654	0.0186363
3	0.1066096	0.1063652	0.0186364

where r_1 and r_2 are the inner radius of the outer cylinder 1 and the outer radius of the inner cylinder 3, Q is the amount of heat passing through the liquid sample, L is the length of the inner cylinder 3, ΔT is the temperature gradient (L=0.1m, r_1=0.01m, r_2=0.012m).

The heat Q released by the internal heater 5 when creating a temperature gradient is determined by the formula:

$$Q = U_H I_H. \tag{2}$$

where I_H is the current in the circuit of the internal heater. The value of the current I_H is calculated according to the formula:

$$I_H = U_{R2}/R2. \tag{3}$$

The procedure for determining the temperature gradient is as follows:

1. The resistances of the internal and external thermometers are calculated when the heater of the internal cylinder is turned on, according to the formulas:

$$R_{TR1} = U_{TR1}/(U_{R1}/R1). \tag{4}$$

$$R_{TR2} = U_{TR2}/(U_{R1}/R1). \tag{5}$$

2. Temperature dependencies of the platinum thermometers ($TR1$, $TR2$) resistance (R_{TR1}, R_{TR2}) are shown in figure 3 and in table 3.
3. The platinum thermometers resistance value, which corresponds to a specific temperature, is determined from the function describing the resistance temperature dependence (figure 3). Temperature values are obtained in degrees Kelvin. Direct calculation of temperature (T) is carried out using formulas:

$$T_{TR1(Q+)} = (RT1 + C_1)/A_1. \tag{6}$$

$$T_{TR2(Q+)} = (RT2 + C_2)/A_2. \tag{7}$$

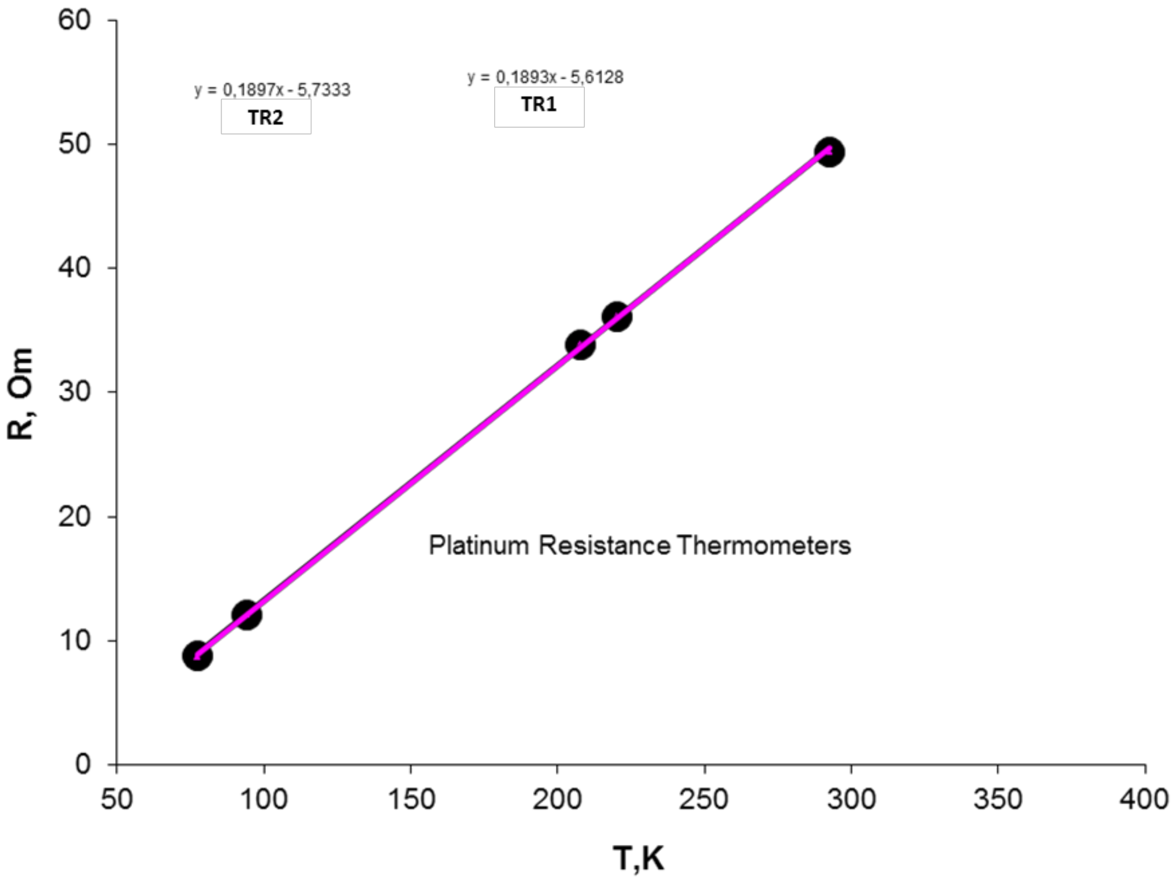

Figure 3. Temperature dependencies of the platinum thermometers resistance (R_{TR1}, R_{TR2}).

Table 3. The coefficients values for temperature dependence of the platinum thermometers resistance.

TR1		*TR2*	
A1	*C1*	*A2*	*C2*
0.1893	5.6128	0.1897	5.7333

4. Calculate using formulas (4-7) the temperature values of thermometers $T_{TR1(Q-)}$, $T_{TR2(Q-)}$ without supplying power to the heater of the inner cylinder.
5. Find the difference in readings of internal and external thermometers when power is applied to the heater of the internal cylinder and without supplying power, according to the formulas:

$$\Delta T_{TR1} = T_{TR1(Q+)} - T_{TR1(Q-)}. \tag{8}$$

$$\Delta T_{TR2} = T_{TR2(Q+)} - T_{TR2(Q-)}. \tag{9}$$

6. The temperature gradient ΔT is determined by the formula:

$$\Delta T = \Delta T_{TR1} - \Delta T_{TR2}. \tag{10}$$

External thermometer *TR2* is used in the laboratory installation to control the temperature stability of the measuring cell and take into account the temperature drift that may occur during the experiment. After determining Q and ΔT, substitute their values together with the values of L, r_1, and r_2 in formula (1) and calculate the value of the thermal conductivity coefficient.

Developed laboratory equipment has certain features and advantages compared to prototypes [14–16, 38, 39]. Firstly, it is a wide range of temperatures for measuring thermal conductivity (150-400K), and secondly, it is compactness and economy in the use of the investigated substances and coolant (liquid nitrogen). The main feature of the design scheme is the cooling mechanism of the cryostat (K) by immersing its lower part in a transport dewar with liquid nitrogen. Such a cooling mechanism provides a significant saving of cryoliquid and allows obtaining a constant temperature of the cryostat external environment in a fairly simple way, which is an important factor in stationary methods of measuring thermal conductivity, in particular, in the procedure of stabilizing the measuring cell temperature.

8. Conclusion

Measuring the thermal conductivity of molecular liquids is associated with a number of difficulties, among which the following can be highlighted: ensuring the measurement process in the low temperatures range; ensuring free expansion of the liquid inside the measuring ampoule when its temperature increases; minimization of heat losses due to heat radiation and uncontrolled heat flows; ensuring the necessary accuracy of measurements. The laboratory equipment for measuring the isobaric thermal conductivity of molecular liquids described in the article allows positively solves the mentioned problems. The use at measurements the modified method of thermal potentiometer allows to avoid errors arising in the values of the thermal conductivity coefficient due to uncontrolled heat flows and different calibration of thermometers and to significantly increase the measurement accuracy.

When measuring the liquids thermal conductivity at constant pressure and under saturated vapors pressure, additional problems arise that are not typical for solid samples, in particular, heat transfer due to convection. The created equipment for measuring the thermal conductivity of liquids by the stationary method of radial heat flow allows, due to the specifics of the measuring technique and the construction features of the measuring cell of coaxial geometry, to avoid convective heat transfer.

The main feature of the design laboratory equipment for measuring the isobaric thermal conductivity of molecular liquids is the mechanism of cooling the cryostat by immersion in a transport dewar with liquid nitrogen. This cooling mechanism provides a significant saving of cryoliquid and allows obtaining a constant temperature of the external environment of the cryostat, which is an important factor in stationary methods of measuring thermal conductivity, in particular, in the procedure of stabilizing the temperature of the measuring cell. The presented laboratory equipment will be useful for forming practical skills of physics specialties students.

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References

[1] Mazur E 2020 *Principles & Practice of Physics* 2nd ed (Pearson Education Limited)
[2] McLoughlin E and van Kampen P (eds) 2019 *Concepts, Strategies and Models to Enhance Physics Teaching and Learning* (Cham: Springer) URL https://doi.org/10.1007/978-3-030-18137-6
[3] Martyniuk O O, Martyniuk O S, Pankevych S and Muzyka I 2021 *Educational Technology Quarterly* **2021**(3) 347–359 URL https://doi.org/10.55056/etq.39
[4] de Winter J and Hardman M (eds) 2020 *Teaching Secondary Physics* 3rd ed (London: Hodder Education Group)
[5] Kanivets O V, Kanivets I M and Gorda T M 2022 *Educational Technology Quarterly* **2022**(4) 347–365 URL https://doi.org/10.55056/etq.429
[6] Rogers B 2018 *The Big Ideas in Physics and How to Teach Them: Teaching Physics 11–18* (Oxfordshire: Routledge)
[7] Loyd D 2013 *Physics Laboratory Manual* 4th ed (Boston: Cengage Learning)
[8] Ayachit N H and Mittal P K 2020 *Engineering Physics: With Laboratory Manual* (New Delhi: Dreamtech Press)
[9] Velychko V, Fedorenko E, Kaidan N and Kaidan V 2021 *Educational Technology Quarterly* **2021**(4) 662–672 URL https://doi.org/10.55056/etq.38
[10] Sinha S K and Dey T K 2006 *Molecular Physics: Kinetic Theory and Thermodynamics* (Alpha Science International)
[11] Lifshitz E M and Pitaevskii L P 2012 *Physical Kinetics* (*Course of Theoretical Physics* vol 10) (Butterworth-Heinemann)
[12] Ginzburg V L, Levin L M and Rabinovich M S 2013 *Molecular Physics, Thermodynamics, Atomic and Nuclear Physics* (*Problems in Undergraduate Physics* vol IV) (Pergamon)
[13] Hirata F 2020 *Exploring Life Phenomena with Statistical Mechanics of Molecular Liquids* (Taylor & Francis Ltd.)
[14] Berman R 1980 *Thermal Conduction in Solids* (Oxford: Oxford University Press)
[15] Prado J I, Calviño U and Lugo L 2022 *Applied Sciences* **12**(1) 329 ISSN 2076-3417 URL https://doi.org/10.3390/app12010329
[16] White G K and Meeson P 2002 *Experimental techniques in low-temperature physics* 4th ed (*Monographs on the Physics and Chemistry of Materials* vol 59) (Oxford: Oxford University Press)
[17] Laubitz M J 1969 Measurement of the Thermal Conductivity of Solids at High Temperatures by Using Steady-State Linear and Quasi-Linear Heat Flow *Thermal Conductivity* vol 1 ed Tye R P (London: Academic Press) chap 3, pp 111–183
[18] Nishiyama K, Yamaguchi T, Takamuku T and Yoshida N (eds) 2021 *Molecular Basics of Liquids and Liquid-Based Materials* Physical Chemistry in Action (Singapore: Springer) URL https://doi.org/10.1007/978-981-16-5395-7
[19] Hansen J P and McDonald I R 2013 *Theory of Simple Liquids: With Applications to Soft Matter* 4th ed (Academic Press) URL https://doi.org/10.1016/C2010-0-66723-X
[20] Hirschfelder J O, Curtiss C F and Bird R B 1964 *The Molecular Theory of Gases and Liquids* (Hoboken: Wiley Interscience)
[21] Kleinstreuer C 2018 *Modern Fluid Dynamics* 2nd ed (Boca Raton: CRC Press)
[22] Patankar S V 2017 *Computation of Conduction and Duct Flow Heat Transfer* (Boca Raton: CRC Press) URL https://doi.org/10.1201/9781315139951
[23] Poling B E, Prausnitz J M and O'Connell J P 2000 *The Properties of Gases and Liquids* 5th ed (McGraw Hill) URL https://www.eng.uc.edu/~beaucag/Classes/ChEThermoBeaucage/Books/Bruce%20E.%20Poling,%20John%20M.%20Prausnitz,%20John%20P.%20O%27Connell%20-%20The%20properties%20of%20gases%20and%20liquids-McGraw-Hill%20Professional%20(2000).pdf
[24] Vargaftik N B, Filippov L P, Torzimanov A A and Totskii E E 1993 *Handbook of Thermal Conductivity of Liquids and Gases* (Boca Raton: CRC Press)
[25] Tsederberg N V (ed) 1965 *Thermal Conductivity of Gases and Liquids* (Cambridge: The MIT Press)
[26] Purskiĭ O I, Zholonko N N and Konstantinov V A 2000 *Low Temperature Physics* **26**(4) 278–281 ISSN 1063-777X URL https://doi.org/10.1063/1.593899
[27] Ingersoll L R and Zobel O J 2019 *An Introduction to the Mathematical Theory of Heat Conduction: With Engineering and Geological Applications* (Franklin Classics)
[28] Purskii O I and Zholonko N N 2004 *Physics of the Solid State* **46**(11) 2015–2020 ISSN 1090-6460 URL https://doi.org/10.1134/1.1825542
[29] Konstantinov V A, Revyakin V P, Sagan V V, Pursky O I and Sysoev V M 2011 *Journal of Experimental and Theoretical Physics* **112**(2) 220–225 ISSN 1090-6509 URL https://doi.org/10.1134/S1063776111010092
[30] Alcocer G 2014 *Determination of the thermal conductivity by using the Hot Wire Method: theory, simulation*

and experiment (Saarbruecken: LAP LAMBERT Academic Publishing)
[31] Mirskaya V A, Nazarevich D A and Ibavov N V 2009 *Bulletin of the Lebedev Physics Institute* **36** 331–332 ISSN 1934-838X URL https://doi.org/10.3103/S1068335609110050
[32] Stanimirović A M, Živković E M, Milošević N D and Kijevčanin M L 2017 *Thermal Science* **21**(3) 1195–1202 URL https://doi.org/10.2298/TSCI160324219S
[33] Zhao D, Qian X, Gu X, Jajja S A and Yang R 2016 *Journal of Electronic Packaging* **138**(4) 040802 ISSN 1043-7398 URL https://doi.org/10.1115/1.4034605
[34] Sánchez-Calderón I, Merillas B, Bernardo V and Rodríguez-Pérez M Á 2022 *Journal of Thermal Analysis and Calorimetry* **147** 12523–12533 ISSN 1588-2926 URL https://doi.org/10.1007/s10973-022-11457-7
[35] Czichos H, Saito T and Smith L (eds) 2007 *Springer Handbook of Materials Measurement Methods* Springer Handbooks (Berlin, Heidelberg: Springer) URL https://doi.org/10.1007/978-3-540-30300-8
[36] Kraemer D and Chen G 2014 *Review of Scientific Instruments* **85**(2) 025108 ISSN 0034-6748 URL https://doi.org/10.1063/1.4865111
[37] Iyengar A S and Abramson A R 2009 *Journal of Heat Transfer* **131**(6) 064502 ISSN 0022-1481 URL https://doi.org/10.1115/1.3084124
[38] Codreanu C, Codreanu N I and Obreja V V N 2007 *Romanian Journal of Information Science and Technology* **10**(3) 215–231 URL http://romjist.ro/content/pdf/01-codreanu.pdf
[39] Lamvik M and Zhou J M 1995 *International Journal of Thermophysics* **16** 567–576 ISSN 1572-9567 URL https://doi.org/10.1007/BF01441922

Journal of Physics: Conference Series

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Fabrication and applications of a novel and multi-feature spectroscope

To cite this article: I B Culaba *et al* 2023 *J. Phys.: Conf. Ser.* **2611** 012012

Fabrication and applications of a novel and multi-feature spectroscope

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Abstract. A spectroscope is an optical device that can stimulate student's interest in the visible light's constituent colors. This educational tool is conventionally used to qualitatively observe the emission spectra of various light sources, which can serve as a springboard to understanding the fundamentals of spectroscopy, the wave nature of light, and the orbital theory of atoms and molecules. This research builds on the functionality and accessibility of a simple spectroscope through the utilization of low-cost readily available materials, and more importantly, improvisation via the inclusion of a magnetic sheet mounted on the entrance slit cover. The magnetic sheet was employed to vary the slit width, to add absorption filters, and to mount a cuvette containing liquid samples. Furthermore, this sheet allowed the simultaneous observation of the emission spectrum of a light source and the transmission or absorption spectrum of the samples. The breadth of data from a variety of activities involving spectra was also made possible by a mobile phone camera as a recording device. In this study, the novel features strengthen the interconnectedness of various concepts in introductory spectroscopy. This elucidates the experimental and theoretical base of STEM Education in domains such as optics and photonics, and molecular spectroscopy.

1. Introduction

In 2013 the Philippines' "Enhanced Basic Education Act of 2013", An Act Enhancing the Philippine Basic Education System By Strengthening Its Curriculum and Increasing the Number of Years for Basic Education, Appropriating Funds Thereof and for Other Purposes, was enacted into a law. It stipulates eight standards and principles in developing the enhanced basic education curriculum and two of these are stated below [1]

The curriculum shall use pedagogical approaches that are constructivist, inquiry-based, reflective, collaborative and integrative.

The curriculum shall be flexible enough to enable and allow schools to localize, indigenize and enhance the same based on their respective educational and social contexts. The production and development of locally produced teaching materials shall be encouraged and approval of these materials shall devolve to the regional and division education units.

The full implementation of the law was fraught with several challenges. In teaching the Sciences there was the lack of science equipment. The junior high school Science teachers had to be retrained to competently teach all the Science subjects (Biology, Chemistry, Physics and Earth Science). Without the proper scientific equipment, even simple ones, students would not be able to learn and properly trained in the scientific method. Furthermore, even the use of simple apparatus in interactive lecture demonstrations can enhance the students' understanding of science concepts [2].

To address these challenges, the Department of Physics, Ateneo de Manila University undertook a program (in 2016) of developing Physics instruments using indigenous materials through the Action Research to Innovate Science Teaching (ARTIST). The ARTIST project, which was co-funded by the Erasmus + Programme of the European Union, was a collaboration of 10 universities from 6 different countries [3].

This paper presents one of the innovative Science instruments which was developed under the project. The simple spectroscope is a convenient tool in Physics for the qualitative study of the emission spectra of different sources of light and the absorption spectra of different materials. The spectra can be easily recorded using the camera of a mobile phone. With this instrument, it is even possible for an interdisciplinary approach to teaching science by integrating diverse fields such as Physics, Chemistry, and Biology. Different designs of simple spectroscopes are found in literature.

A spectroscope is a simple optical instrument which is normally used for the qualitative observations of the emission spectra of different sources of light. It is a useful device for introducing students to spectroscopy. The basic design of a spectroscope consists of a tube (or box) with fixed caps at both ends. At one end of the tube, the cap has a slit where the light enters. The cap at the other end of the tube has a grating over a small hole for observing the spectrum. A schematic diagram of a simple spectroscope is shown in figure 1.

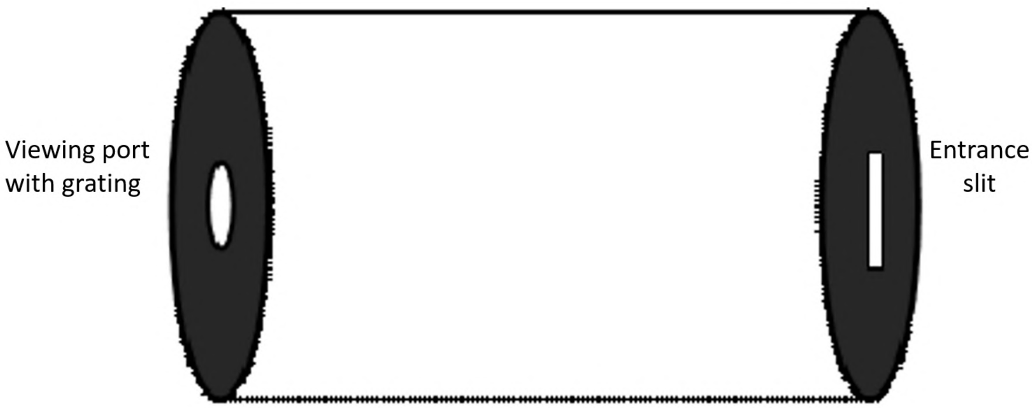

Figure 1: Schematic diagram of a simple spectroscope.

There are spectroscopes which use the reflective property of the CD or DVD gratings, similar to the works of Knauer [4] and Wakabayashi [5, 6]. There are also spectroscopes which use the transmission grating [7,8]. Although spectroscopes are usually for qualitative observations there are designs wherein the angle of diffraction can be measured and the wavelength of the spectrum is calculated [9,10]. Design, fabrication, and implementation of aforementioned devices allow for facility in preparing materials, activities, and resources for introductory lessons in spectroscopy.

In this paper, the fabrication of a novel spectroscope with multiple functionality features is discussed. A magnetic sheet is attached at the entrance slit. Thus, it is possible to vary the slit widths, mount different absorption filters, and hold a cuvette for liquid samples. The emission, transmission, and/or absorption spectra observed using the spectroscope can be recorded using the camera of a mobile phone.

2. Methodology

An important consideration in the fabrication of a spectroscope is its durability [11]. We used the commercially available cylindrical coin banks made of hard cardboard and with black plastic end caps. Coin banks with black-colored caps were used to minimize the intensity of the light inside the tube. Figure 2 shows two sample coin banks with end caps. The ready-made slit, where the coins are dropped, serves as the entrance slit for light. The approximate length and diameter of the tube are 157 mm and 83 mm, respectively. The slit has a typical width and length of 3.5 mm and 31.0 mm, respectively. A magnetic strip, with a slit hole, is mounted on the topmost cap. Figure 2 shows the caps with the magnetic sheet (left) and the grating (right). A 1-cm diameter hole is bored through the center of the other cap with the grating. The 1.5 cm x 1.5 cm grating is taped over the hole. Figure 3 shows the cap with the magnetic sheet and the other cap with the grating mounted (inside) over the observation port (hole).

Figure 2: The coin bank.

Figure 3: The caps with the magnetic sheet and the grating.

There are two demountable caps used – one with 500 lines/mm (commercial grating from Edmund Optics Singapore) and another cap with 662 lines/mm (CD grating). Both gratings are appropriate for observing broadband spectrum, like sunlight or incandescent lamp light.

The magnetic sheet placed at the entrance slit provided the following useful features not found in a typical simple spectroscope:

a. The slit width is adjustable using a pair of razor blades as shown in figure 4a. Utmost care and precaution need to be exercised because the razor blade is very sharp and can easily cause cuts in the skin. When used by children, it is recommended that rectangular steel strips are used instead of the razor blades.
b. Thin steel strips are used to hold thin solid samples, such as cellophane or a small leaf, for observing their transmission/absorption spectra, as shown in figure 4b and figure 4c.
c. In the case of thick transparent solid samples, such as colored acrylic filters, thin steel strips are attached to the samples as shown in figure 4d.
d. For liquid samples, a cuvette is mounted using steel brackets as shown in figure 4e.

Figure 4a: Adjustable slit width.

Figure 4b: Thin cellophane sample.

Figure 4c: Thin leaf sample.

Figure 4d: Thick acrylic sample.

Figure 4e: Cuvette for liquid samples.

Another novelty of this spectroscope design is that by placing a sample at the lower half of the slit, the full spectrum of the light source will pass through the upper half and is simultaneously observed with the spectrum of the light transmitted through the sample. The device then works as a double-beam spectroscope, where the observer directly infers the colors transmitted/absorbed by the sample. Examples of this type of spectral observations are presented in section 3

3. Results and discussion

In this study, we demonstrate the capability of the fabricated spectroscope by acquiring the emission spectra of various light sources and the transmission spectra of solid and liquid samples. The sample spectral data were taken using a smartphone, as an affordable and accessible recording device.

3.1. Emission spectra of different types of sources of light

a. Incandescent lamp

The continuous emission spectrum of the incandescent tungsten coil is shown in figure 5a below. Figure 5b confirms that the light emitted by an incandescent light bulb is predominantly infrared radiation. However, a small amount of visible light is also produced, making the bulb appear to glow. The vast majority of the energy created by an incandescent bulb is given off as heat rather than light.

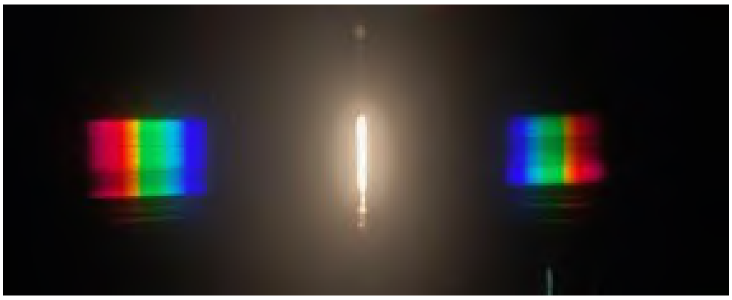

Figure 5a: Emission spectrum of an incandescent lamp.

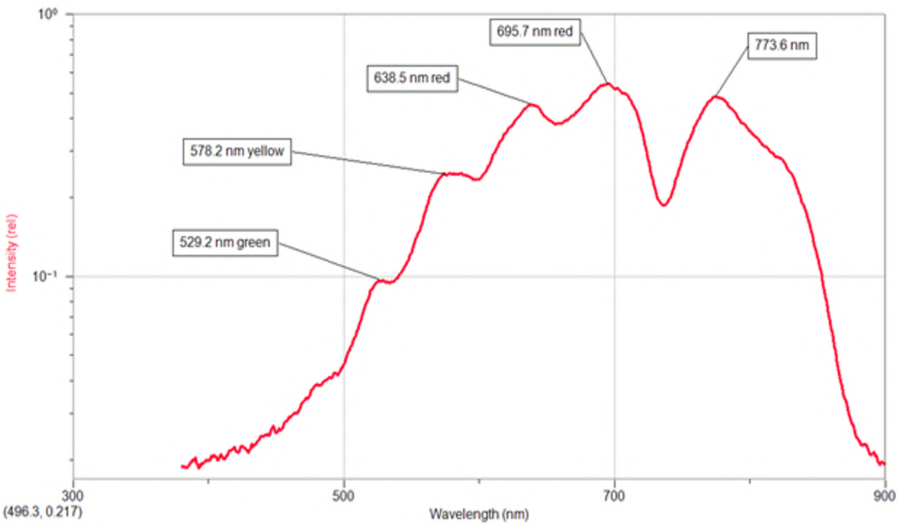

Figure 5b: Vernier SpectroVis Plus spectrometer data for an incandescent lamp.

b. Compact fluorescent lamp (CFL)

The emission spectrum of the compact fluorescent lamp in figure 5c shows the emission spectrum of mercury and the emission spectrum of the phosphor in the tube. While the incandescent light gives a continuous spectrum, the fluorescent light gives discrete lines typical of the mercury spectrum and the phosphor. CFLs radiate a spectral power distribution that is different from that of incandescent lamps. Figure 5d confirms how the the emitted ultraviolet light from the mercury atoms of a CFL is converted into visible light as it strikes the fluorescent coating, and into heat when absorbed by other materials such as glass

Figure 5c: Emission spectrum of a compact fluorescent lamp.

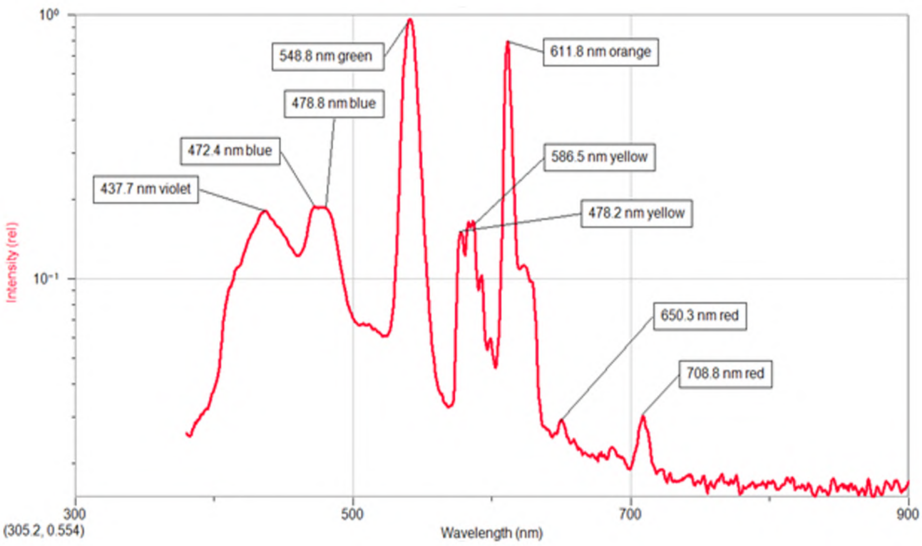

Figure 5d: Vernier SpectroVis Plus spectrometer data for a compact fluorescent lamp.

c. Helium discharge lamp
The emission spectrum of helium in figure 5e shows its unique "fingerprint" lines (right to left) of red, yellow, green, and blue. The helium emission spectrum is a spectrum produced by the emission of light by helium atoms in excited states. Figure 5f prominently displays 8 peaks out of the 12 lines of visible helium spectrum.

d. White light emitting diode (LED) lamp
The LED lamp spectrum in figure 5g shows the blue emission spectrum of the blue LED, and the red and green spectrum produced by the yellow phosphor. The image shows a lot on the blue color's side and doesn't give off a lot of red and green light. Figure 5h confirms these observations through the emission spectra of a commercial white light emitting diode.

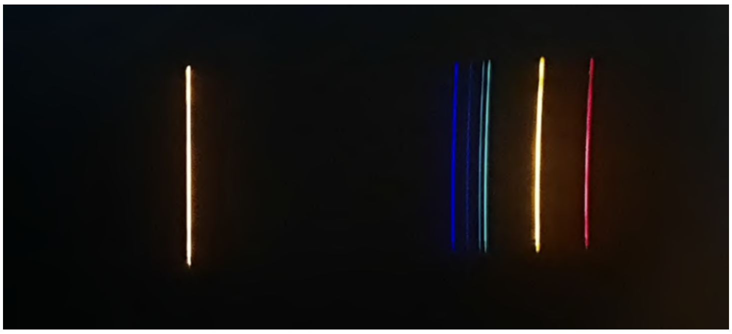

Figure 5e: Emission spectrum of a Helium discharge lamp.

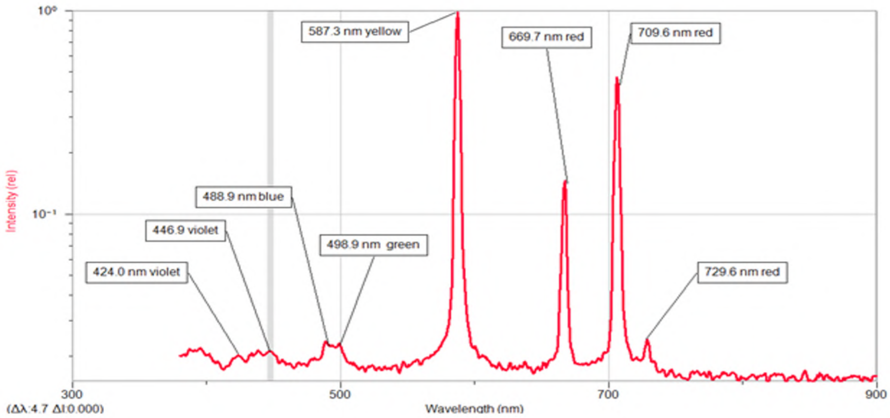

Figure 5f: Vernier spectro-VIS plus spectrometer data for a Helium discharge lamp.

Figure 5g: Emission spectrum of a white light emitting diode (LED) lamp.

3.2. Transmission/Absorption spectra of a small leaf and chlorophyll extract

This activity highlights the integration of concepts and principles in Physics, Chemistry, and Biology. It can be used as a springboard for a multidisciplinary discussion on the subject of photosynthesis. The colors (or the wavelengths) absorbed by chlorophyll are directly observed by using a thin leaf. In figure 6a, the upper half of the image shows the visible spectrum of sunlight while the other lower half is the light transmitted through the leaf. It is evident that the red and blue colors of the spectrum have been absorbed by the leaf, consistent with previous studies involving photosynthesis and chlorophyll [12, 13]. Observing the absorption spectrum of the chlorophyll extract (using 70% isopropyl alcohol) allows for a complementary discussion on which component of the leaf absorbed the said colors, as shown in figure 6b. This allows for students (and teachers) to observe and compare the transmission and absorption spectra of the

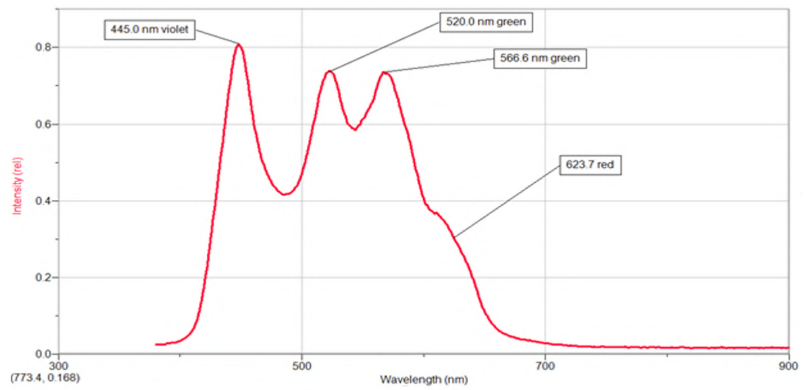

Figure 5h: Vernier SpectroVis Plus spectrometer data for a white light emitting diode (LED) lamp.

samples. The aforementioned activities may provide the foundation for a low-cost experimental introduction to the basic principles of spectroscopy, which is usually hampered by the relatively high cost of scientific equipment [14, 15]. Figure 6c shows the absorption/transmission spectra of chlorophyll dissolved in 70% isopropyl alcohol. These include wavelengths of blue and red light.

Figure 6a: Transmission and absorption spectrum of sunlight after passing through a thin green leaf.

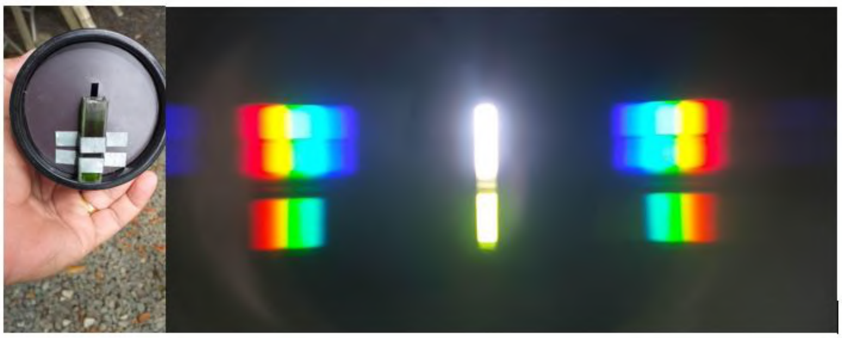

Figure 6b: Transmission and absorption spectrum of sunlight after passing through chlorophyll dissolved in 70% isopropyl alcohol.

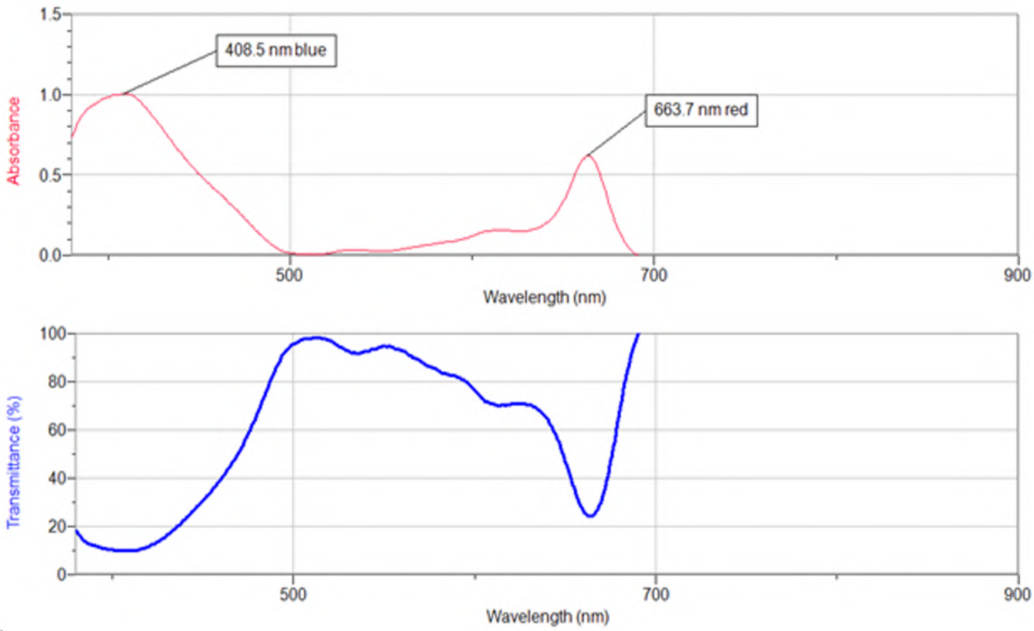

Figure 6c: Vernier SpectroVis Plus spectrometer data for chlorophyll dissolved in 70% isopropyl alcohol.

4. Conclusion

The Philippines' Enhanced Basic Education Act of 2013 promulgated guidelines designed to foster effective and efficient pedagogical approaches that focus on student-centered, inquiry-based, and active learning methods using low-cost and readily available materials and equipment. This work highlights the importance of the novel design, fabrication, and implementation of a low-cost and multi-feature spectroscope that will be useful for both students and teachers in the STEM education subjects such as Physics, Chemistry, and Biology. In particular, the device can be used as a springboard for a multidisciplinary discussion on the subject of photosynthesis. The unique features of the spectroscope (adjustable slit width, magnetic strip with solid and liquid sample holders) allow for more diverse activities that introduce the fundamentals of spectroscopy (emission, absorption, transmission spectra) to a myriad of students and educators in developing countries which may lack the state-of-the-art equipment readily available in countries with more advanced technology. Low-cost instrumentation in optics and photonics lead to exciting possibilities of a multidisciplinary understanding of concepts and principles important in basic spectroscopy.

Acknowledgments

The work was supported by the Action Research to Innovate Science Teaching (ARTIST) project. This project (2016-2019) was co-funded by the European Union under the program ERASMUS+ Capacity Building in Higher Education.

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References

[1] 2013 Enhanced Basic Education Act of 2013 URL https://www.officialgazette.gov.ph/2013/05/15/republic-act-no-10533
[2] Sokoloff D R and Thornton R K 1997 *The Physics Teacher* **35**(6) 340–347 URL https://doi.org/10.1119/1.2344715
[3] 2019 Erasmus+ ARTIST Project URL http://www.erasmus-artist.eu/overview.html
[4] Knauer T 2002 *The Physics Teacher* **40**(8) 466–467 URL https://doi.org/10.1119/1.1526615
[5] Wakabayashi F and Hamada K 2006 *Journal of Chemical Education* **83**(1) 56 URL https://doi.org/10.1021/ed083p56
[6] Wakabayashi F 2008 *Journal of Chemical Education* **85**(6) 849 URL https://doi.org/10.1021/ed085p849
[7] Sokoloff D R (ed) 2006 *Active Learning in Optics and Photonics: Training Manual* (UNESCO) URL https://unesdoc.unesco.org/ark:/48223/pf0000217100
[8] Kovarik M L, Clapis J R and Romano-Pringle K A 2020 *Journal of Chemical Education* **97**(8) 2185–2195 URL https://doi.org/10.1021/acs.jchemed.0c00404
[9] 2000 Optics: Light, Color, and their Uses - An Educators Guide With Activities in Science and Mathematics Open Educational Resource EG-2000-10-64-MSFC National Aeronautics and Space Administration URL https://www.nasa.gov/pdf/626184main_58258main_Optics.Guide.pdf
[10] Cortel A and Fernandez L 1986 *Journal of Chemical Education* **63**(4) 348 URL https://doi.org/10.1021/ed063p348
[11] Edwards R K, Brandt W W and Companion A L 1962 *Journal of Chemical Education* **39**(3) 147 URL https://doi.org/10.1021/ed039p147
[12] Shafiq I, Hussain S, Raza M A, Iqbal N, Asghar M A, Raza A, Fan Y, Mumtaz M, Shoaib M, Ansar M, Manaf A, Yang W and Yang F 2021 *Journal of Integrative Agriculture* **20** 4–23 ISSN 2095-3119 URL https://doi.org/10.1016/S2095-3119(20)63227-0
[13] Chand B, Kumar M, Prasher S, Sharma A and Kumar M 2022 *Journal of Physics: Conference Series* **2267**(1) 012143 URL https://doi.org/10.1088/1742-6596/2267/1/012143
[14] Gräb P, Geidel E and Schmitt H C 2021 *World Journal of Chemical Education* **9**(4) 144–151 URL http://pubs.sciepub.com/wjce/9/4/7/index.html
[15] Sandak J, Sandak A, Zitek A, Hintestoisser B and Picchi G 2020 *Sensors* **20**(2) 545 ISSN 1424-8220 URL https://doi.org/10.3390/s20020545

Interactive technology use during the study of the Universe

Interactive technology use during the study of the Universe

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Abstract. The development of students' key competences and their scientific worldview is one of the significant tasks of secondary education. Understanding of the Universe, its objects, structure and research methods is an important part of natural and mathematic worldview. Problem-based learning is a relevant form for develop critical thinking during the study of these topics in the course of astronomy. In the conditions of distant learning this can be realized with the help of interactive online platforms whereas practical tasks can be realized through the use of simulators, mobile and computer applications. This will contribute the development of students' key competences and practical skills. This research offers to emphasize the Universe study and interactive technology use in order to develop research, information and digital competences as well as competences in natural sciences and technologies.

1. Introduction

Astronomy is the science about the Universe, its structure, its development as a whole and its constituent objects in specific. Astronomy finishes the study of all physics branches as well as the formation of integrated scientific picture of the Universe structure. It is astronomy that demonstrates performing of physical laws and phenomena, defining the characteristics of celestial objects due to the observe results.

The school programme in astronomy uses a historical approach to its study. A few hours are devoted to the study of the Universe issues and practical tasks are almost not provided. Nowadays the situation is observed that the important issue on forming scientific worldview and understanding the Universe nature, its structure and development is studies mainly theoretically and briefly [1]. The Universe is, on the one hand, a big natural laboratory for demonstrating the use of physical laws, on the other hand, new technologies and discoveries in physics are necessary for researching the past and prediction the future of the Universe. Currently some hypotheses exist on the development of the Universe, galaxies and presence of nonstandard objects. Everything mentioned above should not evoke false thoughts on imperfection of physical laws but on the contrary, they should show the importance and perspectives of scientific research. For example, finding Higgs boson or gravitational waves.

In the school programme the attention is devoted to cosmological paradoxes and existing cosmological models of the Universe. However, the connection with physical laws and research methods of parameters of celestial bodies are highlighted not enough in the programme and textbooks. Basic school textbooks in astronomy [2–4] consider these topics in different ways. In the textbook [2] there is the topic "The Universe structure and evolution" such issues are considered as Galaxies, active galactic nuclei, observing principles of cosmology (cosmological paradoxes), main eras in the Universe history, relic radiation, geometric forms of the Universe and their solving. In the textbook [3] only a brief review of galaxy system, cosmological principles and the Universe models. The educational manual in astronomy for the profiled school by Kriachko [5] provides issues as development of ideas of the Universe, existing cosmological models of the Universe and observance justification of the Big Bang theory.

As we see, the study of such important issue as the Universe in the school course of astronomy is relevant and requires improvement. Involvement of the latest educational technologies will contribute better students' understanding of theoretical material. Consideration of issues about the Universe are preceded by the study of peculiar objects and their physical characteristics, research methods in astronomy. But it is also necessary while studying topics connected to the Universe and its development to emphasize not only highlighting of the cosmological principles and existing Universe models but also their connection with physical phenomena, laws, observe methods, defining physical parameters. The active use of practical tasks, astronomical simulations and interactive technologies can also increase interest to study the material and improve its understanding [1, 5–7]. Such an approach to study astronomy will facilitate broadening of knowledge and understanding physics, nature and really will form integrated scientific picture of the world.

The difficulty of studying the Universe issue lies also in the necessity of practical tasks for qualitative study and in the topic about the Universe such tasks are offered very few. Some tasks to this topic can be found in the collection by Kuzmenkov [8]. These tasks have physical orientation, cognitive and creative character. They are oriented on the students of higher education institutions, so in the course of school astronomy only some of them can be used for setting problem-based tasks or as research tasks in astronomy.

The practical constituent of educational material can be realized through the use of applications and simulators for computers or mobile phones. The examples of tasks are presented in the works [9–14], for the organization of practical tasks the use of application-simulator of virtual reality Universe Sandbox 2 has become popular (for the study of other evolution processes in the Universe, for example, black holes [11] and dependence of physical parameters of stars and planets and if life would be possible on this planet).

2. Problem overview

Interactive technologies are such technologies which provide interrelation between the user and computer system or webservice which supposes information bilateral exchange. Such technologies allow participants to interact actively with the information that is presented on the screen and to impact on it. Interactive technologies can be different: from software for computers and mobile devices to interactive boards, digital posters and game systems. This is an actual problem and has been represented in such works as [15–24].

Johnson et al [25] define interactive learning method as "learning that involves students to interaction with a teacher in order to gain knowledge and to develop skills that will enhance the level of understanding and collecting educational material". The research [15] points out that interactive learning and respectively technologies provide educational interaction not only between a teacher and students but also between students who interact actively among themselves in order to find new knowledge.

According to Bacca et al [26] interactive technologies are used for providing more effective learning and improvement of students' mastering knowledge. The basic idea of an interactive technology lies in a student to become an active participant of the educational process. The interactive learning method supposes active cooperation between a students and educational material that enables to provide individualization of educational process and to increase effectiveness of knowledge mastering.

Interactive technologies can contain video lessons, webinars, online games, interactive simulations, tests and other instruments. The use of interactive technologies contributes to the development of such key competences as critical thinking, forming the students' skills of individual work etc. The research of students' attitude to the use of active learning forms, their involvement to educational process being described in the work [27] demonstrate the increase of students' motivation and knowledge level.

Activization of motivation to study astronomy and students to be involved into educational process is teachers' significant tasks especially during distant learning. To reach this goal it is appropriate to combine problem-based learning and the use of interactive techniques [28] such as interactive online boards iDroo (`https://app.idroo.com/dashboard/boards`), Miro (`https://miro.com/app/dashboard/`) etc., online resources: WordArt (`https://wordart.com`), Answergarden (`https://answergarden.ch`), interactive presentations with the ability to make polls Menti (`https://www.mentimeter.com`) and others. Such interactive technologies allow to involve maximum quantity of students to the process, to visualize their answers or to fulfill tasks. These technologies can be used for frontal questioning in the classroom or during distant learning. Answers are anonymous so students will not be afraid of making mistakes and expressing their suppositions especially on problem-based questions as there are no exact answers and the main tasks is to evoke students' thinking and expressing their point of view. And during an interview a teacher gives clear explanations why some answers can exist and the other ones are not based on the physics laws. This contributes to the activization of cognitive activity, the development of critical and analytical thinking. Such an approach of studying the Universe, its development, the role of physics in understanding and research of natural phenomena.

Interactive technologies enable teachers to create their own interactive materials for lessons and that helps to personalize educational process and to provide an individual approach to every student. Appropriateness of the use of interactive technologies at astronomy classes is indicated in the works by [10–12].

The research having been made within Eurydice project (European information portal in the sphere of education) has shown that the use of interactional technologies in the educational process increases the level of students' independence, provides more activity and interest in the learning process [29]. The research results of the issue of using interactional technologies in the European education have indicated that interactive technologies contribute to increase of time devoted to practical work that is an important factor in the formation of students' skills. Moreover, the use of interactive technologies in the educational process is especially effective for students who have different levels of skills and individual peculiarities. These technologies allow to differentiate training and to adapt the material according with the needs of every student so that it increases the effectiveness of educational process.

The preparation of well-rounded responsible citizens who are able for self-education and innovations lies in the reformation of modern educational system and competence training. Interactive technologies can contribute to the development of students' key competences such as critical thinking, cooperation, communication and the development of informational literacy. One of the key competences is critical thinking which supposes the ability to analyze information, to make conclusions and to take reasonable decisions. The use of interactive technologies such as games and simulations can contribute to the development of this competence by giving students an opportunity to conduct their own research and experiments, moreover, to learn how to solve problems and take decisions.

Interactive technologies can help students to interact with classmates and a teacher through the use of virtual boards, chats and common project activity. It develops not only communicative skills but also contributes to the formation of social competences such as empathy and tolerance.

Interactive online boards, platforms for interactive presentations are designed for team work, allow to create and display graphic images, texts and mathematic formulas, to incorporate illustrations, documents in real time. The majority of online boards are freely accessible, have visually attractive and intuitively understood interface. The most widespread ones are such as IDroo, Miro, Twiddla (`https://www.twiddla.com`), Awwapp (`https://awwapp.com`), Whiteboard Fox (`https://whiteboardfox.com`).

Online boards have some similar useful functions such as:

- Creating a new plan draft or pin tasks to be fulfilled;
- An ability to draw by hand on the board using different colours and brushes;
- Uploading graphs, schemes, formulas, tables etc.;
- Editing and deleting objects;
- An ability to present video from the Internet directly on the board;
- An ability to share links with their students;
- Storing the material having been created during the work on the board;
- Support of different formats as pdf, jpg, png, and also an ability to export the board into pdf;
- Built-in chat for the conversation with students.

Interactive online boards are useful during distant learning when it is necessary not only to involve all students in the educational process but also to demonstrate the algorithm of task solution and the order of actions. Besides interactive boards at classes interactive presentations can be used. The use of online platforms such as Canva (`https://www.canva.com/`) or Menti for creating presentations will allow to involve bigger quantity of students into the educational process and convert them from listeners to active doers of the educational process. Platform Canva enables to create both a presentation and a board at which a students' team can work simultaneously. Platform Menti allows to create presentations with interactive survey of different types. It is appropriate to organize problem-based learning at lessons. Depending on settings the results can be seen on the screen at once in the forms of a word cloud, open answers, a choice of one or more answers and so on. Constant interactive cooperation with the class allows to support students' attention and their communication. At the beginning of the lesson such questions facilitate knowledge actualization, checking students' level of awareness of the topic, problem-based education organization and in the end of the lesson it can be checking of knowledge mastering, the level of understanding and information comprehension.

The main advantages of using interactive online technologies at lessons are:

- Interactivity allows teachers and students to write and create elements on the board, a student can answer on the board, to solve tasks and everything is expressed in real time.
- An ability of distant learning enables teachers and students to work from any place of the world so that it provides convenience and flexibility of training.
- Ease of use: it is easy in use and has intuitively understood interface that allows a teacher and students to create and edit the image fast.
- Free access: the access is free that provides wide accessibility for teachers and students.

Furthermore, the platforms as PhET, EdEra, iLearn, Virtual STEM-Centre of Junior Academy of Sciences of Ukraine, Learning.ua, Human.ua, Matific, LearningApps.org and others are appropriately used as interactive instruments for studying physics, mathematics and astronomy [27,30–37]. The most popular among teachers is PhET Interactive Simulations which is a free educational Internet resource that contains more than 150 interactive simulations in different branches of science, in particular, physics, chemistry, biology and mathematics. This resource was created by University of Colorado at Boulder aiming at providing students and teachers with convenient access to virtual research and experiments.

Every simulation on PhET site contains interactive environment that allows users to interact with peculiar physical phenomena and to conduct experiments in safe and controlled environment. Simulations can be used for fulfilling laboratory works at biology, chemistry, physics and astronomy lessons (mainly sciences about the planet).

Vascak and SimPop websites offer free access to a great amount of animations connected with physics and astronomy that can be used in the educational process. Every animation is accompanied by a brief description of a physical phenomenon that is demonstrated and also it includes tips how to control and change parameters in the programme. The research [27] describes example of using online platform Padlet during studying the topic: the Sun and its physical characteristics. A significant amount of astronomic simulations is offered by the group of astronomers of the University of Nebraska-Lincoln (`https://astro.unl.edu`). The groups of artists and programmers headed by the doctor Kevin Lee worked out various educational materials in astronomy including online laboratories, questions for discussion, animations and others (`https://astro.unl.edu/animationsLinks.html`). Currently 360 simulations and animations (figure 1) in different chapters of astronomy have been worked out as well as their brief instructions of using. These instructions are ready to be used by students during accomplishing practical tasks and will help teachers to use them significantly effectively.

Interactive technologies give students new knowledge, opportunities and perspectives of individual work organization, facilitate every student's development, include science into the educational process, reflect real life situations in physics and astronomy. This creates new opportunities for mastering practical skills at lessons, gives experience, makes training an interesting process, helps to understand difficult terms, phenomena and processes.

3. Results and discussion

This research offers the use of interactive technologies during the study of the topic "The Universe". These technologies were offered to the senior school students during the visits of lectures at university and students while studying the course in Modern concept of the Universe.

Before starting the study of the Universe students are offered to answer the questions (knowledge actualization) and presenting further theoretical material was based on the discussion of students' answers. The question was demonstrated on the interactive board or screen. The Universe study can be started with such questions:

1. Which objects (and structural parts) does the Universe consist of?
2. How are they researched? Which ranges of electromagnetic radiation are different Universe structural elements investigated in?
3. Which devices is the Universe investigated by? Which methods are used?

Answers to these questions can be arranged into the word cloud (figure 2) or as open answers for that presentation on the platform Menti (`https://www.menti.com/al8ji37p4d7c`) has been used. Not all the answers can be right, however, the general picture of students' knowledge about the Universe will be understood and that can be a draft for the study of this issue. Besides the platform Menti for this task the platform WordArt (`https://wordart.com`) or Answergarden (`https://answergarden.ch/view/3142727`) can be used.

Problem-based questions, being given to a students' team or individually, are presented on the interactive board and students find answers and tick right answers during the study of a new topic. The students gave answers to some questions at the beginning of the class and during the study of the material they corrected these answers on the board the access to which was open during the whole lesson. The students of not profiled classes can be offered these questions in the form of "find the pair". In this case cards with questions and answers are shown on the board and every team must find answers to the questions among these cards. While studying the topic "The Universe" such questions were offered:

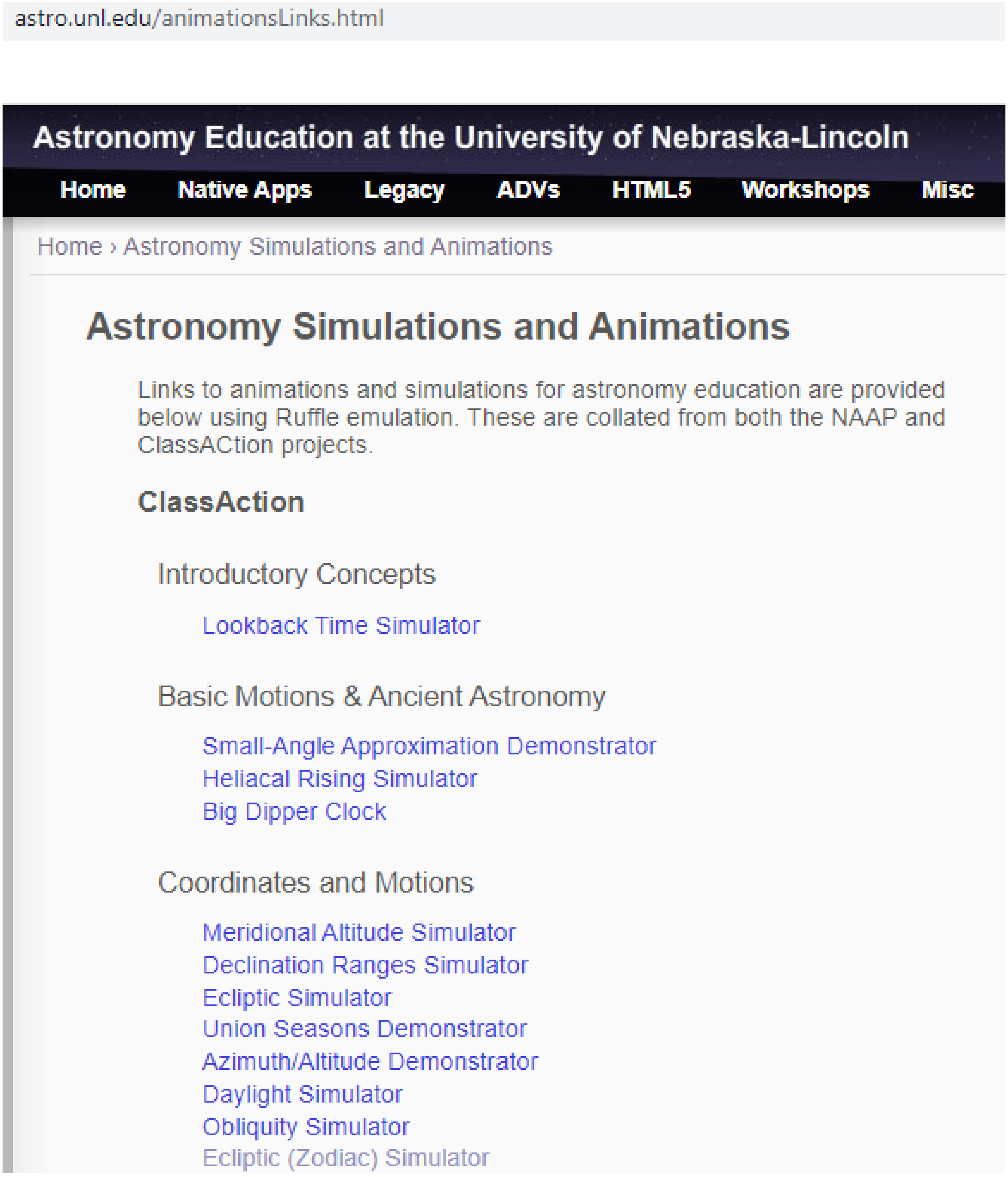

Figure 1. The main window with animations.

1. What is the most widespread chemical element in the Universe?
2. What is the temperature of the Universe?
3. What is the size of the Universe?
4. How was the temperature of the Universe measured?
5. How is the age of the Universe defined?
6. Where do heavy elements appear in the Universe from?

Figure 2. The example of using interactive presentation for creating a word cloud.

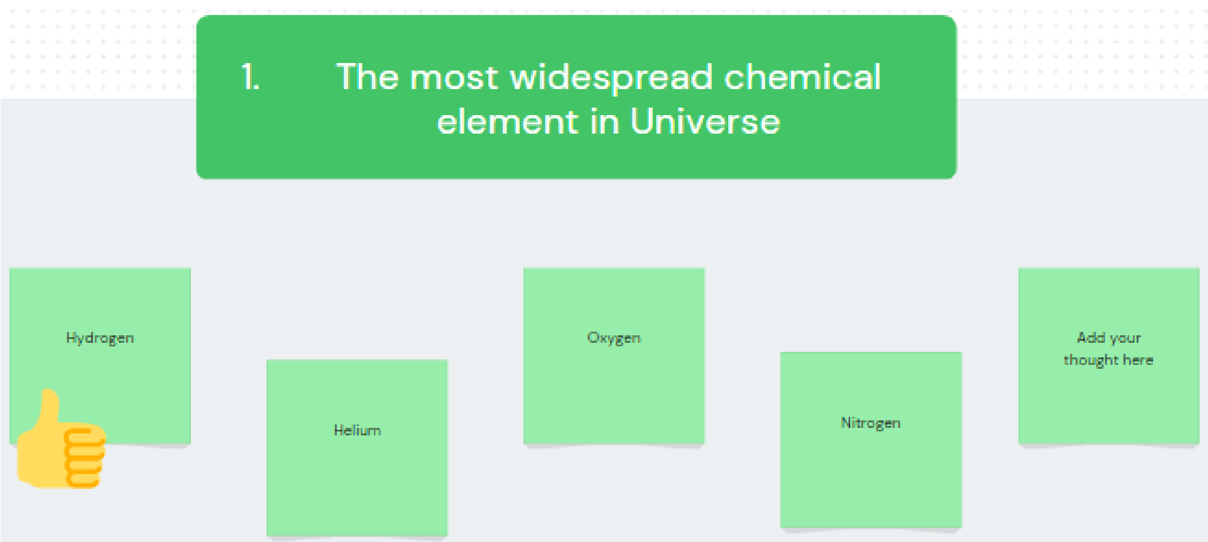

Figure 3. The example of using interactive board for students' frontal questioning.

Further more serious issues are considered during the explanation of which significant attention should be paid to physics laws, make an accent on new observance data which were taken by astrophysicists and what else should be done. Here is the list of such questions:

- The development of the Universe research and technological perspectives.
- The formation, the development and the future of the Universe. Different scenarios of the Universe development.
- The form and the size of the Universe and their importance and definition.

- Observational data proving the Big Bang theory and the development of the Universe.
- Cosmologic paradoxes of the Universe.
- Dark matter and dark energy.

The narration should be accompanied by astronomic simulations and animations, being offered by different platforms, during the study of these issues. For example, the platform PhET and appropriate simulation, giving opportunity to demonstrate and master the Doppler effect, were used during the study of such issue as methods of the Universe research (figure 4).

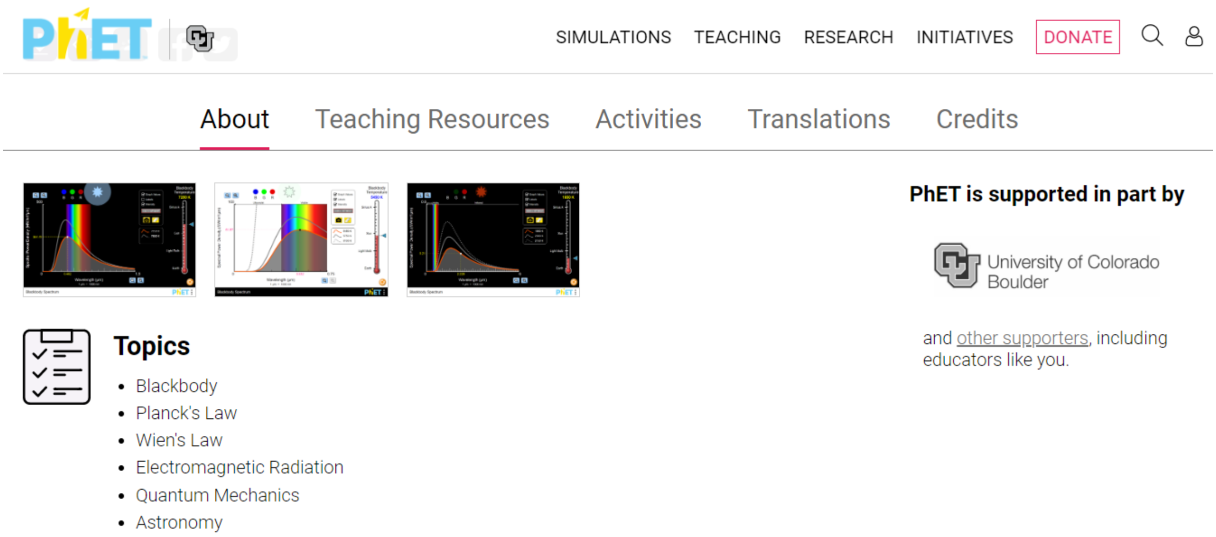

Figure 4. The example of the simulator to study the Doppler effect.

The task for students (figure 5): Changing the star temperature write down:

1. The wave length which accounts the maximum radiation.
2. Define which colour the star will become (according to the spectrum or which colour will be more out of those on the upper picture).
3. Make a conclusion about the dependence of temperature on the wave length which accounts the maximum radiation.

Students formalize the results in the form of a table.

During the study of other issues and stating practical tasks the demonstrations, being offered by the astronomer team of the University of Nebraska-Lincoln, were used.

During the study of the Universe understanding of its development and the Universe objects evolution is important. The most widespread object is stars, in the school programme it is offered, at first, to study magnitudes, then stars and some of their parameters, and the evolution is considered alongside with the galaxy. In this research stars have been considered as one of the Universe objects and the attention was paid to all of the physical parameters and the reasons of their changes at once. The use of simulation of star arrangement on the Hertzsprung–Russell diagram should be used depending on the parameters.

The tasks for the students:

1. Run a simulation (figure 6).
2. Fix the data for the Sun which will become units of measurement for other stars.

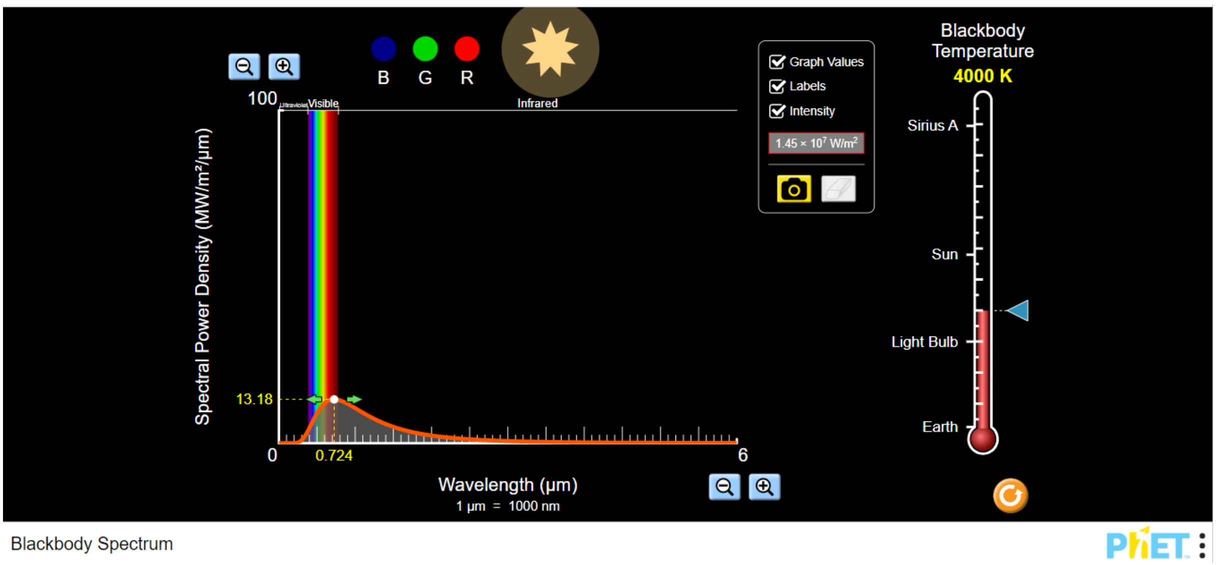

Figure 5. The task on defining the star temperature.

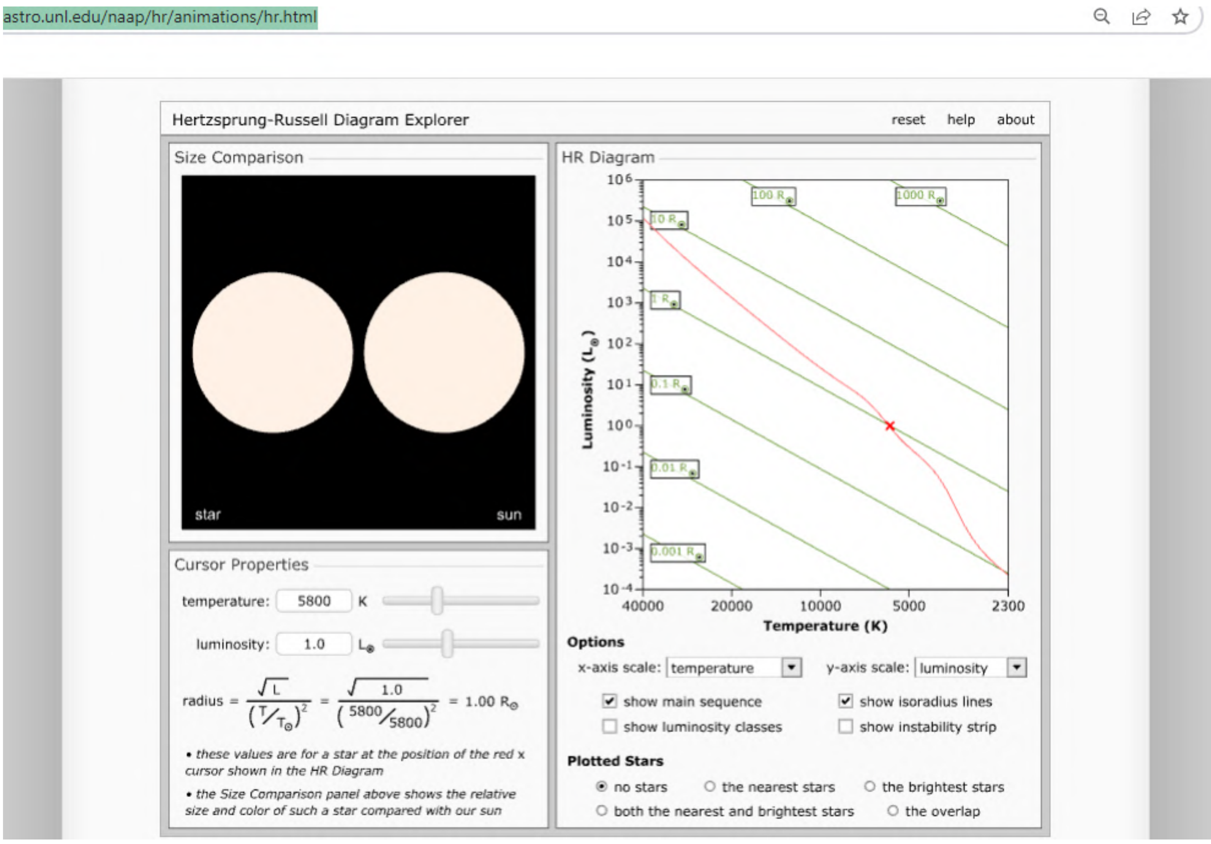

Figure 6. The example of simulation in demonstration depending on physical parameters (temperature, luminosity and sizes) and arrangement on the Hertzsprung–Russell diagram.

3. Change star temperature and follow how the star will move on the diagram depending on temperature increase and decrease. How will star sizes change?

4. Repeat the previous task changing luminosity.
5. Make conclusions.

Use other simulation `https://astro.unl.edu/smartphone/hrdiagram/` (figure 7) and fulfill the instructions to the simulation (they are offered under the picture).

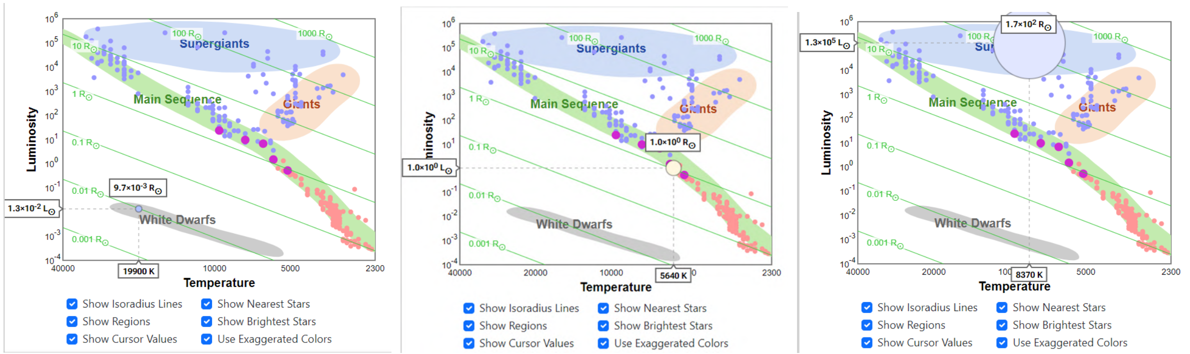

Figure 7. Star arrangement on the Hertzsprung–Russell diagram depending on different parameters.

While forming the concept of star arrangement and matter in the Universe it is appropriate to remind and show an example of three-dimensional star arrangement in stellar constellations, for example, the Big Dipper: `https://astro.unl.edu/classaction/animations/coordsmotion/bigdipper.html` (figure 8).

To demonstrate divergence of galaxies during the Universe expansion and Hubble's Law such animations were used:

- *Balloon Universe.* An animation of coins attached to a balloon, providing an analogy to the expansion of the universe. The coins represent galaxies, which maintain their scale while the space between them grows.
- *Hubble's Law.* A simple simulator for visualizing the expansion of the universe. Users can see vectors describing the velocities of galaxies and note that all galaxies are moving away from us. They can then change their perspective to another galaxy and note that Hubble's Law is seen from there as well.

The Aladin platform may be offered for more prepared students and the students who make scientific and research papers [38]. This interactive sky atlas, which allows users to consider and study digitalized astronomic shots, uses active computer connection with the Internet in order to get access to open astronomic catalogues and databases such as NASA, SIMBAD, VizieR etc. (Aladin is an interactive sky atlas allowing the user to visualize digitized astronomical images or full surveys, superimpose entries from astronomical catalogues or databases, and interactively access related data and information from the Simbad database, the VizieR service and other archives for all known astronomical objects in the field.) The application is used as an instrument for professional astronomers working in the sphere of science and education and spreads free.

4. Conclusions

Interactive technologies allow to create more dynamic and interesting environment for the study that contributes to the activization of students' cognitive and motivational processes. Virtual laboratories enable students to conduct experiments and research in safe and controlled environment. Mobile applications and games may stimulate interest to the study and encourage creativity and innovation digital skills.

In the research we have used such services as:

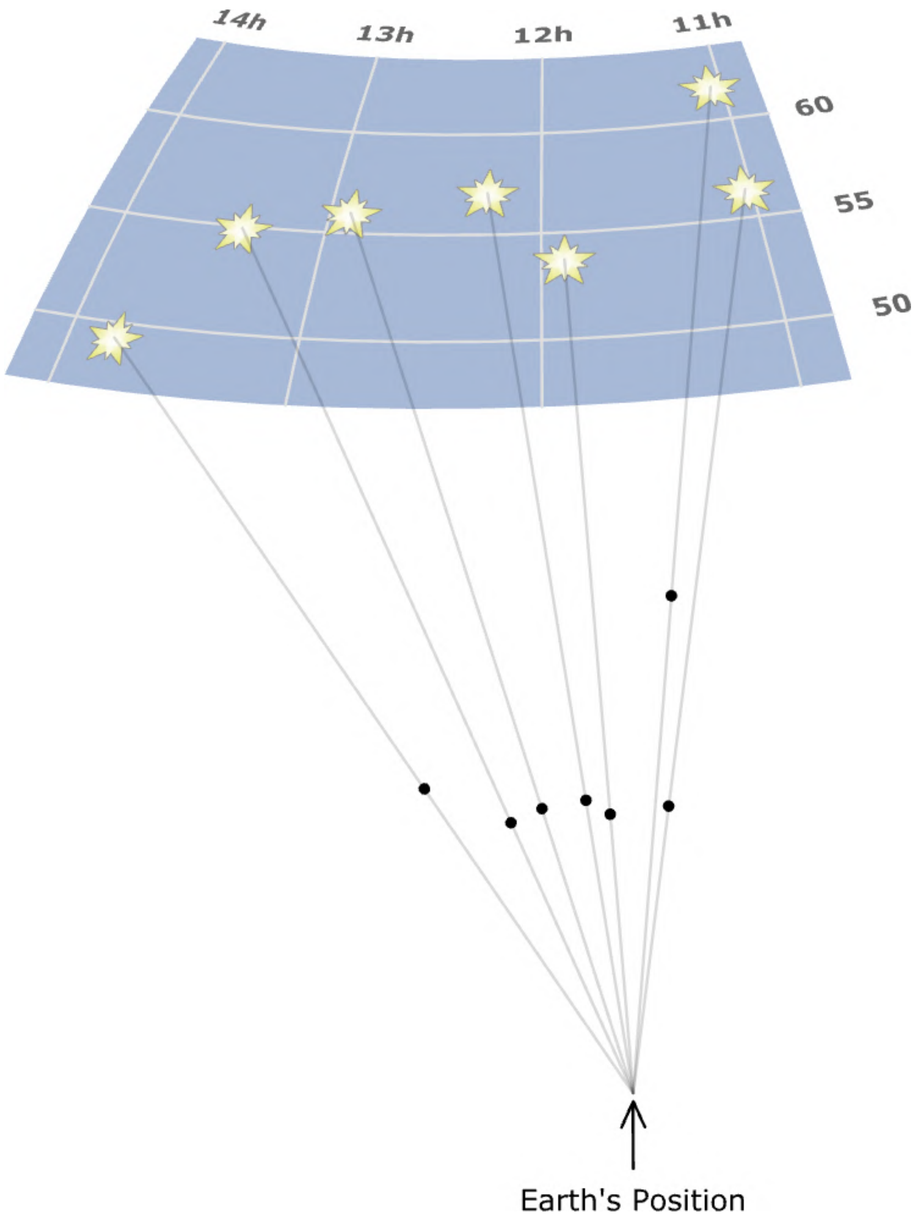

Figure 8. Demonstrates how the stars of the Big Dipper, which are at various distance from earth, project onto the celestial sphere to give the familiar asterism.

- interactive boards (for new concepts and terms),
- interactive presentations (for actualization of knowledge, frontal questioning, material and problem-based issue consolidation),
- computer, mobile applications and simulations (for practical tasks).

Peculiar significant technologies of interactive learning appear during distant learning and also during the study of natural sciences in the cases when the real demonstration or experiment cannot be conducted. In such cases interactive technologies help to use problem-based issues and the simulation use is to realize practical work and tasks. During the study of the Universe at the astronomy classes interactive learning forms facilitate not only students' activization but also are an effective way of forming scientific picture of the world. In the research it is offered to change the approach to the study of the topic “The Universe” and to start forming the understanding of the whole structure in astrophysics issues and up to the end of the course in astronomy. It will enable to allocate time for conducting practical tasks which will be realized through the use of interactive technologies and simulations.

The results of the use of interactive technologies indicate that this form of learning makes students active participants of the educational process, increase the level of interrelation between a teacher and students, personalizes the educational process. And as a result the effectiveness of mastering knowledge, students’ interest and motivation increase, it develops their critical and analytical thinking, communicative skills and skills in expressing their thoughts. Students’ questioning before and after the use of the offered approach of studying the topic “The Universe” proves the increase of the level of understanding physical laws, the Universe structure, how and why it develops and the perspectives of its future.

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References

[1] Malchenko S L 2021 *Journal of Physics: Conference Series* **1840**(1) 012016 URL https://doi.org/10.1088/1742-6596/1840/1/012016
[2] Pryshliak M P 2019 *Astronomy* (Kharkiv: Ranok) URL https://shkola.in.ua/1085-astronomiia-11-klas-pryshliak-2019.html
[3] Syrotiuk V and Miroshnichenko Y 2019 *Astronomy* (Kyiv: Geneza) URL https://pidruchnyk.com.ua/1273-astronomiya-11-klas-syrotyuk.html
[4] Holovko M V, Kriachko I P, Melnyk Y S, Neporozhnia L V and Sipii V V 2019 *Physics and astronomy* (Kyiv: Pedagogichna dymka) URL https://pidruchnyk.com.ua/1276-fizyka-i-astronomiya-11-klas-golovko.html
[5] Kriachko I P 2018 *Metodyka navchannia astronomii v starshii zahalnoosvitnii shkoli* (Kyiv: Nashe nebo) URL https://www.astroosvita.kiev.ua/metod/Metodyka-navchannia-astronomii.pdf
[6] Bilyk R M and Optasyuk S V 2021 *Collection of Scientific papers Kamianets-Podilskyi National Ivan Ohiienko University. Pedagogical series* **27** 136–140 URL http://ped-series.kpnu.edu.ua/article/view/251740
[7] Kuz’myns’kyi O V, Zabolotnyi V F and Myslitska N A 2022 *Scientific notes of Vinnytsia Mykhailo Kotsiubynskyi State Pedagogical University. Section: Theory and methods of teaching natural sciences* **3** 30–40 URL https://doi.org/10.31652/2786-5754-2022-3-30-40
[8] Kuzmenkov S H 2010 *Zori: astrofizychni zadachi z rozviazanniam [Stars. Astrophysical tasks with solutions]* (Kyiv: Osvita Ukrainy)
[9] Vakaliuk T A, Kontsedailo V V, Antoniuk D S, Korotun O V, Mintii I S and Pikilnyak A V 2019 Using game simulator Software Inc in the Software Engineering education *Proceedings of the 2nd International Workshop on Augmented Reality in Education, Kryvyi Rih, Ukraine, March 22, 2019* (*CEUR Workshop Proceedings* vol 2547) ed Kiv A E and Shyshkina M P (CEUR-WS.org) pp 66–80 URL https://ceur-ws.org/Vol-2547/paper05.pdf
[10] Malchenko S L, Mykoliuk D V and Kiv A E 2019 Using interactive technologies to study the evolution of stars in astronomy classes *Proceedings of the 2nd International Workshop on Augmented Reality in Education, Kryvyi Rih, Ukraine, March 22, 2019* (*CEUR Workshop Proceedings* vol 2547) ed Kiv A E and Shyshkina M P (CEUR-WS.org) pp 145–155 URL https://ceur-ws.org/Vol-2547/paper11.pdf
[11] Malchenko S L, Tsarynnyk M S, Poliarenko V S, Berezovska-Savchuk N A and Liu S 2021 *Journal of Physics: Conference Series* **1946**(1) 012010 URL https://doi.org/10.1088/1742-6596/1946/1/012010
[12] Tkachenko I A 2016 *Methodical system of teaching astronomy at pedagogical universities* The thesis for the degree of Doctor of Pedagogical Sciences, specialty 13.00.02. – Theory and methods of teaching (astronomy) National Pedagogical University named after M.P. Dragomanov Kyiv URL https://nrat.ukrintei.ua/searchdoc/0516U000931/
[13] Sannikov S, Zhdanov F, Chebotarev P and Rabinovich P 2015 *Procedia Computer Science* **66** 720–729 ISSN 1877-0509 4th International Young Scientist Conference on Computational Science URL https://doi.org/10.1016/j.procs.2015.11.082

[14] Zacharia Z C and Olympiou G 2011 *Learning and Instruction* **21**(3) 317–331 ISSN 0959-4752 URL https://doi.org/10.1016/j.learninstruc.2010.03.001
[15] Volkova N P 2022 *Educational Dimension* **7** 21–80 URL https://doi.org/10.31812/educdim.4444
[16] Shepiliev D S, Semerikov S O, Yechkalo Y V, Tkachuk V V, Markova O M, Modlo Y O, Mintii I S, Mintii M M, Selivanova T V, Maksyshko N K, Vakaliuk T A, Osadchyi V V, Tarasenko R O, Amelina S M and Kiv A E 2021 *Journal of Physics: Conference Series* **1840**(1) 012028 URL https://doi.org/10.1088/1742-6596/1840/1/012028
[17] Bartrum P 2018 The Impact of Interactive Technology on the Future of School Education URL https://mdreducation.com/2018/05/22/interactive-technology-education/
[18] Song H S, Pusic M, Nick M W, Sarpel U, Plass J L and Kalet A L 2014 *Computers & Education* **71** 198–205 ISSN 0360-1315 URL https://doi.org/10.1016/j.compedu.2013.09.017
[19] Tabler T 2019 *Ukrainian Journal of Educational Studies and Information Technology* **7**(1) 54–66 URL https://doi.org/10.32919/uesit.2019.01.05
[20] Okopna Y, Morska N, Stakhova O, Voinalovych L, Protas O and Kravchenko O 2020 *Systematic Reviews in Pharmacy* **11**(8) 287–289 ISSN 09758453 URL https://cutt.ly/kwo0eelc
[21] Toma F, Ardelean A, Grădinaru C, Nedelea A and Diaconu D C 2023 *Sustainability* **15**(8) ISSN 2071-1050 URL https://doi.org/10.3390/su15086885
[22] Abykanova B, Nugumanova S, Yelezhanova S, Kabylkhamit Z and Sabirova Z 2016 *International Journal of Environmental and Science Education* **11**(18) 12528–12539 URL https://eric.ed.gov/?id=EJ1124626
[23] Bilousova L, Gryzun L and Zhytienova N 2021 *Educational Technology Quarterly* **2021**(3) 415–428 URL https://doi.org/10.55056/etq.34
[24] LoPresto M C and Slater T F 2016 *Journal of Astronomy & Earth Sciences Education (JAESE)* **3**(1) 59–76 URL https://doi.org/10.19030/jaese.v3i1.9685
[25] Johnson D W, Johnson R T and Holubec E J 1994 *Cooperative Learning in the Classroom* (Association for Supervision and Curriculum)
[26] Bacca J, Baldiris S, Fabregat R, Graf S and Kinshuk 2014 *Journal of Educational Technology & Society* **17** 133–149 ISSN 11763647, 14364522 URL http://www.jstor.org/stable/jeductechsoci.17.4.133
[27] Andrieieva A 2020 *Astronomy and today: materials of the IX All-Ukrainian scientific conference* ed Zabolotnyi V and Mozghovyi O (Vinnytsia: Vinnytsia Mykhailo Kotsiubynskyi State Pedagogical University)
[28] Akimkhanova Z, Turekhanova K and Karwasz G P 2023 *Education Sciences* **13**(4) 393 ISSN 2227-7102 URL https://doi.rog/10.3390/educsci13040393
[29] European Education and Culture Executive Agency and Eurydice 2019 Digital Education at School in Europe Eurydice report European Education and Culture Executive Agency URL https://doi.org/10.2797/763
[30] Khavrus V and Shelevytsky I 2010 *Physics Education* **45** 641–653 ISSN 00319120 URL https://doi.org/10.1088/0031-9120/45/6/010
[31] Khavrus V and Shelevytsky I 2012 *Physics Education* **47** 680–692 ISSN 00319120 URL https://doi.org/10.1088/0031-9120/47/6/680
[32] Velychko V, Fedorenko E, Kaidan N and Kaidan V 2021 *Educational Technology Quarterly* **2021**(4) 662–672 URL https://doi.org/10.55056/etq.38
[33] Kanivets O V, Kanivets I M and Gorda T M 2022 *Educational Technology Quarterly* **2022**(4) 347–365 URL https://doi.org/10.55056/etq.429
[34] Martyniuk O O, Martyniuk O S, Pankevych S and Muzyka I 2021 *Educational Technology Quarterly* **2021**(3) 347–359 URL https://doi.org/10.55056/etq.39
[35] Bobyliev D Y and Vihrova E V 2021 *Journal of Physics: Conference Series* **1840** 012002 URL https://doi.org/10.1088/1742-6596/1840/1/012002
[36] Vlasenko K, Volkov S, Sitak I, Lovianova I and Bobyliev D 2020 *E3S Web of Conferences* **166** 10012 ISSN 25550403 URL https://doi.org/10.1051/e3sconf/202016610012
[37] Vlasenko K, Chumak O, Sitak I, Lovianova I and Kondratyeva O 2019 *Universal Journal of Educational Research* **7** 1892–1900 ISSN 23323205 URL https://doi.org/10.13189/ujer.2019.070907
[38] Bonnarel F, Fernique P, Bienaymé O, Egret D, Genova F, Louys M, Ochsenbein F, Wenger M and Bartlett J G 2000 *Astron. Astrophys. Suppl. Ser.* **143** 33–40 URL https://doi.org/10.1051/aas:2000331

Journal of Physics: Conference Series

The use of ICT for mathematical calculations in the water quality assessment in the teaching of ecologists

The use of ICT for mathematical calculations in the water quality assessment in the teaching of ecologists

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Abstract. Research goal of the paper is the demonstration of computer technology integration in the modern educational process of teaching ecologists in practical classes on assessing the quality of water in water bodies, containing mathematical calculations. The use of modern information computer technologies in education will effectively contribute to the acquisition of a range of knowledge and skills on methods for water quality assessing in the field of water use and protection of water resources. The ability to use ICT will provide the ecologists with the ability to respond quickly to changes in the environment and make effective decisions in environmental management in future production activities.

1. Introduction

The use of computer technology is an integral attribute of the life of modern society. The sustainable development of any state depends on how effectively its potential is used to solve a wide range of current problems, including environmental. The content of environmental education in Ukraine is formed at the state level with the involvement of a wide range of scientists and practitioners and modern international experience [1–3].

The normative content of the standard of higher education for bachelor teaching in the specialty "Ecology" determines the program results of teaching, among which, along with the ability of graduates to solve problems in the field of environmental protection using generally accepted standard approaches, attention is drawn to the need to use software tools, GIS technologies, choose the best methods and tools for environmental research, data collection and processing [4, 5].

The implementation of one of the state environmental policy tasks is to ensure the protection, reproduction and rational use of water resources [6], is possible only if the water quality of the water body is rationing. The quality of water resources is an important component of a high-quality environment, which is ensured by establishing a set of acceptable values for indicators of its composition and properties [7, 8]. Therefore, special attention and relevance in the process of teaching ecologists acquire practical works of the environmental assessment of the state of water bodies through lengthy and cumbersome mathematical calculations.

To successfully solve complex practical issues of modern ecology, especially those related to the assessment and prediction of the quality and condition of ecosystems, mathematical models, which are usually written in the form of algebraic, transcendental and differential equations are used [9]. These equations are the basis of the simulation mathematical model, which allows, using software, to determine (calculate), predict, evaluate, analyze various options (scenarios) of changes in space and time of the main indicators (characteristics) of the state of ecosystems depending on external and internal factors, which affect the course of various hydrophysical, hydrochemical and hydrobiological processes [10–15].

One of the means of increasing the efficiency of water quality assessment of water bodies is the operational processing of information on the status of water quality, which is achieved through the use of ICT [16]. This is relevant for expediting the process of assessing the state of water bodies [17], and for the formation of the general competence of the future ecologist – skills of using information and communication technologies to solve complex specialized environmental problems [4]. Practical skills acquired during the learning process will allow the graduate to respond quickly to changes in the state of the environment and make effective decisions in environmental management.

The purpose of the paper is the demonstration of computer technology integration into the modern educational process of teaching ecologists in practical classes, which include mathematical calculations, during the formation of a complex of knowledge and skills of future ecologists.

2. Related works

The potential use of information and communication technologies (ICT) is enormous in a wide range of various disciplines teaching, for example, for the disciplines of the natural cycle, computer learning packages and the Internet resources can offer a variety of opportunities for learning ranging from non-interactive content provision to creating a learning environment using virtual reality technology [18–20].

Various groups of authors focus their attention both on the experience of using ready-made resources and on the creation and implementation of their own software developments that can optimize, improve the learning process; and also open the possibility of reaching to a whole new level [21–23].

Researches focusing on opportunities of expanding the scope of use information technologies are widespread. This expansion is directly related to their development. The article [24] is confirmed, that more diverse technologies expand the capabilities of the institution and even able to change its organization. This implementation process leads to a change in teachers and students motivation, the emergence of new forms of knowledge representations and more sophisticated human-computer interaction.

An example of such an experience is the presented organization of work in New South Wales schools [25]. Here are used information web sites, computer learning packages as tutorial material, computer learning packages made by students, simulations, virtual field trips and virtual laboratories. The article focuses on materials used in student learning, on forms of electronic communication with providing a list of resources.

The effectiveness of both research and educational activities is also increased through the formation of a complex vision of the problems of reality and the use of various approaches to their solution. In [26], was confirmed, the involvement of computer mathematics systems and the latest programming environments contributed to the progress of the computer modeling the method based on mathematical models of biological problems. The use of such integration made it possible to direct the content of education to familiarization and mastering of methods of modern systematic research for the purpose of in-depth study, qualitative analysis of objects and increasing the effectiveness of the formation of professional competences.

Ou et al. [27] considered the creation of a learning environment using virtual reality technology for discipline "Engineering hydrology". The creation of virtual reality scene is using Virtual Reality Modeling Language, which is a modeling language for creating scene models of the real world or three-dimensional scenes imagined by people, which has the platform-independent nature. Virtual reality scenes provides three-dimensional visualization of the watershed and hydraulic projects and interactive inquire of project information.

It is proposed to create a system that allows to manage learning content, organize and implement the process of engineering hydrology courses learning, supports a student-oriented training mode, which can be based, for example, on the problem of cases and projects.

Teachers can set up a virtual classroom on the platform and students can choose any section of the course for learning and discussion and learn the content by themselves; teachers can also track students' learning progress, make timely adjustments to meet the needs of learners to take full advantage of information technology to implement curriculum integration.

Theoretical and practical approaches to the use of information and communication technologies in teaching and learning presented in [28]. The authors established a chronology of the changing role of information and communication technologies in acquisition of environmental competences. In addition to analyzing the use of multimedia presentations in environmental education, an analysis of the possibility of using environmental problems from Internet resources in the educational process at some universities in Europe and the USA was carried out. The study supplements the theory and practice of environmental education. Specific recommendations on professional development opportunities with attracting information and communication technologies in environmental educational process were given.

Existence free, open source learning management systems for online learning, for example, Moodle, makes it possible to create e-classrooms of Hydrology courses. Sraj and Brilly [29] demonstrate effective experience of combination of traditional and distance based education. The created e-classrooms are a quality addition to the traditional educational process because besides the availability of the study materials that are easily accessed and uploaded in such e-classrooms, students can communicate with each other and with their teacher whenever their schedules permit, work in groups, examine their knowledge etc. The teacher can guide students, follows their progress and their collaboration, gathers and reviews assignments etc.

The effectiveness of complementing traditional forms of learning with information and communication technologies during the course "Environmental Monitoring" at A. Yasawi International Kazakh-Turkish University is presented in [30]. The authors compare and evaluate two groups of students, for the teaching of which only the traditional forms of teaching and forms using information and communication technologies are used. A comparison of the capabilities that each of the approaches is able to provide was made

Of course, the use of information and communication technologies in the educational process made it possible to resolve many didactic problems. Study the phenomena and processes in difficult ecological, technical and biological systems goes to a new level on the basis of use of means of computer graphics and computer modeling and to represent them in time scale convenient for studying.

The analysis of the research makes it possible to assert that the use of information technologies in environmental disciplines teaching requires further development. Examples of the use of e-classrooms, virtual environments and visualization tools are common, but the calculation component is also important. It can be greatly simplified by developing and using specialized software.

Irrespective of the proposed technology or discipline, which is studied with its use, the correct implementation of information technology will ensure the formation of the necessary special competences of the future specialist.

3. Mathematical models of water quality assessment of water bodies

Ecological education is a continuous process of upbringing, teaching, self-education and personal development, aimed at the formation of standards of moral behavior of future ecologists, their duties and responsibilities in relation to the environment, as well as obtaining special knowledge and practical skills in environmental protection, environmental management and ecological safety.

Recognizing the complexity and scale of goals in the field of environmental protection, teachers and scientists declare that it is possible in principle to achieve them, but acknowledge that temporary criteria and rationing of the educational process often lead to the inability to spend a lot of time on intermediate stages and calculations. Therefore, we suggest the way to speed up mathematical processing of environmental information using ICT, and free up time to teach students to analyze, assess, and make decisions about a problem. An example is the experience of implementation into the process of learning the discipline "Conservation and proper utilization of water resources" the automatic mathematical calculations on the practical classes which are dedicated to determining water quality according to existing methods.

In the activities of institutions State Environment Inspectorates, State Hydrometeorological Service and Ukraine Water Resources Board the hydrochemical Institute's method of assessment of water quality is applied [31]. Also the common method of complex assessment of water quality is calculation of water pollution indexes [32].

Complex assessment of the water quality is used in cases where it is necessary to follow the trend of spatio-temporal changes in the water status by influence of natural and anthropogenic processes. The rational approach to assessment of the water quality is a comparative analysis of existing methods of complex assessment, which is proposed by Odessa State Environmental University specialists [33].

Integrated indexes, on the basis of which the assessment is carried out, are calculated for all indexes of waters quality or their parts. They characterize the status of water as a whole, while information on separate indicators is lost.

The sequence of assessment consists of two stages: at the first stage, the indicator value is calculated, and at the second, the verbal characterization of water quality is given according to the calculated index value and the quality scale. The evaluation has several points.

Water pollution index *(WPI)* calculated by the formula:

$$WPI = \frac{1}{6}\sum_{i=1}^{6}\frac{C_i}{MPC_i}, \tag{1}$$

where MPC_i – maximum permissible concentrations of chemical component; C_i – actual concentrations of chemical ingredients; 6 – number of ingredients.

Therefore, the number of indicators that are taken to calculate the *WPI* should be six, and include dissolved oxygen (O_2), biochemical oxygen demand (BOD_5), total ammonium (NH_4^+), nitrites (NO_2^-), petroleum hydrocarbons (*PH*), phenolic compounds (C_6H_5OH).

Unlike other indicators, for dissolved oxygen in calculating *WPI* takes the ratio: standard (MPC_i)/factual concentration (C_i). The criteria of assessment of the water quality by *WPI* are shown in table 1.

The I class includes waters, which are least affected by anthropogenic load. The values of their hydrochemical and hydrobiological indicators are close to the natural values for this region. Waters of the II class are characterized by certain changes compared to natural ones, however, these changes do not violate the ecological balance. The III class includes waters that are under significant anthropogenic load, the level of which is close to the ecosystem sustainability limit. Waters of the IV–VII classes refer to waters with disturbed environmental parameters, and their ecological state is characterized as an ecological regress.

Modified water pollution index (*MWPI*) [33] also calculated on six indicators: biochemical oxygen demand (BOD_5) and dissolved oxygen (O_2) are compulsory, and the remaining four indicators are taken by the highest ratio to *MPC* from the list: sulphates (SO_4^{2-}), chlorides

Table 1. The criteria of assessment of the water quality by Water pollution index (*WPI*).

Water quality class	Characteristic of class	Water pollution index value
I	Very clean	< 0.3
II	Clean	$0.3 - 1.0$
III	Poorly contaminated	$1.0 - 2.5$
IV	Moderately contaminated	$2.5 - 4.0$
V	Contaminated	$4.0 - 6.0$
VI	Very contaminated	$6.0 - 10.0$
VII	Extremely contaminated	> 10.0

(Cl^-), chemical oxygen consumption (*COD*), total ammonium (NH_4^+), nitrites (NO_2^-), nitrates (NO_3^-), phosphate (PO_4^{3-}), iron (*Fe*), manganese (Mn^{2+}), copper (Cu^{2+}), zinc (Zn^{2+}), chromium (Cr^{6+}), nickel (Ni^{2+}), aluminum (Al^{3+}), plumbum (Pb^{2+}), mercury (Hg^{2+}), arsenic (As^{3+}), petroleum hydrocarbons (*PH*), synthetic surfactants.

The hydrochemical Institute's method of estimation of water quality [32] is to get an unambiguous assessment of the water quality and classifying water on its basis by the level of suitability for the main types of water use.

According to methods [32, 33], an assessment based on a combinatory index (*CIP*) includes several stages: determination of the nature of contamination by the value of the conditional complexity factor; setting water quality category and class by the value of the combinatory index; highlighting priorities pollutants by quantity and composition of limiting indicators of pollution; conducting a differentiated assessment of the limiting indicators of pollution.

Conditional complexity factor is calculated by the formula:

$$K = \frac{m'}{m} \cdot 100\%, \tag{2}$$

where m' – number of substances, the content of which exceeds *MPC*; m – total number of standard ingredients due to research program.

At $K < 10\%$ the survey is conducted on specific pollutants. The maximum concentration and availability of excesses of *MPC* (1 *MPC*, 10 *MPC*, 100 *MPC*) are determined.

At $K \geq 10\%$ a three-stage classification is carried out.

The first stage of classification is based on establishing the degree of persistency of pollution (frequency P of cases of *MPC* excess):

$$P_i = \frac{N_{MPC_i}}{N_i}, \tag{3}$$

where N_{MPC_i} – number of analysis results in which the content of the i-th ingredient exceeds its maximum permissible concentration; N_i – total number of analysis results of the i-th ingredient.

The second stage of classification is based on establishing a level of contamination, the extent of which is the multiplicity K of exceeding the *MPC*:

$$K_i = \frac{C_i}{MPC_i}. \tag{4}$$

Assessment points are determined according to table 2 and table 3.

Table 2. Classification of water bodies by the repeatability of pollution.

Repeatability, %	Water pollution characteristic	Partial assessment points: conditionally expressed	Partial assessment points: absolute values
0–10	single	a	1
10–30	unsteady	b	2
30–50	steady	c	3
50–100	characteristic	d	4

Table 3. Classification of water bodies by the multiplicity of excess of standards.

Multiplicity of excess of standards	Water pollution characteristic	Partial assessment points: conditionally expressed	Partial assessment points: absolute values
0–2	low level	a_1	1
2–10	average level	b_1	2
10–50	high level	c_1	3
50–100	very high level	d_1	4

In the process of determining the first and second degrees of water classification for each of the ingredients, generalized assessments of the water quality are calculated according to table 4.

For the final third degree of classification, the combinatory index of pollution (*CIP*) is calculated by adding generalized assessment points S_i for all n indicators:

$$CIP = \sum_{i=1}^{n} S_i, \tag{5}$$

Classification of water quality is performed depending on the value of *CIP* and the number of limiting indicators of pollution (*LIP*) (table 5 and table 6). Water *LIP* is any indicator the value S_i by which is greater than or equal to 12.

A key factor in the effectiveness of mechanisms for solving environmental problems in assessment of the water quality is the ability to conduct a comparative analysis of the data obtained by different methods. The need to promptly obtain complete reasonable information for data analysis emphasizes again the need to use computer technology with appropriate software, an example of which we describe in the next section of the article.

4. Software for optimizing the processing of environmental information

In this research, we present the experience of using ICT to speed up cumbersome mathematical calculations in practical classes on determining water quality according to the existent methods in the process of studying the discipline "Conservation and proper utilization of water resources" when teaching bachelors in the specialty "Ecology".

We developed a software product that allowed replacing the "manual" processing of ecological information. Previously, the time (number of hours) that was allocated for assessing the water

Table 4. Assessment of the state of water bodies by selected indicators.

Complex characteristics of water pollution status of water bodies	General assessment points: conditionally expressed	General assessment points: absolute values	Characteristics of water quality of water bodies
		Single pollution	
low level	$a \cdot a_1$	1	poorly contaminated
average level	$a \cdot b_1$	2	moderately contaminated
high level	$a \cdot c_1$	3	contaminated
very high level	$a \cdot d_1$	4	contaminated
		Unsteady pollution	
low level	$b \cdot a_1$	2	moderately contaminated
average level	$b \cdot b_1$	4	contaminated
high level	$b \cdot c_1$	6	very contaminated
very high level	$b \cdot d_1$	8	very contaminated
		Steady pollution	
low level	$c \cdot a_1$	3	contaminated
average level	$c \cdot b_1$	6	very contaminated
high level	$c \cdot c_1$	9	very contaminated
very high level	$c \cdot d_1$	12	extremely contaminated
		Characteristic pollution	
low level	$d \cdot a_1$	4	contaminated
average level	$d \cdot b_1$	8	very contaminated
high level	$d \cdot c_1$	12	extremely contaminated
very high level	$d \cdot d_1$	16	extremely contaminated

quality in water bodies according to the discipline curriculum was sufficient for processing according to two (the simplest) methods (*WPI* and *MWPI*) according to one type of standard. Using a computer allowed within the same practical works also to perform processing according to The hydrochemical Institute's method of assessment of quality water (*CIP*). In addition, there is enough time for calculations for all three types of standards (for water bodies for fishery standards, drinking needs, cultural and recreational purposes). Students manage to perform a comparative analysis of the results and make a list of recommendations for solving the ecological problem.

Let us consider in more detail the general functional and architectural features of the developed software (table 7).

The developed software consists of a local database, an interface for interacting with the user, a reporting system and the calculation automation system, as indicated in the scheme (figure 1).

The main program window (figure 2) consists of: an interface for presenting tabular data, a section for sorting data by date, a section for entering data, and a section for choosing a method for calculation of surface water quality.

According to the results of measurements, the student enters into the table the values of

Table 5. Water quality classification of water bodies by values of CIP and LIP (0–2).

Water quality class	Discharge of quality class	Water contamination characteristic	Value of CIP without LIP	Value of CIP 1LIP (k=0,9)	Value of CIP 2LIP (k=0,8)
I	-	Poorly contaminated	1n	0.9n	0.8n
II	-	Moderately contaminated	$1n \div 2n$	$0.9n \div 1.8n$	$0.8n \div 1.6n$
III	*a*	Contaminated	$2n \div 3n$	$1.8n \div 2.7n$	$1.6n \div 2.4n$
III	*b*	Contaminated	$3n \div 4n$	$2.7n \div 3.6n$	$2.4n \div 3.2n$
IV	*a*	Very contaminated	$4n \div 6n$	$3.6n \div 5.4n$	$3.2n \div 4.8n$
IV	*b*	Very contaminated	$6n \div 8n$	$5.4n \div 7.2n$	$4.8n \div 6.4n$
IV	*c*	Very contaminated	$8n \div 10n$	$7.2n \div 9.0n$	$6.4n \div 8.0n$
IV	*d*	Very contaminated	$10n \div 11n$	$9.0n \div 9.9n$	$8.0n \div 8.8n$

Table 6. Water quality classification of water bodies by values of CIP and LIP (3–5).

Water quality class	Discharge of quality class	Water contamination characteristic	Value of CIP 3LIP (k=0,7)	Value of CIP 4LIP (k=0,6)	Value of CIP 5LIP (k=0,5)
I	-	Poorly contaminated	0.7n	0.6n	0.5n
II	-	Moderately contaminated	$0.7n \div 1.4n$	$0.6n \div 1.2n$	$0.5n \div 1.0n$
III	*a*	Contaminated	$1.4n \div 2.1n$	$1.2n \div 1.8n$	$1.0n \div 1.5n$
III	*b*	Contaminated	$2.1n \div 2.8n$	$1.8n \div 2.4n$	$1.0n \div 2.0n$
IV	*a*	Very contaminated	$2.8n \div 4.2n$	$2.4n \div 3.6n$	$2.0n \div 3.0n$
IV	*b*	Very contaminated	$4.2n \div 5.6n$	$3.6n \div 4.8n$	$3.0n \div 4.0n$
IV	*c*	Very contaminated	$5.6n \div 7.0n$	$4.8n \div 6.0n$	$4.0n \div 5.0n$
IV	*d*	Very contaminated	$7.0n \div 7.7n$	$6.0n \div 6.6n$	$5.0n \div 5.5n$

the ingredients for the corresponding date. Next, choose the assessment methods, standards, according to which calculations will be made. The program assesses the water quality by pressing the “Calculate” button, and the calculation results are displayed above the table in text form (figure 3). The calculation windows for each of the three methods are presented below (figure 3, figure 4, figure 5).

The main menu of the program includes the functions of exiting the application, editing database records, setting parameters for assessing surface water quality (figure 6).

This software was created using the integrated development environment Microsoft Visual Studio in the programming language $C\#$. The mdb format database was selected as the data storage tool. This solution allows providing software support for all versions of the Windows operating system starting with XP, allows using the software even on very “weak” personal computers, which is one of the essential real factors in present conditions.

The choice of these technologies is grounded by the following aspects:

- the possibility of using this software on personal computers in modern educational

Table 7. Description of the database tables of the information system for surface water quality analysis.

№	Table name	Short description of the tables contents
1	Drinking	Indicators of maximum permissible concentrations for drinking needs are stored
2	Recreational	Indicators of maximum permissible concentrations for cultural and recreational purposes are stored
3	Fishery	Indicators of maximum permissible concentrations for fishery standards are stored
4	WPI	Water quality assessment criteria by the water pollution index are stored
5	CIP-2-1	Water body classification criteria by repeatability are stored
6	CIP-2-2	Classification criteria for water bodies on the level of contamination are stored
7	CIP-2-3	Criteria for assessing the status of water bodies are stored
8	CIP-2-4	Classification criteria for the quality of water bodies by the combinatory index of pollution are stored
9	Result	Surface water quality assessment data for all methods are stored
10	Data	Quality indicators of a water sample, that was taken at a particular point in time, are stored

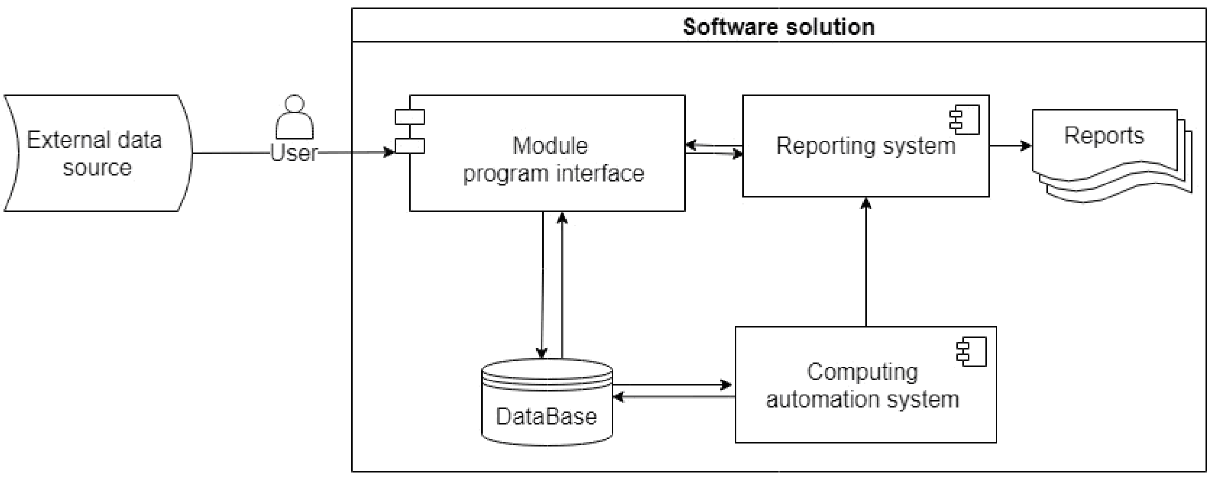

Figure 1. Functional scheme of the information system.

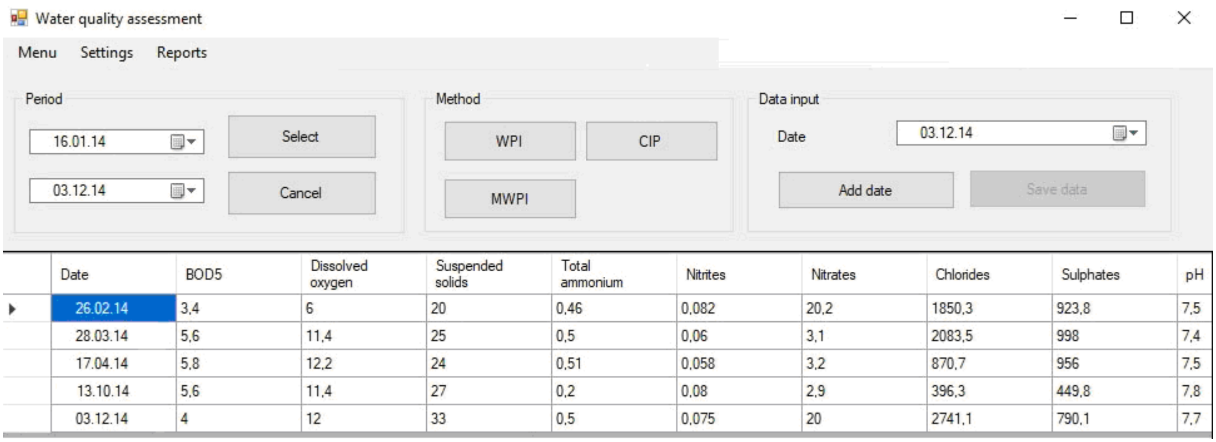

Figure 2. The main window of the program.

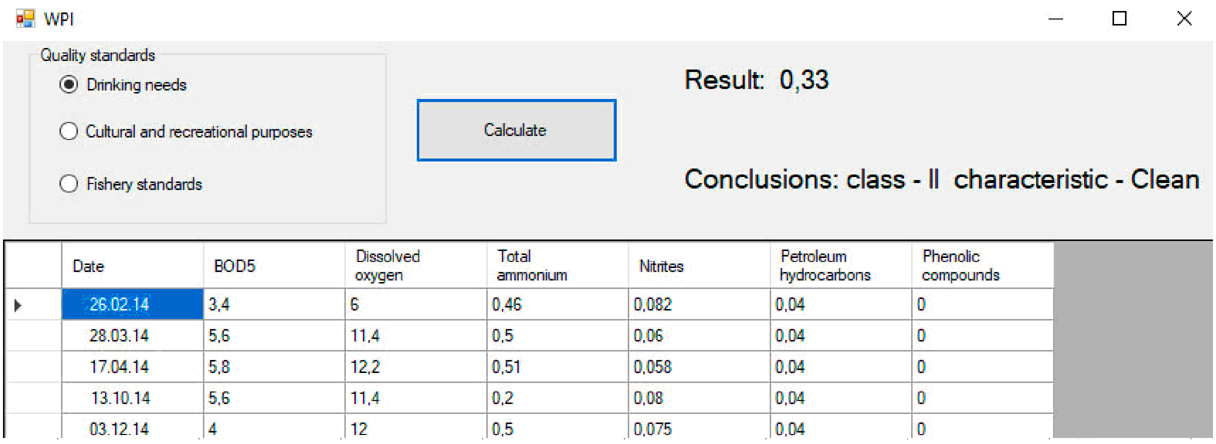

Figure 3. Window for assessing water quality according to the *WPI*.

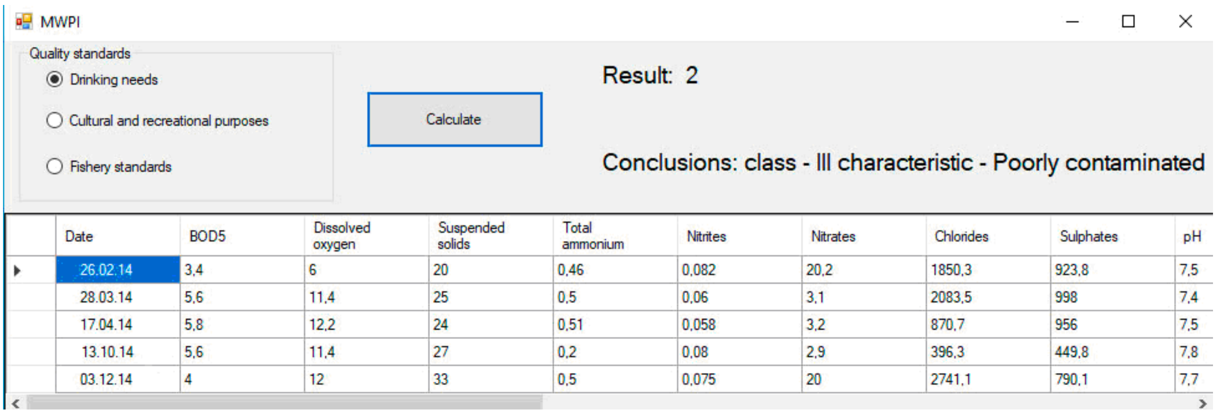

Figure 4. Window for assessing water quality according to the *MWPI*.

institutions;

- expanding capabilities for working with data which are not provided by the direct functionality of the program, due to the use of a local database of the mdb format. This

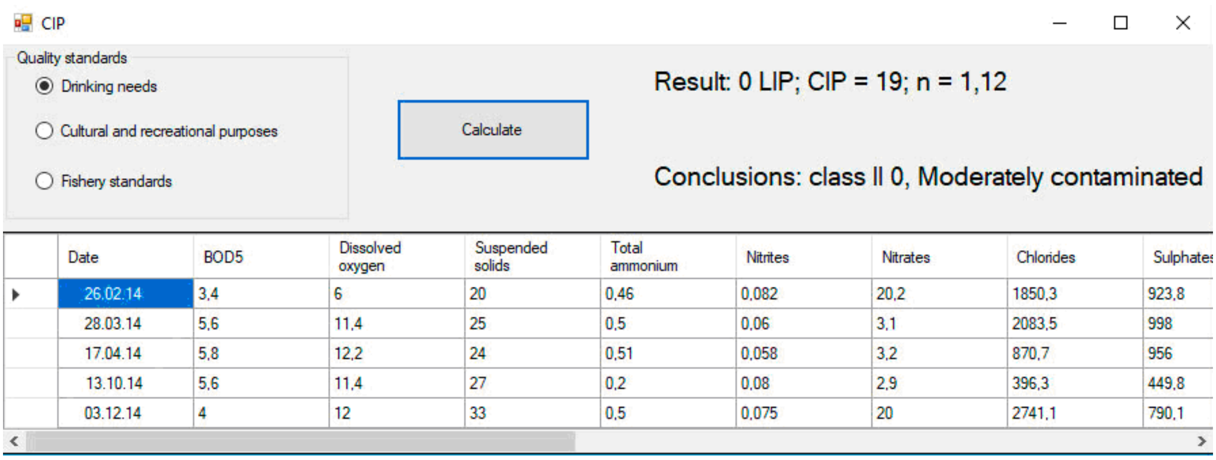

Figure 5. Window for assessing water quality according to the *CIP*.

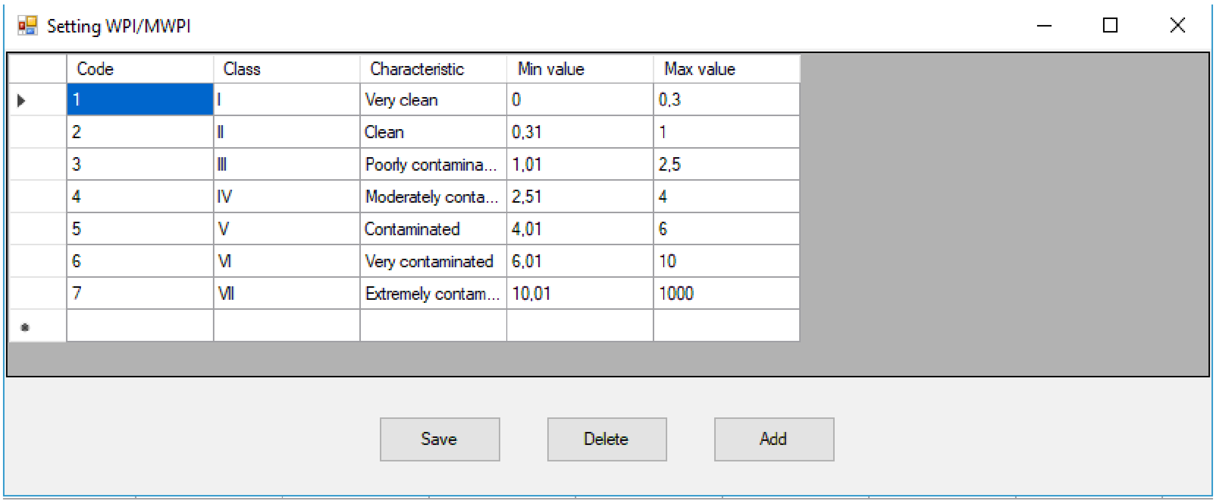

Figure 6. Window for water quality assessment criteria according to *WPI*.

format allows the user to edit the database using the standard Microsoft Office suite (using Microsoft Access), starting with 2003;

- simplicity of working with software due to the lack of an authorization module.

The software, which was created in the presented format, allows students with primary knowledge of the basics of working with a computer to use it both for educational purposes and in their future professional activities. Therefore, it can be recommended for use in structural departments of state environmental inspectorates, water quality control organizations and environmental protection departments.

The software product is successfully integrated into the complex of practical works in the discipline "Conservation and proper utilization of water resources" when a complex assessment of the water quality of surface water bodies is carried out. The software product has clear user instructions for working with the system, a convenient and simple interface, ease of data entry, the ability to expand the number of indicators that are used to analyze water quality.

Automation of mathematical calculations made it possible to reduce the time of practical work by 6 times. Previously, manual water quality assessment was performed during one practical lesson (90 minutes). Now 15 minutes is enough to form an array of data and immediately receive the assessment results.

The remaining time allows students to determine the quality of water not by one, but by three methods, perform a comparative analysis of the results and make a decision on the possibility of using the water body for the needs of a particular water user.

Five years of practical experience in the discipline “Protection and rational use of water resources” with the use of ICT allows us to claim that students not only quickly, accurately and reasonably establish the fact of an environmental problem (pollution of a water body), but also acquire the ability to analyze critically the received information. Thus, the bases of system analysis are formed in future ecologists’ thinking, which are necessary for the formation of large-scale and strategic decision-making thinking in the field of water management.

5. Conclusions and outlook

The article highlights an example of integration of software for mathematical calculations (on the example of a complex assessment of water quality according to modern calculation methods) in the formation of a set of knowledge and skills of future ecologists for use in professional activities in the area of ecology, environmental protection, and balanced environmental management.

The software product is integrated into the educational process of students-ecologists in a complex of practical works on the discipline “Conservation and rational use of water resources” during complex assessment of the water quality of surface water bodies. This makes it possible to reduce the time of practical work by 6 times, to increase the number of studied methods for assessing water quality, to perform a comparative analysis of the results and to make a decision on the possibility of using a water body.

The development and implementation of information technologies in the educational process requires further research aimed at creating varied application software. Automation of the processing of ecological information will ensure prompt receipt of complete and reliable information about the quality of the environment. The introduction of ICT in education will optimize the educational process, enhance the cognitive and creative activities of students, increase efficiency and productivity, create conditions for in-depth learning of special disciplines. The potential of using modern computer means will contribute to the expansion of methods, forms and ways of educating ecologists.

References

[1] Lavrentieva O, Pererva V, Krupskyi O, Britchenko I and Shabanov S 2020 *E3S Web of Conferences* **166** 10031 ISSN 25550403 URL `https://doi.org/10.1051/e3sconf/202016610031`

[2] Vardanian M 2022 *Children’s Literature in Education* **53**(1) ISSN 00456713 URL `https://doi.org/10.1007/s10583-021-09437-w`

[3] 2012 *International Standard Classification of Education ISCED 2011* (Montreal, Quebec: UNESCO Institute for Statistics) URL `https://uis.unesco.org/sites/default/files/documents/international-standard-classification-of-education-isced-2011-en.pdf`

[4] 2018 Standard of higher education in specialty 101 “Ecology” branch of knowledge 10 “Natural sciences” URL `https://mon.gov.ua/ua/osvita/visha-osvita/naukovo-metodichna-rada-ministerstva-osviti-i-nauki-ukrayini/zatverdzheni-standarti-vishoyi-osviti`

[5] Kholoshyn I, Nazarenko T, Bondarenko O, Hanchuk O and Varfolomyeyeva I 2021 *Journal of Physics: Conference Series* **1840**(1) 012017 ISSN 17426588 URL `https://doi.org/10.1088/1742-6596/1840/1/012017`

[6] 2019 The Law of Ukraine ’On the Fundamentals (strategy) of the State Environmental Policy of Ukraine till 2030’ URL `https://zakon.rada.gov.ua/laws/show/2697-19#Text`

[7] Stoliarenko V, Chernova M and Yakovchuk O 2020 *E3S Web of Conferences* **166** 01005 ISSN 25550403 URL `https://doi.org/10.1051/e3sconf/202016601005`

[8] Alokhina T and Gudzenko V 2021 *E3S Web of Conferences* **280** 11003 ISSN 25550403 URL `https://doi.org/10.1051/e3sconf/202128011003`

[9] Lavryk V 2002 *Methods of mathematical modeling in ecology* (Kyiv: KM Academy Publishing House)
[10] Mokin V and Kryzhanovsky E 2002 *Geoinformatic Systems in Ecology* (Vinnitsa: VNTU)
[11] Bystriantseva A, Shakhman I and Bystriantsev M 2019 Spatio-Temporal Representation of the Ecological State of the Surface Waters of the Lower Section of the Dnieper River using GIS Technologies *Proceedings of the 15th International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer. Volume I: Main Conference, Kherson, Ukraine, June 12-15, 2019* (*CEUR Workshop Proceedings* vol 2387) ed Ermolayev V, Mallet F, Yakovyna V, Mayr H C and Spivakovsky A (CEUR-WS.org) pp 127–140 URL https://ceur-ws.org/Vol-2387/20190127.pdf
[12] Shakhman I and Bystriantseva A 2021 *Journal of Ecological Engineering* **22**(1) 195–205 URL https://doi.org/10.12911/22998993/128858
[13] Mitryasova O, Ciesla M, Nosyk A and Mats A 2021 *Journal of Ecological Engineering* **22**(8) 111–122 URL https://doi.org/10.12911/22998993/140264
[14] Sillberg C V, Kullavanijaya P and Chavalparit O 2021 *Journal of Ecological Engineering* **22**(9) 70–86 URL https://doi.org/10.12911/22998993/141364
[15] Aalipour M, Stastny B, Horky F and Amiri B J 2022 *Water* **14**(6) 920 URL https://doi.org/10.3390/w14060920
[16] Kobets V, Bystriantseva A and Shakhman I 2018 *CEUR Workshop Proceedings* **2105** 151–166 URL https://ceur-ws.org/Vol-2105/10000151.pdf
[17] Shakhman I A and Bystriantseva A N 2018 Assessment of ecological state and ecological reliability of the lower section of the Dnieper river *International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM* vol 18 (International Multidisciplinary Scientific Geoconference) pp 113–119 URL https://doi.org/10.5593/sgem2018/5.2/S20.015
[18] Burov O 2021 *Educational Technology Quarterly* **2021** 689–700 URL https://doi.org/10.55056/etq.43
[19] Klochko O V and Fedorets V M 2022 *Educational Technology Quarterly* **2022** 276–306 URL https://doi.org/10.55056/etq.431
[20] Burov O Y and Pinchuk O P 2023 *Educational Technology Quarterly* **2023** 58–68 URL https://doi.org/10.55056/etq.435
[21] Kanivets O V, Kanivets I M and Gorda T M 2022 *Educational Technology Quarterly* **2022** 347–365 URL https://doi.org/10.55056/etq.429
[22] Prokhorov O V, Lisovichenko V O, Mazorchuk M S and Kuzminska O H 2022 *Educational Technology Quarterly* **2022** 366–387 URL https://doi.org/10.55056/etq.430
[23] Marchuk G V, Levkivskyi V V, Graf M S, Dombrovska Y A and Panarina I V 2023 *Educational Technology Quarterly* **2023** 92–105 URL https://doi.org/10.55056/etq.30
[24] Cox M J 2008 Researching IT in Education *International Handbook of Information Technology in Primary and Secondary Education* ed Voogt J and Knezek G (Boston, MA: Springer US) pp 965–981 ISBN 978-0-387-73315-9 URL https://doi.org/10.1007/978-0-387-73315-9_61
[25] Peat M and Fernandez A 2000 *Journal of Biological Education* **34**(2) 69–73 URL https://doi.org/10.1080/00219266.2000.9655688
[26] Tsidylo I M, Shevchyk L O, Hrod I M, Solonetska H V and Shabaga S B 2022 *Journal of Physics: Conference Series* **2288** 012014 URL https://doi.org/10.1088/1742-6596/2288/1/012014
[27] Ou J, Dong Y n and Yang B 2009 Virtual reality technology in engineering hydrology education *2009 International Symposium on Computer Network and Multimedia Technology* pp 1–4 URL https://doi.org/10.1109/CNMT.2009.5374601
[28] Demeshkant N, Dankievich L and Narolsky N 2017 *Gospodarka, Rynek, Edukacja* **18**(3) 51–56 URL https://www.researchgate.net/publication/321082313
[29] Sraj M and Brilly M 2012 E-classrooms at Hydrology courses *Proceedings of the 9th International Conference on Urban Drainage Modelling* vol 4 (Belgrade) URL https://www.researchgate.net/publication/256846895
[30] Berkimbaev K M, Akeshova M M, Meirbekov A T and Meirbekova G P 2013 *Life Science Journal* **10**(6s) 501–507 URL https://doi.org/10.7537/marslsj1006s13.77
[31] Emel'janova V P, Danilova G N and Kolesnikova T H 1983 Ocenka kachestva poverhnostnyh vod sushi po gidrohimicheskim pokazateljam [Evaluation of the quality of surface water on hydrochemical indicators] *Gidrohimicheskie materialy [Hydro-chemical materials]* vol LXXXVIII (Leningrad: Gidrometeoizdat) pp 119–129
[32] Snizhko S 2001 *Assessing and predicting the quality of natural waters* (Kiev: Nika-Tsentr)
[33] Jurasov S, Safranov T and Chugaj A 2012 *Evaluation of the quality of natural waters: Tutorial* (Odessa: Ecology)

Journal of Physics: Conference Series

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Digitalization of geographic higher education: problems and prospects

To cite this article: O V Bondarenko *et al* 2023 *J. Phys.: Conf. Ser.* **2611** 012015

Digitalization of geographic higher education: problems and prospects

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Abstract. The article addresses the relevant issue of today – digitalization of geographic higher education. The future of geographic education in the digital world depends on the use of digital technologies, which are dramatically changing approaches to teaching geography. The generalization of scientific literature and the analysis of pedagogical experience allow the authors to define the concept digitalization of geographic. The article explores some challenges in the implementation of digital technologies in geographic disciplines in higher education: narrowing geographic education digitalization to the use of various gadgets; the application of general purpose digital technologies; underestimation of GIS technologies during the study of geography; occasional use of VR, AR technologies and mobile applications of geographic and cartographic content; the lack of educational and methodological support and proper technological availability. The authors pay special attention to the prospects for the development of geographic education digitalization, which are envisioned in the introduction of "Digitalization of geographic education" into the curriculum of future geography teachers training; the use of high-quality free educational resources (ArcGIS Online, QGIS); the creation of own geo-information platforms ("Digital Geography"); and updating of the material and technical base of the scientific research laboratory on the methodology of teaching geo-information technologies.

1. Introduction

1.1. The problem statement

Pandemic restrictions and the introduction of martial law in Ukraine have caused the search for adequate ways of the educational process organization and forms of learning in educational institutions [1]. Higher education institutions are actively introducing distance and blended learning accompanied by extensive use of digital technologies [2–5]. These current changes have resulted in mastering various digital educational technologies and methods of their application by teachers. "What initially seemed like a temporary measure gradually turned into routine educational practices that are being normalized and institutionalized" [6]. Meanwhile, the active digitalization of education in general and geographic one in particular faces a number of challenges that hinders its progress [7]. Primarily, teachers and students lack of individual experience of working in a digital environment relevant to the pace and content of the digitalization of society that might be explained by the absence of focus on the formation of the essential digital competencies in the educational curriculums of future geography teachers training. Moreover, there is a shortage of digital tools and electronic educational resources for a full-fledged educational and methodological maintenance of the geography study accompanied by the lack of high-quality digital educational geographic content and open access available for all participants in the educational process.

Therefore, the relevance of the research problem is determined by a range of contradictions, namely,

- between the social significance of the geographic education digitalization and its actual state;
- between an ever-increasing amount of independent and individual work of students and the necessity to facilitate all types of educational and cognitive activity of geographer students anytime and anywhere with available and appropriate means of GIS technologies, ICT, and mobile ones particularly;
- between the potentials of modern digital technologies and an inappropriate level of their mastering by students and teachers of higher education institutions.

Overall, educational digitalization requires as corresponding scientific and methodological, as technological and financial support.

We envision the solution of our research issue in the theoretically substantiated and practically approved methodical system of digitalization of geographic education via creating the informational educational environment of higher educational institutions. The latter comprises the implementation of digital technologies (GIS, mobile and cloud ICT and teaching aids), taking into account the methodological conditions, and aims at the formation of professional competence of future geography teachers, specifically digital one. However, this publication focuses on defining the concept of "digitalization of geographic education", clarifying its essence, advantages and disadvantages.

1.2. The objective of the article

The article aims to determine the essence and the content of digitalization of geographic education, to disclose the challenges and prospects of its development.

1.3. Theoretical background

Digitalization of education has become the subject of many scientific studies devoted to the theoretical and methodological foundations of distance education (Myroslav I. Zhaldak [8], Yukhum I. Mashbyts [9], Illia O. Teplytskyi [10], Svitlana V. Shokaliuk [11]); blended learning (Liudmyla I. Bilousova [12], Kateryna P. Osadcha [13], Iryna S. Mintii [14], Serhiy O. Semerikov [15], Yurii V. Tryus [16]); development of the informational and educational environment (Mariia A. Kislova [17], Kateryna I. Slovak [18], Liubov F. Panchenko [19], Kateryna V. Vlasenko [20], Olena O. Lavrentieva [21], Mariana M. Kovtoniuk [22], Tetiana A. Vakaliuk [23], Yuriy L. Kuchyn [24], Oleksandr Yu. Burov [25]); and information and communication competence of teachers in the conditions of a cloud-oriented educational environment (Kateryna V. Vlasenko [26], Iryna V. Lovianova [27], Tetiana A. Vakaliuk [28], Nataliia V. Morze [29], Mykhailo V. Moiseienko [30]); adaptive cloud-oriented system of training and professional development of teachers of secondary school (Hanna B. Varina [31], Yuliya H. Nosenko [32], Kateryna P. Osadcha [33]); determination of teachers readiness and need of digital tools and ICT during quarantine (Oksana V. Ovcharuk [34]); digital transformation of education (Tetiana V. Sych [7], Olga P. Pinchuk [35], Oksana V. Ovcharuk [36], Andrey V. Pikilnyak [37]).

Volodymyr Yu. Areshonkov highlights that digitalization of higher education is a necessary response to social challenges [38]. Analyzing the problems arising in the field of higher education, the author identifies a number of tasks for state administration bodies, teams and university administrations, which fulfillment contributes to the processes of digitalization of university education. The digital transformation of education should result in the digital competence of an educator (Nataliia V. Morze [29]).

The researches concerning geographic education can be of a great interest in view of our scientific problem. Rafael de Miguel González, Karl Donert, and Kostis Koutsopoulos [39] summarize the experience of using geospatial technologies during the study of geography, keeping the attention focus on the implementation of web GIS in educational practice, and the formation of geospatial competencies in the process of education digitalization. Scientists argue that education equipped with GIS technologies currently occupies a worthy place among the methods of learning, and can facilitate the solution of many social issues.

Angrla Hogan [40] clarifies the nature of the difficulties occurring during the digitalization of geographic education such as low level of digital literacy of students and teachers; narrowing digitalization to the use of ICT only; underestimation of field studies in geography, etc. Nicola Walshe and Grace Healy [41], considering the future of geographic education in the digital world, emphasize that digital technologies dramatically changes approaches to teaching geography. The authors state that the implementation of digital technologies can be a challenging task accounted for technical problems, lack of experience in their use, and an overwhelming information for analysis and systematization. However, the advantages of digital technologies in geography education far outweigh the problems, and therefore provide powerful opportunities for realizing their didactic potential during education. The results of the analysis of geography curricula regarding digital technologies made by Carina Peter and Sandra Sprenger [42] prove that digitalization in higher education institutions is mostly reduced to the use of various gadgets at class and GIS technologies or remote sensing of the Earth.

However, the COVID-19 crisis has already affected and continues to transform geographic education. There is an urgent need to provide educational institutions with appropriate technologies and software accompanied by educational curricula updating, supplemented with various digital technologies (VR, AR technologies, mobile applications, etc.). The issue of distance and blended learning, which require digital technologies for visualization of educational content and digital communication between participants in the educational process, is still relevant. Stefania Palmentieri [43], analyzing his own pedagogical experience of emergency distance education in geography in higher education, emphasizes the necessity of taking advantage of the best practices of effective online study of geography. The researches on the history and prospects of GIS implementation in the geography education [44, 45] and scientific and methodological support for the digitalization of education in Ukraine [6] are within the scope of this publication.

The previous works of the authors concern cloud technologies as means of creating educational resources of remote sensing of the Earth and an information database covering more than 800 aerial photographs that can be used during the study of geography [46]. The authors address pedagogical methods of using Earth remote sensing data in modern school practice [47]; and characterize the use of GIS technologies during the study of school geography [48].

Nevertheless, the analysis of scientific research allows us to immerse into the core of the problem we are studying, and reveal certain gaps related to some of its important aspects, specifically the definition of the essence and content of digitalization of geographic education.

2. Results and discussion

The abrupt and mass transition from the real classrooms to virtual networks brought to life radical changes in the organization of the educational environment and accentuated the urgency for the general digitalization of education, and specifically geographic one.

The latest scientific literature interprets digitalization of education as the introduction of modern ICT technologies into the educational process aiming to equip the youth with the 21st century skills, for instance, to analyze the reliability of received information, to apply critical thinking, etc. Educational digitalization involves extensive use of varied multimedia content for educational purposes, and interactive learning methods for the intensification of educational process [49].

Digitalization of education assumes the augmented, virtual and mixed reality, cloud, mobile and Internet technologies, educational gamification, distance learning, open online courses for mass audience, and the launch of digital universities. It is a prerequisite for the raise of the level of organization of the educational process, the insurance of the availability of electronic resources and services, the increase of ICT competence level among students and teachers.

We consider the digitalization of geographic education to be the introduction of modern digital technologies in the process of geographic disciplines study aimed at the formation of future teacher professional competence. The implementation of geographic education digitalization may ensure the sustainability of the overall educational process and the professional training of future geography teachers especially in the conditions of social crisis phenomena. The geography students should acquire skills by working with appropriate equipment and software such as GIS, digital weather stations, tools for creation of new generation electronic educational resources while taking geography courses, and thus develop their professional competence. The digital technologies in geographic education will provide an opportunity to explore various physical and socio-geographical objects, phenomena and processes, to identify their causes and predict their effects on sustainable social development.

Nowadays, digital technologies evolve extremely rapidly, so their implementation in the education has a number of advantages that affect its quality. The remote mode enables students to master geographic disciplines synchronously or asynchronously outside the classroom, regardless of the location; to adapt the pace and schedule of study to their individual needs. The digital technologies opens up many new opportunities, primarily related to multi-channel pedagogical communication: video lessons, presentation, teacher's live speech, student group chat, etc.

VR and AR technologies are gaining their importance in geography education as they offer a new and innovative approach to the study of geography making the process more interactive and engaging for students. These technologies can visualize the object as much as possible. If previously many geographical phenomena and processes were presented in 2-D format, now they can be in the form of 3-D models available in normal, anaglyph or stereoscopic modes. Students receive information in a ready-to-perceive look, without spending time and cognitive effort on its interpretation. Educational AR and VR technologies enrich visual and contextual learning, improving the content of information, and contributing to the productive assimilation of what is learned.

However, the global transition to e-learning has vividly manifested a great lack of tried-and-tested uniformed educational methods in digital pedagogy. Teachers of higher education institutions worked out their methods by trial and error or borrowed them from related fields, i.e. business or television online conferences, business trainers, and even teenage streamers. So, geography teachers were no exception.

The general analysis of the experience of digitalization in geographic education uncover a variety of technologies currently applied by teachers in the educational process (table 1).

The review of the methods of geography teaching argues that secondary school teachers most often make use of some digital technologies of general purpose, for example, Classtime, LearningApps, MiiKlas, Na Urok, Mozaika Education, videoscribing technologies, blogs, online puzzle generators, tapes, tests, etc. The above-mentioned technologies help to acquire knowledge of geography and provide communicative interaction between a teacher and students. Higher education institutions mostly implement GIS technologies (Google Earth, Google Maps, DataGraf, MapInfo, ArcGIS), which train students to work with cartographic materials. Geography teachers in secondary school very rarely put into practice specialized digital

Table 1. Digital educational technologies (DET) used in geographic education.

A variety of DET	DET used in higher education institutions	DET used in school
Digital educational technologies of general purpose		
Educational platforms (Open Source)	Moodle, Google Classroom	Google Classroom, Human
Educational platforms of online courses / online education studios	Coursera, Udemy, EdX, Prometheus, EdEra, Osvitoria	Prometheus, EdEra, Osvitoria
Educational portals	All-Ukrainian school online, Na Urok, Vseosvita	All-Ukrainian school online, Na Urok, Vseosvita
Communication applications for the implementation of video conferences	Zoom, GoogleMeet, Viber, Telegram	GoogleMeet. Zoom, Viber,
Platforms of virtual educational simulations	Labster	
Online services for didactic purpose	LearningApps, Mozaika Education	Classtime, LearningApps, MyClass, Na Urok, Mozaika Education
Electronic journals and notebooks	The possibility is provided in Moodle, or automated educational process management systems are used	New knowledge
Specialized digital educational technologies		
GIS	MapInfo, ArcGIS Online, QGIS, DataGraf et al.	
Cloud services	Google Earth, Seterra, Gismeteo, Gapminder (Trendalyzer), Our World in Data, Google Maps	Google Earth, Seterra, Gismeteo, Google Maps

technologies if ever.

All above facts considered bring to light certain problems in geography teaching practice:

- narrowing the digitalization of geographic education to the use of various gadgets or general purpose digital technologies;
- underestimation of GIS technologies, technologies of remote sensing of the Earth, satellite navigation;
- occasional use of VR, AR technologies, mobile applications with cartographic content, etc.;
- geography student may be unaware of wide range of services and application used at school due to their diversity;
- a teacher tends to use the limited technologies that he managed to master on his own, without proper methodical support;
- specialized digital technologies, particularly cartographic ones, are rarely used in school practice due to the lack of necessary educational and methodological support and proper

technological access.

The list of observed problems and pitfalls cannot be considered exhaustive, since the application of digital technologies causes a number of other challenges of a technical and psychological nature. Yet, the humanization of the education in the age of digitalization requires a teacher to manage student's educational motivation during group facilitation as the self-organization basis. However, we do not dwell on the detailed characteristics of all the difficulties, as we only note that the real state of educational digitalization, especially geographical one, unfortunately does not fully correspond to social needs and the level of modern geographical science development. The potential possibilities of digital technologies are much wider than the level of their use in educational practice.

In connection with the above stated, we envision the prospects for further digitalization of geographic education as following:

1. The development of the normative course "Digitalization of geographic education" and its implementation into the master's degree training (3 credits, 90 hours). The course is aimed at the study of digital technologies of general purpose and specialized, which are used by geography teachers in their professional activities. The introduction of the course is planned for the 2023-2024 academic year.
2. Capacity building of geographic education by using a variety of high-quality open educational resources (ArcGIS Online, QGIS, etc.), accompanied by the creation of own geo-information platforms (for example, such as "Digital Geography"). All materials created should be flexible and provide the user with a set of tools to create new information modules. The planned resources (GIS "Digital Geography") and toolkits are supposed to contribute to quality of teaching and ensure tangible results in the mastery of modern digital technologies by students.
3. Revitalization of the research laboratory on the methods of teaching geo-information technologies in order to popularize the digitalization of geographic education as among future as practicing teachers. The authors of this publication have already created and tested a database of educational satellite images for geography study to use in secondary and higher schools; we also work on writing a series of methodological recommendations how to use digital technologies in the study of geography.
4. Equipping a modern educational laboratory and updating the material and technical base of the research laboratory on the methods of teaching geo-information technologies with for the information technology equipment. The basic digital infrastructure of such laboratories contains laptops (to collect, save, analyze and visualize digital geoinformation), the quadcopter (to monitor natural and anthropogenic objects, phenomena and processes), the autonomous weather station (to measure atmospheric indicators of weather conditions online), the plotter (for large format printing of digital geoinformation), the scanner (to scan and vectorize geoinformation), the interactive board, projector and screen (to visualize digital geoinformation).

We believe that the implementation of the specified aspects of digitalization of geographic education in the near future should have a positive effect on the professional competence of future geography teachers, their commitment to professional development, and mastery of information technologies.

3. Conclusion

The theoretical generalization of scientific resources and the analysis of educational practice let us consider the digitalization of geographic higher education not only as one of the actual directions of its modernization, but also as a rather promising way of popularization of geography among student. Modern digital technologies have powerful didactic opportunities for daily learning exploration of planet Earth. They allow studying the Earth in its physical dynamics and the world in its socio-economic aspect.

Presently the implementation of digital technologies in the study of geography has a number of issues, among which are the shortage of digital tools and electronic educational resources for full-fledged educational and methodological maintenance of the study of geography accompanied by the lack of high-quality digital educational geographical content, and open access available for all participants in the educational process, etc. The provision of appropriate technological and financial support to a certain extent will contribute to overcoming these shortcomings in the digitalization of geographic higher education. With the view of increasing the potential of geographic higher education, we are planning in the near future to use various high-quality open educational resources (ArcGIS Online, QGIS, etc.), to create our own geo-information platforms; to revitalize the scientific research laboratory on the methodology of teaching geo-information technologies and to update its material base. The authors of the article have developed the course "Digitalization of Geographical Education" for the Master's degree training, which results they intend to highlight in their further scientific works.

We see the prospects for further scientific research in solving the following tasks: to determine the state, directions and prospects of digitalization of geographic education; to develop a model of the methodical system of digitalization of geographic education and to identify methodical conditions for its effective implementation; to implement digital technologies, in particular GIS, VR and AR technologies in higher education institutions in order to form the professional competence of future geography teachers; to check experimentally some components of the projected methodical system of digitalization of geographic education; to develop methodical recommendations for the implementation of the methodical system of digitalization of geographic education.

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References

[1] Kovalchuk V I, Maslich S V and Movchan L H 2023 *Educational Technology Quarterly* **2023**(1) 1–17 URL https://doi.org/10.55056/etq.49

[2] Syvyi M J, Mazbayev O B, Varakuta O M, Panteleeva N B and Bondarenko O V 2020 Distance learning as innovation technology of school geographical education *Proceedings of the 3rd International Workshop on Augmented Reality in Education, Kryvyi Rih, Ukraine, May 13, 2020* (*CEUR Workshop Proceedings* vol 2731) ed Burov O Y and Kiv A E (CEUR-WS.org) pp 369–382 URL https://ceur-ws.org/Vol-2731/paper22.pdf

[3] Bobyliev D Y and Vihrova E V 2021 *Journal of Physics: Conference Series* **1840**(1) 012002 URL https://doi.org/10.1088/1742-6596/1840/1/012002

[4] Mintii I S, Vakaliuk T A, Ivanova S M, Chernysh O A, Hryshchenko S M and Semerikov S O 2021 Current state and prospects of distance learning development in Ukraine *Proceedings of the 4th International Workshop on Augmented Reality in Education (AREdu 2021), Kryvyi Rih, Ukraine, May 11, 2021* (*CEUR Workshop Proceedings* vol 2898) ed Lytvynova S H and Semerikov S O (CEUR-WS.org) pp 41–55 URL https://ceur-ws.org/Vol-2898/paper01.pdf

[5] Martyniuk O O, Martyniuk O S, Pankevych S and Muzyka I 2021 *Educational Technology Quarterly* **2021**(3) 347–359 URL https://doi.org/10.55056/etq.39

[6] Kremen V, Bykov V, Liashenko O, Lytvynova S, Lugovyi V, Malovanyi Y, Pinchuk O and Topuzov O 2022 *Herald of the National Academy of Educational Sciences of Ukraine* **4**(2) 1–49 URL https://doi.org/10.37472/v.naes.2022.4223

[7] Sych T, Khrykov Y and Ptakhina O 2021 *Educational Technology Quarterly* **2021**(2) 293–309 URL https://doi.org/10.55056/etq.27

[8] Zhaldak M I, Franchuk V M and Franchuk N P 2021 *Journal of Physics: Conference Series* **1840**(1) 012001 URL https://doi.org/10.1088/1742-6596/1840/1/012001

[9] Smulson M, Mashbyts Y and Zhaldak M 2012 *Dystantsiyne navchannya: psykholohichni zasady [Distance learning: psychological principles]* (Kirovohrad: Imeks-LTD)

[10] Semerikov S O, Teplytskyi I O, Soloviev V N, Hamaniuk V A, Ponomareva N S, Kolgatin O H, Kolgatina L S, Byelyavtseva T V, Amelina S M and Tarasenko R O 2021 *Journal of Physics: Conference Series* **1840**(1) 012036 ISSN 17426588 URL https://doi.org/10.1088/1742-6596/1840/1/012036

[11] Lehka L V and Shokaliuk S V 2018 *CEUR Workshop Proceedings* **2292** 76–82 ISSN 16130073 URL https://ceur-ws.org/Vol-2292/paper07.pdf

[12] Bilousova L, Gryzun L and Zhytienova N 2021 *Educational Technology Quarterly* **2021**(3) 415–428 URL https://doi.org/10.55056/etq.34

[13] Osadcha K, Osadchyi V, Kruglyk V and Spirin O 2021 *Educational Dimension* **5** 109–125 URL https://doi.org/10.31812/educdim.4721

[14] Mintii I S 2023 *Educational Dimension* URL https://doi.org/10.31812/ed.539

[15] Tkachuk V, Yechkalo Y, Semerikov S, Kislova M and Hladyr Y 2021 Using Mobile ICT for Online Learning During COVID-19 Lockdown *Information and Communication Technologies in Education, Research, and Industrial Applications* ed Bollin A, Ermolayev V, Mayr H C, Nikitchenko M, Spivakovsky A, Tkachuk M, Yakovyna V and Zholtkevych G (Cham: Springer International Publishing) pp 46–67 ISBN 978-3-030-77592-6

[16] Tryus Y V and Herasymenko I V 2021 *Journal of Physics: Conference Series* **1840**(1) 012034 URL https://doi.org/10.1088/1742-6596/1840/1/012034

[17] Tkachuk V, Yechkalo Y V, Semerikov S, Kislova M and Khotskina V 2020 Exploring Student Uses of Mobile Technologies in University Classrooms: Audience Response Systems and Development of Multimedia *Proceedings of the 16th International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer. Volume II: Workshops, Kharkiv, Ukraine, October 06-10, 2020* (*CEUR Workshop Proceedings* vol 2732) ed Sokolov O, Zholtkevych G, Yakovyna V, Tarasich Y, Kharchenko V, Kobets V, Burov O, Semerikov S and Kravtsov H (CEUR-WS.org) pp 1217–1232 URL https://ceur-ws.org/Vol-2732/20201217.pdf

[18] Morkun V, Semerikov S, Hryshchenko S and Slovak K 2017 Environmental Geo-information Technologies as a Tool of Pre-service Mining Engineer's Training for Sustainable Development of Mining Industry *Proceedings of the 13th International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer, ICTERI 2017, Kyiv, Ukraine, May 15-18, 2017* (*CEUR Workshop Proceedings* vol 1844) ed Ermolayev V, Bassiliades N, Fill H, Yakovyna V, Mayr H C, Kharchenko V S, Peschanenko V S, Shyshkina M, Nikitchenko M S and Spivakovsky A (CEUR-WS.org) pp 303–310 URL https://ceur-ws.org/Vol-1844/10000303.pdf

[19] Panchenko L 2021 *Educational Technology Quarterly* **2021**(4) 673–688 URL https://doi.org/10.55056/etq.41

[20] Vlasenko K, Chumak O, Achkan V, Lovianova I and Kondratyeva O 2020 *Universal Journal of Educational Research* **8**(8) 3527–3535 ISSN 23323205 URL https://doi.org/10.13189/ujer.2020.080828

[21] Lavrentieva O, Horbatiuk R, Skripnik L, Kuchma O, Penia V and Pahuta M 2021 *Journal of Physics: Conference Series* **1840**(1) 012060 ISSN 17426588 URL https://doi.org/10.1088/1742-6596/1840/1/012060

[22] Kovtoniuk M, Kosovets O, Soia O and Tyutyun L 2022 *Educational Technology Quarterly* **2022**(3) 183–202 URL https://doi.org/10.55056/etq.35

[23] Vakaliuk T 2021 *Educational Technology Quarterly* **2021**(2) 257–273 URL https://doi.org/10.55056/etq.17

[24] Kuchyn Y, Naumenko O, Vlasenko O, Lytvynova S, Burov O, Kucherenko I and Mykytenko P 2022 *Educational Technology Quarterly* **2022**(1) 73–87 URL https://doi.org/10.55056/etq.10

[25] Burov O 2021 *Educational Technology Quarterly* **2021**(4) 689–700 URL https://doi.org/10.55056/etq.43

[26] Vlasenko K V, Chumak O O, Lovianova I V, Achkan V V and Sitak I V 2022 *Journal of Physics: Conference Series* **2288**(1) 012038 ISSN 17426588 URL https://doi.org10.1088/1742-6596/2288/1/012038

[27] Lovianova I, Krasnoschok A, Kaluhin R, Kozhukhar O and Dmytriyev D 2021 *Educational Technology Quarterly* **2021**(2) 331–346 URL https://doi.org/10.55056/etq.14

[28] Vakaliuk T, Spirin O, Korotun O, Antoniuk D, Medvedieva M and Novitska I 2022 *Educational Technology Quarterly* **2022**(3) 232–250 URL https://doi.org/10.55056/etq.32

[29] Morze N, Buinytska O, Varchenko-Trotsenko L, Vasylenko S, Nastas D, Tiutiunnyk A and Lytvynova S 2022 *Educational Technology Quarterly* **2022**(2) 152–168 URL https://doi.org/10.55056/etq.6

[30] Moiseienko M 2020 *Educational Dimension* **3** 347–357 URL https://doi.org/10.31812/educdim.v55i0.4379

[31] Varina H B, Osadchyi V V, Osadcha K P, Shevchenko S V and Lytvynova S H 2021 *CTE Workshop Proceedings* **8** 521–538 URL https://doi.org/10.55056/cte.305

[32] Nosenko Y H, Popel M V and Shyshkina M P 2019 *CTE Workshop Proceedings* **6** 173–183 URL https://doi.org/10.55056/cte.377

[33] Osadcha K, Osadchyi V, Semerikov S, Chemerys H and Chorna A 2020 The Review of the Adaptive Learning Systems for the Formation of Individual Educational Trajectory *Proceedings of the 16th International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer. Volume II: Workshops, Kharkiv, Ukraine, October 06-10, 2020* (*CEUR Workshop Proceedings* vol 2732) ed Sokolov O, Zholtkevych G, Yakovyna V, Tarasich Y, Kharchenko V, Kobets V, Burov O, Semerikov S and Kravtsov H (CEUR-WS.org) pp 547–558 URL https://ceur-ws.org/Vol-2732/20200547.pdf

[34] Ovcharuk O and Ivaniuk I 2021 *Educational Dimension* **5** 75–88 URL https://doi.org/10.31812/educdim.4719

[35] Pinchuk O P, Sokolyuk O M, Burov O Y and Shyshkina M P 2019 *CTE Workshop Proceedings* **6** 90–101 URL https://doi.org/10.55056/cte.370

[36] Ovcharuk O V, Gurzhii A M, Ivaniuk I V, Kartashova L A, Hrytsenchuk O O, Vakaliuk T A and Shyshkina M P 2022 *CTE Workshop Proceedings* **9** 16–27 URL https://doi.org/10.55056/cte.96

[37] Pikilnyak A V, Stetsenko N M, Stetsenko V P, Bondarenko T V and Tkachuk H V 2021 *CTE Workshop Proceedings* **8** 70–81 URL https://doi.org/10.55056/cte.204

[38] Areshonkov V 2020 *Herald of the National Academy of Educational Sciences of Ukraine* **2**(2) 1–6 URL https://visnyk.naps.gov.ua/index.php/journal/article/view/106

[39] de Miguel González R, Donert K and Koutsopoulos K (eds) 2019 *Geospatial Technologies in Geography Education* Key Challenges in Geography (Cham: Springer) URL https://doi.org/10.1007/978-3-030-17783-6

[40] Hogan A 2021 *Digital Technologies and the Senior Geography Classroom: Teachers' Perceptions of the Impact on Teaching and Learning* Ph.D. thesis Auckland University of Technology URL https://openrepository.aut.ac.nz/handle/10292/13922

[41] Walshe N and Healy G (eds) 2020 *Geography Education in the Digital World: Linking Theory and Practice* (London: Routledge)

[42] Peter C and Sprenger S 2022 *Erdkunde* **76**(1) 3–19 URL https://doi.org/10.3112/erdkunde.2022.01.01

[43] Palmentieri S 2022 *AIMS Geosciences* **8**(1) 52–67 URL https://doi.org/10.3934/geosci.2022004

[44] Peresadko V A, Saulenko A S and Bainazarov A M 2019 *Problems of Continuous Geographic Education and Cartography* (30) 81–93 URL https://doi.org/10.26565/2075-1893-2019-30-09

[45] Chubrei O 2020 *Systema pidhotovky maybutnikh uchyteliv heohrafiyi do profesiynoyi diyal'nosti na zasadakh kompetentnisnoho pidkhodu [The system of training future geography teachers for professional activity based on the competence approach]* (Chernivtsi: Technoprint) URL https://archer.chnu.edu.ua/xmlui/handle/123456789/3255

[46] Kholoshyn I V, Bondarenko O V, Hanchuk O V and Varfolomyeyeva I M 2020 *CTE Workshop Proceedings* **7** 474–486 URL https://doi.org/10.55056/cte.388

[47] Kholoshyn I V, Varfolomyeyeva I M, Hanchuk O V, Bondarenko O V and Pikilnyak A V 2019 *CTE Workshop Proceedings* **6** 391–402 URL https://doi.org/10.55056/cte.399

[48] Kholoshyn I, Nazarenko T, Bondarenko O, Hanchuk O and Varfolomyeyeva I 2021 *Journal of Physics: Conference Series* **1840**(1) 012017 URL https://doi.org/10.1088/1742-6596/1840/1/012017

[49] Ishchenko A Y 2020 Natsional'na platforma tsyfrovoyi osvity yak priorytetnyy instrument onovlennya vitchyznyanoyi osvitn'oyi systemy [National digital education platform as a priority tool for updating the national education system] Tech. rep. National Institute for Strategic Studies URL https://niss.gov.ua/en/node/3628

Journal of Physics: Conference Series

PAPER • OPEN ACCESS

The use of GIS in renewable energy specialist’s learning

To cite this article: I S Zinovieva *et al* 2023 *J. Phys.: Conf. Ser.* **2611** 012016

The use of GIS in renewable energy specialist's learning

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Abstract. In recent years, the global trend has been to gradually shift from traditional energy sources to renewable ones, with the aim of improving the environment and preventing climate change. Geographic Information Systems (GIS) are technologies that enhance the efficiency of these renewable energy resources (RER). Modern GIS provides a wide range of functionalities for the entire decision-making process. For instance, in solar power generation, GIS can address challenges such as remote monitoring of sites designated for solar power plants and evaluating their suitability. It also enables effective management of information on station operations, real-time electricity production and distribution, and planning and management of energy production resources. As GIS continues to evolve, scientists and energy professionals are discovering more applications in the RER field. However, it's crucial to focus on training highly skilled specialists in RER to ensure GIS becomes a truly effective management tool in their professional activities. Research indicates that most student training programs in RER worldwide do not sufficiently cover GIS studies, particularly open-source software. To address this gap, the authors have developed a targeted plan for incorporating GIS into RER specialist training. The goal of this course is to familiarize future engineers with the theoretical, methodological, and technological foundations of GIS creation and operation. It also aims to help students understand the general principles of operation and acquire practical skills in using GIS to solve applied problems. The authors emphasize the importance of laboratory work, particularly using SagaGIS, to develop skills in working with raster and vector images, geospatial data analysis and decision-making, working with cartographic models and remote sensing data, and applying geoinformation methods to create structural, parametric, and thematic digital maps. The authors suggest using open GIS in training to facilitate a quality understanding for future RER specialists on the processes of creating, operating, and using GIS for real-world applications.

1. Introduction

The need for vast energy resources is crucial for human survival and development, making energy security a significant global challenge in the 21st century [1, 2]. The recent armed aggression of the Russian Federation against Ukraine has underscored the urgency of this issue, prompting many countries to focus on renewable energy resources (RER) due to rising energy prices and the need to find new suppliers and logistics channels.

Renewable energy resources refer to energy sources that naturally replenish themselves, such as solar radiation, wind, plant biomass, water flows, and geothermal sources. Utilizing RER can improve environmental conditions by reducing harmful emissions, increase a country's energy independence and security, and decrease reliance on traditional energy resources like coal, gas, oil, and refined products. However, it's worth noting that until recently, Ukraine's use of RER has been relatively low due to factors such as low and uneven energy flow density, seasonal dependence, significant investment capital intensity for such projects, and a lack of qualified experts in the field.

Enhancing education quality is a critical aspect of human development, including in Ukraine. As the modern world rapidly evolves with advancing information technologies, the domestic higher education system struggles to adapt its curricula and plans to meet market and societal demands. This issue is particularly relevant in training specialists in Electrical Power Engineering, Electrical Engineering, and Electromechanics (field of knowledge 14 "Electrical Engineering").

The educational and professional training program for students majoring in 141 "Electricity, Electrical Engineering, and Electromechanics" is designed to primarily train competitive professionals. These professionals are expected to have developed professional competencies in the field of RER and be capable of designing, creating, and operating power plants using renewable energy sources.

Currently, in Ukraine, such specialists are trained in eight higher educational institutions (figure 1). These include:

1. Chernivtsi National University named after Yuri Fedkovych
2. Kherson National Technical University
3. National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"
4. National Aerospace University M.E. Zhukovsky "Kharkiv Aviation Institute"
5. O.M.Beketov National University of Urban Economy in Kharkiv
6. National Technical University "Dnipro Polytechnic"
7. National University "Odesa Polytechnic"
8. Ivano-Frankivsk National Technical University of Oil and Gas

Education is provided according to the educational programs of the first (bachelor's), second (master's), and third (educational-scientific) levels of higher education.

According to the qualification requirements for specialists in specialty 141 "Power Engineering, Electrical Engineering, and Electromechanics", they are expected to possess knowledge and skills in various disciplines. These include mathematical and natural science cycles, electrical engineering and electrical technology, as well as computer technology. They

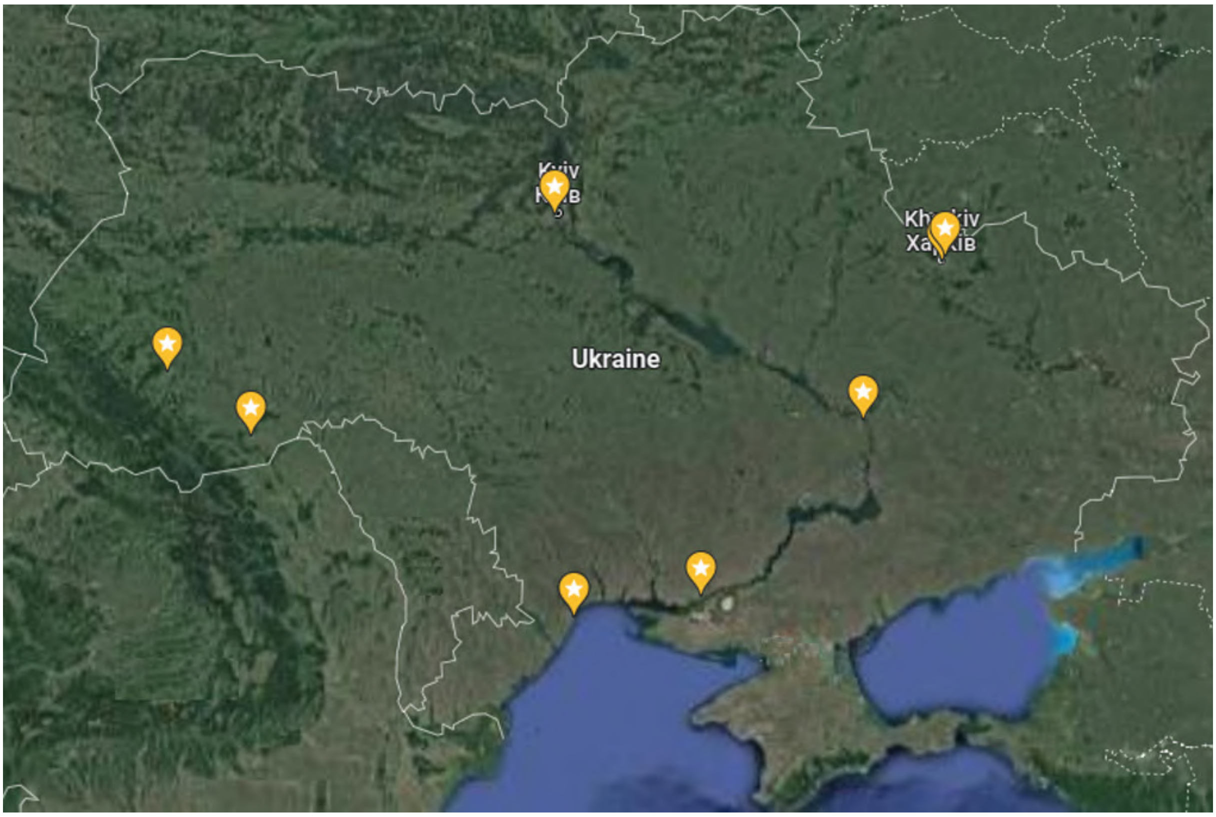

Figure 1. Territorial location of Ukrainian higher education institutions that train specialists in RER.

should also be proficient in computer and information technology for modeling and designing modern electrical equipment [3].

An examination of the curricula and educational and professional programs for specialty 141 "Electric Power, Electrical Engineering and Electromechanics" [4–11] reveals that the training program for future specialists in RER at the aforementioned higher education institutions includes disciplines in information technology. These include "Information and Communication Technologies in Electrical Engineering", "Automated Control Systems for Technological Processes in Electrical Networks", "Intelligent Systems in Energy", "Automation of Renewable Energy Plants", and "Electromechanical Technical Systems". These disciplines aim to develop the professional competencies of future professionals by teaching them to use modern IT and software to address various challenges in their professional activities.

One potential area of application for the knowledge of future specialists in the field of RER is socio-environmental. This field addresses issues related to efficient use of natural resources, environmental protection, government transparency, land management, and more. Most of these issues rely on the development, implementation, and use of geographic information systems and technologies.

The functionality of GIS includes [12]:

- Data input: This involves importing from existing digital datasets or digitizing sources.
- Data conversion: This includes converting data from one format to another, transforming map projections, changing coordinate systems, storing, manipulating, and managing data in internal and external databases, performing map metric operations, geodetic data processing operations, overlay operations, and cartographic algebra operations.

- Spatial analysis: This function provides analysis of the location, relationships, or other spatial relationships of objects. It includes visibility/invisibility zone analysis, proximity analysis, network analysis, creation and processing of digital terrain models, and analysis of objects within buffer zones.
- Spatial modeling (geomodeling): These operations are similar to those used in mathematical cartographic modeling and cartographic research methods. It also includes visualization of input, derivative or final data (cartographic visualization, design, and creation of cartographic images).
- Data output: This involves graphic, tabular, and textual documentation including its reproduction, documentation, and report generation.
- Support for decision-making processes.

Modern Geographic Information Systems (GIS) are more than just systems for automated processing of geospatial data, vectorization, and real-time visualization of objects and events. They also offer a robust set of geospatial analysis tools and strategic support for management decisions. Given these capabilities, it's surprising that there's a lack of discipline in the curricula and educational and professional programs of higher education institutions in Ukraine that would highlight the methods and ways of using GIS by RER specialists [13, 14].

Back in 2016, in the dissertation of Agapova [15], it has been observed that one of the shortcomings in the training of mapping specialists is their limited proficiency in modern cartographic GIS services. This includes web GIS, information and reference cartographic internet services, among others. It's crucial to address this gap to ensure that these specialists are equipped with the necessary skills to effectively utilize these advanced tools in their professional field. Similar opinions are found in other publications [16, 17]. And, as practice shows, as of mid-2022, this problem in Ukraine still exists.

At the national level, the use of GIS is regulated by a number of regulations, including the concept of the National Automated System "Open Environment" [18], the Concept of Digital Competencies [19], and the Law of Ukraine "On National Geospatial Data Infrastructure" [20].

As Ukraine is in the process of automating various aspects of social and environmental spheres of activity, it is important to pay attention to the need for high-quality training of highly qualified specialists not only in geodesy, land use, and management but also in RER. These circumstances require higher education institutions to strengthen the geographic information vector of their students. Among other things, modern GIS and software should be used in educational practice to best meet the educational goals and professional competencies of future RER specialists.

2. Materials and methods

The field of geoinformatics in Ukraine is relatively young, and consequently, there is a scarcity of robust methodological support for educators in this discipline [12, 21, 22]. The majority of existing scientific and methodological developments in this area primarily focus on the design and application of Geographic Information Systems (GIS) to solve practical scientific and real-world problems [17, 23–32].

For instance, Volkov [23] highlights that environmental management presents a classic spatial problem where source information comprises both spatial and attributive data, collectively providing insights into environmental quality.

Zatserkovny [24] systematically organizes the fundamental aspects of geographic information technologies and systems, emphasizing the creation and preservation of electronic maps through these technologies. The presentation delves into the models and algorithms that underpin spatial analysis in GIS and explores software tools for data integration and technology implementation.

Mokin et al. [25] describe the integration of mathematical models into surface water monitoring practices using GIS. They detail a range of methods, techniques, algorithms, and software tools applied to critical applications in flood water monitoring and the modeling of ecological processes in aquatic ecosystems within Ukraine.

In a different context, Iatsyshyn et al [33] discuss the implementation of a specific course titled "Methods and Means of Environmental Monitoring of the Surface Layer of the Atmosphere" to train future professionals in ecology and environmental protection using specialized software and modeling systems. This experience offers valuable insights that can be considered when developing the curriculum for the course "GIS for RER's specialist".

It is worth noting that, when exploring the use of GIS in the context of Renewable Energy Resources (RER), international experiences can provide valuable insights. For instance, Marcu [34] investigates the use of a GIS system model based on ArcGIS tools to assess the potential of RER, especially in the establishment of new power plants utilizing solar and geothermal energy sources.

Additionally, Jeong and González-Gómez [35] explore the incorporation of a web application into the STEM education system. This application aids in assessing the suitability of biomass plant locations, allowing students to evaluate multiple alternatives and make informed decisions regarding biomass settings at various operational levels. The authors emphasize the importance of employing such tools to realize the "lifelong learning" strategy.

Furthermore, the combination of Earth remote sensing (ERS) with modern GIS techniques for studying RER capabilities is highlighted in [36]. The authors investigate the optimal locations for renewable energy sources across the globe, emphasizing the simplification and streamlining of RER research processes through remote sensing methods and GIS.

To provide organizational and methodological support for the pedagogical process, textbooks, manuals, laboratory workshops, and other educational materials have been developed (e.g., Pavlenko [37], Svitlychnyi and Plotnytskyi [38], Shipulin and Kucherenko [39]). These resources offer valuable information on GIS concepts, structures, types, and construction specifics, along with practical recommendations and case studies for a range of applied tasks. However, they require adaptation to suit the training programs within the RER field.

The growing number of studies in this area underscores the increasing importance and relevance of GIS in contemporary society. Nevertheless, many of these advancements are primarily targeted at experienced professionals in environmental management and may not readily translate into educational contexts for specialty 141 "Electric Power, Electrical Engineering, and Electromechanics". This analysis reveals a gap in the use of GIS as a means to develop professional competencies in RER specialists.

In light of these findings, it is essential to address the disparity between national higher education standards for RER specialists and the current practices used to cultivate professional competencies in future professionals. One potential solution is the development and integration of a GIS course into the curriculum for specialty 141 "Electric Power, Electrical Engineering, and Electromechanics".

The research methods employed in this work encompass analysis, systematization, the examination of practical experiences, comparative analysis, and the selection of specialized software, utilizing export valuations methodology. SAGA GIS and Google Earth served as the tools for processing geospatial data and fostering the professional competencies of RER specialists.

3. Results

The cultivation of professional competencies among future specialists in Renewable Energy Resources (RER) entails a multifaceted approach that encompasses the adoption of environmentally sustainable practices to harness the georesource potential of the environment. This process necessitates a comprehensive integration of various natural sciences, including physics, chemistry, biology, ecology, construction, geology, geography, mathematics, mechanics, computer technology, information and communication technologies, as well as proficiency in information systems and artificial intelligence.

Upon scrutinizing the educational programs and curricula of higher educational institutions in Ukraine, particularly within the discipline of specialty 141 "Electric Power, Electrical Engineering, and Electromechanics" it becomes evident that the training of future RER specialists predominantly emphasizes the utilization of natural and technical sciences, while the fundamental sciences receive comparatively limited attention.

The imperative for future specialists in the RER field to acquire proficiency in Geographic Information Systems (GIS) is well-founded, driven by professional requirements, societal significance, and the growing demand within the field. This competency aligns with the imperative to foster a holistic understanding of renewable energy and its sustainable integration into our environment (figure 2).

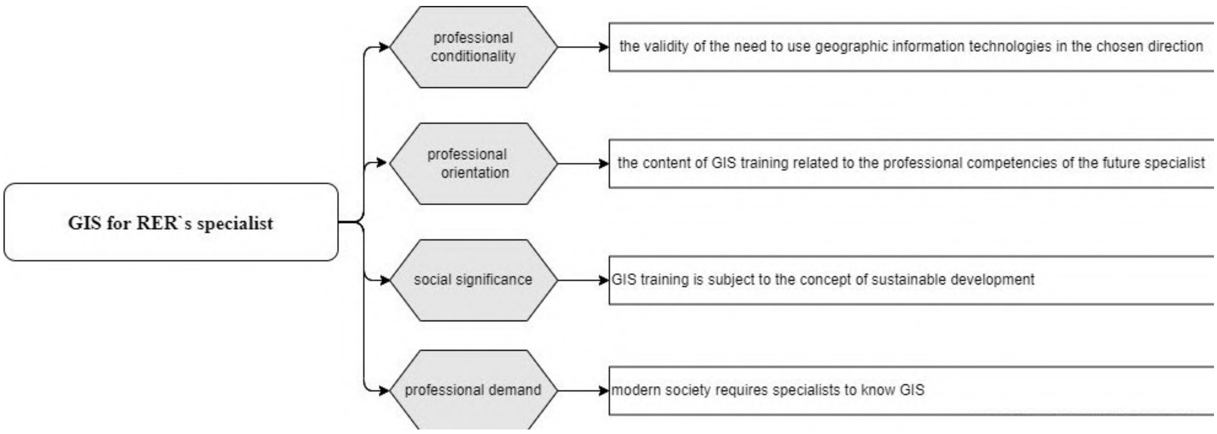

Figure 2. Justification of the need to study the discipline "GIS for RER's specialist".

The course titled "GIS for RER's specialist" is dedicated to the exploration of fundamental principles related to contemporary computer systems for mapping and geospatial analysis of real-world objects and events. Its overarching objective is to advance the pursuit of energy balance through the utilization of alternative energy sources. GIS represent cutting-edge tools that facilitate decision-making across both time and space domains. Their functionality relies on current information processing methods and is simultaneously accessible to a broad audience thanks to visualization technologies.

The primary aim of this course is to familiarize future engineers with the theoretical, methodological, and technological underpinnings of geographic information systems. Students will acquire a comprehensive understanding of the general principles governing GIS operation while also honing practical skills for employing GIS to address practical challenges. These tasks encompass:

1) equipping applicants with the knowledge and skills essential for proficiently operating modern geographic information systems;
2) cultivating the practical competencies of future specialists, enabling them to effectively utilize standard geographic information systems to address real-world challenges, including:
   - use of mapping skills in the design and operation of alternative energy stations;
   - use of instruments of geospatial measurements on the earth's surface, assessment of the suitability of land allocation for alternative energy stations;
   - vectorization and geometrization of areas allocated for renewable energy sources;

Table 1. Priority goals of implementation of the discipline "GIS for RER's specialist" in the educational process of training specialists in the field of RER (author's development).

Number of goal group	The name of the goal group	Detailing goals in the group
I	Cognitive goals	• understanding of the complexity of the issue of energy production from alternative sources; • the ability to perceive and identify cause-and-effect relationships and to understand the key importance of the need to maintain energy balance through the use of alternative energy sources; • formation of the ability to understand analogies and model descriptions of problems; • formation of the ability to abstract thinking, analysis and synthesis; • development of critical thinking skills.
II	Valuable goals	• acquisition of skills of caring and responsible attitude to things, phenomena, robots, environment; • use of GIS in the context of sustainable development.
III	Operational goals	• developing the ability to solve specialized problems and solve practical problems during professional activities in the field of RER; • acquisition of skills to work individually and in a team with tasks of different nature; • learn to actively use modern information technologies in the educational process and further professional activity.

- analysis of climatic conditions and their impact on the geo resource potential of the environment;
- remote monitoring of sites and operation of the alternative energy station;
- management of information on electricity generation and distribution in real-time;
- planning and management of energy production resources.

The inclusion of the course "GIS for RER's specialist" within the educational curriculum for training professionals in the RER field serves three overarching sets of objectives, as outlined in the table 1.

The course "GIS for RER's specialist" is typically offered during the 5th to 7th semesters of the first (bachelor's) level of higher education. Given the paramount significance of this discipline, it is recommended for inclusion among the normative courses with a professional orientation.

The lecture component of the course is structured to provide applicants with theoretical foundations related to GIS development and utilization. It encompasses the exploration of key types of GIS, their architectural aspects, and hardware and software requirements. A summary of lecture topics offered for future RER specialists is presented in table 2.

The primary objective of laboratory and practical sessions within the course is to facilitate the mastery of methodologies and contemporary technologies employed for data processing and conversion into GIS. These sessions serve as platforms where students can reinforce, broaden, and deepen their knowledge acquired during lectures and through independent study of relevant literature. During these hands-on classes, applicants develop practical proficiency in GIS utilization.

The laboratory component of the “GIS for RER’s specialist” course relies on the utilization of an open-source system, specifically SAGA GIS. The rationale for selecting this system is expounded below.

Upon analyzing university curricula in the domain of “Geoinformation Systems” across various specializations, it becomes evident that the majority of educational practices employ proprietary GIS software, predominantly from the ArcGIS product family [14]. These proprietary systems necessitate paid user licenses. The appropriateness of employing specific software within the educational framework hinges on the instructor’s proficiency and experience in teaching geographic information systems. There is a widespread belief that the Environmental Systems Research Institute’s ArcGIS software lineup is a global leader in GIS development and implementation. Consequently, utilizing these products in the educational process is deemed to bestow students with a competitive edge in the job market. It is noteworthy that, according to the analytical platform G2 Crowd, the top three most commonly used GIS systems globally are: 1) Esri ArcGIS; 2) Google Earth Pro; 3) BatchGeo [40].

Conversely, while ArcGIS products serve as valuable corporate GIS solutions, their license costs render them inaccessible to small and medium-sized businesses, government budgets, and other organizations within our country. Consequently, we believe there is a substantial risk that students equipped solely with ArcGIS skills (given its convenience, thoughtful design, and round-the-clock support) may encounter difficulties working within other software environments. In their developmental stages, they might instinctively attempt to emulate the principles of the familiar system.

In our view, it is advisable to cultivate students’ proficiency with both proprietary and open-source GIS. This approach will substantially enrich students’ practical experience and enable them to grasp the mechanisms of geospatial data transformation, regardless of the specific GIS type employed.

Open-source software refers to software whose source code can be accessed and modified by users. Key attributes of open-source software include free distribution, accessibility to the source code, and permission to modify or alter the source code. The primary driving force behind the growth of the open GIS sector globally is the inherent limitations of proprietary GIS systems. These limitations extend to the inability to cater to all market demands, especially within the realm of small or non-profit organizations, such as research laboratories, educational institutions, and government agencies, that lack the financial resources to procure the requisite number of licenses. This situation is particularly relevant in Ukraine, where there is a clear recognition of the importance and necessity of GIS across various domains. Nevertheless, the tangible resources for implementing GIS are often insufficient. Consequently, relying solely on the study of ArcGIS or MapInfo, even at an advanced user level, is not deemed essential in preparing future computer science specialists for the job market. Hence, we emphasize the necessity of integrating open GIS into the educational process.

Broadly, open GIS can be categorized into three classes: desktop (installed on a computer), web-based (accessible through a web browser), and spatial databases (containing geospatial data). For the purposes of this discussion, we will focus on open desktop GIS. The global landscape boasts a vast array of over 350 open desktop GIS solutions. Among the most prevalent worldwide are QGIS, GRASS GIS, Whitebox geospatial analysis tools (Whitebox GAT), SAGA GIS, gvSIG, ILWIS, uDIG, and MapWindow GIS (as per GISGeography’s 2022 report [41]).

Table 2. Content of the lecture part of the discipline "GIS for RER's specialist".

Name of topics	Issues included in the topic
Topic 1. General information about geographic information systems	Subject, goals, and objectives of the course. Definition of GIS. Basic terms and concepts (concept of a map, spatial objects, scale, spatial coordinates, map scale, vector, and raster models). History of GIS development and current state. Areas of application of GIS.
Topic 2. Geographic information systems and technologies	A set of methods for using spatially distributed information. The role of satellite technologies in the development of GIS. Approaches to GIS classification. Characteristics of the main types of GIS. Advantages and disadvantages of working with GIS. Typical GIS structure. Basic functionality. Characteristics of the main subsystems. Hardware and peripherals. Information support of GIS work.
Topic 3. Data entry and processing in GIS	The role of data in GIS, their types, and forms of presentation. Data sources (space images, maps, aerial, photo, and orthographic images, attribute data, geodetic survey data). GIS data collection and processing technology. Spatial models and data structures. Raster and vector data models.
Topic 4. Coordinate systems	Topographic data binding. Geographical coordinates, positions of points on the Earth's surface. Attributive description. Cartographic projections. Types of projections and their classification. Their connection and transformation. Topographic basis of geological maps and their nomenclature.
Topic 5. Conversion of graphic information into digital in GIS	Methods of digitizing raster images. Scanning and creating raster data structures. Necessity and methods of conversion of vector and raster information. Layered presentation of information. Stages of creating a digital map model. Structure of digital topographic, parametric, and thematic maps.
Topic 6. Analysis of spatial data	Data aggregation, cartographic overlay (vector layer, points on polygons, lines on polygons, polygons on polygons, raster layer). Spatial interpolation (classification of methods). Surface analysis (calculation of topographic attributes, calculation of slope and exposure, visibility analysis). Network analysis (the task of finding the optimal path, route tracing, salesman task, model "identification – allocation").
Topic 7. Tools for visualization in GIS	Visualization of data with the help of surfaces. Relief visualization methods (2D, 3D, in conditions of blur, dynamic). Using the matrix format of electronic card data. Representation of surfaces in three-dimensional space.
Topic 8. Working with remote sensing data	Earth remote sensing (ERS) data collection and decryption technology. The main features of ERS data collection and decryption technology. ERS data decryption functionality in modern GIS.

Table 3. Comparative characteristics of the functionality of open desktop GIS [16].

Features	GIS							
	QGIS [42]	GRASS [43]	Whitebox GAT [44]	SAGA GIS [45]	gvSiG [46]	ILWIS [47]	uDIG [48]	MapWindow [49]
Year of development	2002	1982	2009	1990	2004	1980s (since 2007 – open license)	2004/2005	1998
Purpose and functionality	cartography (creation, design, modeling), support for raster, vector, geospatial analysis, plug-ins for automation of procedures	created, analysis of image and graphics design, geospatial analysis, data management support for raster, vector, satellite data	educational and research goals, geospatial analysis, vectorization and image processing tools, spatial filters, multicriteria project evaluation	teaching and research goals, geospatial analysis, cartography, support for raster, vector, satellite data	3-D visualization, geospatial analysis in real-time, cartography, support for raster, vector, satellite data	cartography, support for raster, vector, geospatial analysis, geospatial data management, 3-D visualization	creation of vector maps, their scaling, complex vector visualization, geospatial data management	cartography, geospatial analysis, support for raster, vector
Number of available tools	>500	>300	>400	>600	>200	>100	>100	>100
Supported operating system	Windows, Linux, Mac OS X, Android	Windows, Linux, Mac OS X	Windows, Linux, Mac OS X	Windows, Linux, Mac OS X	Windows, Linux, Mac OS X	Windows	Windows, Linux, Mac OS X	Windows
Programming language	C++	C	Python, JavaScript	C++, Python	Java	C++	Java	MS Visual C
Availability of translation of accompanying documentation	Ukrainian – partially	-	-	-	-	-	-	-

Table 3 provides a comprehensive overview of these systems' general characteristics.

Evidently, the functionality offered by these open GIS solutions is on par with their commercial counterparts. These open GIS systems undergo regular updates and continued development, as evidenced by an analysis of available installation versions and the frequency of updates. Architecturally, open GIS systems exhibit a multilevel modular structure, akin to proprietary counterparts. Most open GIS applications have modest hardware requirements and are compatible with a range of operating systems, except for ILWIS and MapWindow GIS, which are exclusively compatible with Windows.

A noteworthy aspect of the considered open desktop GIS applications, as indicated in table 3, is their diversity in programming languages. In their current iterations, they support scripting in a variety of languages familiar to students, including Python, R, Perl, C#, PHP, among others.

An examination of the user interface within open GIS reveals that while they may slightly trail behind ArcGIS and MapInfo in terms of convenience and user-friendliness (intuitiveness), they still offer accessible options. Practical experience demonstrates that SAGA GIS is particularly user-friendly and comprehensible for undergraduate students [16]. In contrast, mastering the tools and functionalities of GRASS GIS may pose a greater challenge due to the need for students to possess basic skills and an understanding of the principles underpinning this GIS, given its continuous procedure implementation and operational command utilization.

Following a comprehensive analysis and considering the objectives associated with cultivating professional competencies in the course "GIS for RER's specialist", the author's team has selected SAGA GIS as the primary toolkit for the course. Key rationale:

- SAGA GIS (abbreviation for System for Automated Geoscientific Analyzes) – specialized software designed for scientific geospatial analysis and modeling of open-source data [50];
- availability of the necessary functionality for training needs. The following types of data are supported: bitmaps, tables, and databases, ERS data, vector objects (points, lines, polygons, shapes, TIN classes, etc.), metadata;
- legal and free use of software for the needs of the educational process. Use under the GNU General Public License;
- technical and hardware requirements of GIS;
- completeness of the description of technical documentation.

Working with digital terrain models in the SAGA GIS environment is possible with the help of tool libraries. The system (according to the latest version of the official SAGA-GIS Tool Library Documentation v 8.5.1) has the following key class sets: Climate and Weather – a group of tools for processing and analyzing climate and weather data (includes 32 tools); Garden – a group of tools for working with fractals, exchanging data with web services, adding elements of gamification (10 tools); Grid – a group of tools for working with raster objects (118 tools); Imagery – a group of tools for clustering, classification and other processing of vector images (59 tools); Import / Export – a set of tools facilitating data import and export (117 tools); Projection – a group of tools for working with projections of objects and surfaces, transformation of coordinate systems, presentation of geospatial data in recognized formats (32 tools); Shapes – a group of tools for working with vector objects and data (122 tools); Simulation – a group of tools for modeling processes (40 tools); Spatial and Geostatistics – a group of tools for spatial analysis and geostatistics (50 tools); TIN – a group of tools for processing triangulation irregular network (8 tools); Terrian Analysis – a group of tools for terrain analysis (101 tools); Visualization – a group of data visualization tools (19 tools).

Each SAGA GIS tool is derived from a key set of a system class, and has a standard interface for the system, but specific functionality (data processing algorithm, input and output data, configuration parameters, etc.).

If necessary, SAGA GIS provides the ability to download third-party Load Tool Libraries from open data sources. The cycle of laboratory work of the discipline "GIS for RER's specialist" includes:

Lesson №1. Comparison of proprietary and open geographic information systems (at the student's free choice);

Lesson №2. Comparison of desktop, mobile, and web GIS functionality. Introduction to Google Earth software implementations;

Lesson №3. Mastering the skills of creating and editing your own vector map (for example, Google Earth Pro);

Lesson №4. Introduction to the functionality of open GIS (for example, SAGA GIS);

Lesson №5. Working with raster images in a GIS environment (for example, SAGA GIS);

Lesson №6. Working with vector images in the GIS environment (for example, SAGA GIS);

Lesson №7. Conversion of graphic information into digital in GIS (on the example of SAGA GIS);

Lesson №8. Geocoding and vectorization in GIS environment (on the example of SAGA GIS);

Lesson №9. Working with ERS (satellite imagery) data in a GIS environment (for example SAGA GIS).

For example, in the second laboratory work, future RER specialists will get acquainted with the capabilities and interface of the Google Earth product line. Educational tasks are:

1) finding by name, coordinates, and other attributes of alternative energy facilities (applicants are offered different options for work);
2) acquaintance with the available styles of displaying maps and objects on them (styles "Earth", "Researcher", "Everything", "My Map"; modes: 2D, 3D, "street mode"; cloud animation). When working with the "My Card" style, students configure the card of the alternative energy object found in item 1;
3) determination of the distance from the object of alternative energy found in item 1 to settlements (other objects), measurement of spatial parameters of placement of the object of alternative energy (figure 3). Comparison of the obtained measurement results with real technical indicators, the establishment of the reasons for possible deviations;
4) calculation of the potential% of satisfaction of energy needs of the population of the nearest settlement by the object of alternative energy (indicators of real power applicants can find on the Internet);
5) perform tasks 1-3 in web, desktop, and mobile (optional) versions of Google Earth. Comparison of functionality, and conclusions.

In the SAGA GIS Raster Imaging Skills (Laboratory №5), students are asked to analyze climatic conditions and assess the geo resource potential of the environment to house alternative energy stations in the region (applicants are offered different jobs options). For example, for the task of obtaining electricity from the kinetic energy of raindrops (as a way to renew the energy of autonomous power sources of radio devices) in Ukraine, the student performs the following tasks:

1) Master the skills of cutting, combining, overlaying, and mathematical processing of data from raster images;
2) To assess the precipitation levels in Ukraine based on global monitoring reports for the year 2021 (figure 4);

Figure 3. Measurement of the area of SES "Starokozache" (Ukraine, Odesa region) using Google Earth.

3) Assess the possibility of using raindrops to generate electricity according to the data obtained;
4) Draw conclusions about the feasibility of the whole and the priority regions of the installation.

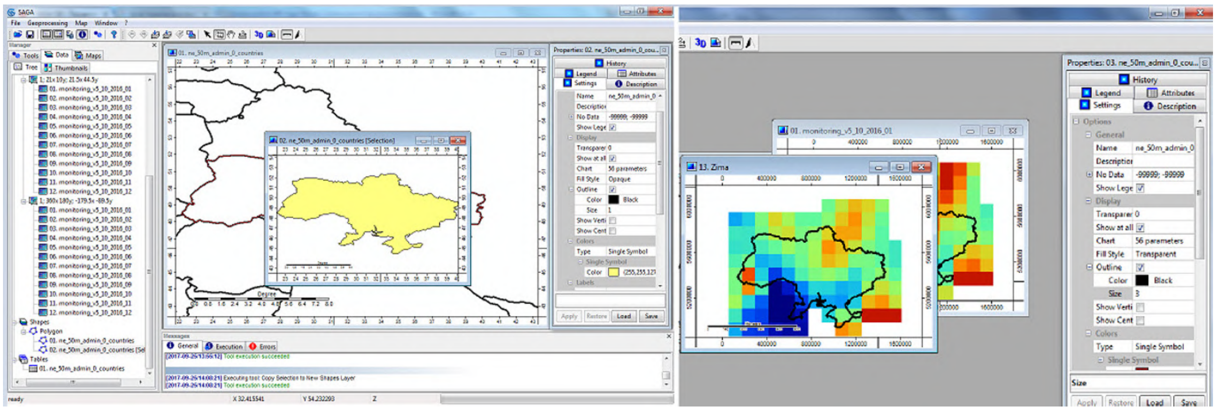

Figure 4. Determining the average level of precipitation in Ukraine in the 4th quarter of 2022 year (December, January, February).

During the tasks of this laboratory №5, students learn to work with a raster form of data representation (grid), in particular: cut and paste images, overlay one image on another, perform mathematical operations on grid data (eg, search for maximum or minimum values, etc.), change the pixel size and volume, etc.

All laboratory works are logically interconnected, as a result of their performance future specialists in the field of RER acquire skills in GIS, develop skills in working with raster and vector images, develop knowledge of analytical processing of geospatial data and decision making, gain experience in cartographic models and ERS data in terms of solving specific applications of renewable energy.

4. Discussion

Renewable and unconventional energy sources are crucial for the sustainable development of the global community. The shift towards cleaner and renewable forms of energy is driven by a wide range of objectives, including advancing economic development, improving energy security, enhancing energy access, and mitigating climate change. In recent years, there has been an active search for new improvements to existing technologies in this area, bringing them to a cost-effective level and expanding the scope of use. GIS has been found to have great potential for use in RER.

The use of GIS is gaining momentum in Ukraine, driven by several factors. Firstly, the reform of most branches of government aims to make their work more transparent and efficient. Secondly, the development of an appropriate legislative framework and a unified strategy for the development of the digital economy is underway. In Ukraine, the utilization of GIS predominantly exhibits the following defining traits:

- narrow coverage (there is a significant growth potential);
- tendencies to develop their own software products based on existing GIT;
- GIS is not universal in nature, but is aimed at solving specific problems;
- the use, for the most part, of information and reference and cartographic functions, insufficient use of the potential of the analytical capabilities of modern GIS;
- these systems are known for their cross-platform compatibility, reliance on web services and cloud technologies, as well as seamless integration with geospatial databases.

Among the constraining factors and the main problems of GIS development in Ukraine we can name:

- slowness in the organization and implementation of reforms;
- low level of informatization in the country as a whole;
- problems with the system of legal and regulatory support for the development of GIS. It should be noted that in Ukraine there are practically no standards in the field of GIS development, which forces developers to create their own ideology, architecture, and standards for geodata information models for each project. Thus, the level of technological solutions is directly dependent on the knowledge and experience of developers, which, of course, does not contribute to the effective implementation and high-quality use of GIS;
- economic and other problems in the country do not allow most enterprises to introduce modern GIT into their activities due to their cost and the long period of return on investment.

It is obvious that the intensive introduction of GIS into the work of modern subjects of the RER sphere at all levels of government (from the state to a separate enterprise) is one of those factors that can lead to a predictable increase in efficiency and effectiveness of their work. We believe that in the near future, GIS solutions that meet the following requirements will be relevant for Ukrainian business: they will provide an opportunity to solve problems that are important for enterprises in a complex; focused on medium and small businesses, respectively, will be more accessible financially; will have a structure (platform) that will ensure ease of integration of GIS into the existing information infrastructure without additional investment; use the tools (methods, technologies, methods, etc.) of artificial intelligence, IoT, Big Data, which will reduce potential risks from doing business and increase the level of operational stability, profitability, and work efficiency; will be "transparent" for both users and investors.

In this context, the development of highly skilled professionals in the RER sector necessitates the incorporation of GIS-focused coursework within the educational programs and curricula of the specialization known as "Electric Power, Electrical Engineering and Electromechanics" (specialty 141).

The paper proposes the content and technology of teaching such a discipline, which is called "GIS for RER's specialist". Its purpose is to acquaint future specialists in the field of RER with the theoretical, methodological, and technological bases of the creation and operation of geographic information systems, master the general principles of work, and gain practical skills in using GIS to solve a number of RER's issues. Mastering the material of this discipline will provide training for highly qualified specialists capable of working with GIS, in particular with raster and vector images, able to perform analytical processing of geospatial data and make decisions based on it.

When selecting GIS tools for the course, the primary focus is on employing systems licensed under the GNU General Public License. The advantages of incorporating open-source GIS in higher education institutions are as follows:

(i) *Cost Savings*: There is no requirement to purchase licenses, reducing financial burdens.
(ii) *Enhanced Student Competencies*: Students gain proficiency in using various GIS tools and learn to combine them to address practical challenges.
(iii) *Comparable Functionality*: Open-source GIS offerings boast functionality on par with their commercial counterparts.
(iv) *Hardware Flexibility*: Most open-source GIS software operates efficiently without demanding high-end hardware specifications.
(v) *Cross-Platform Compatibility*: Open-source GIS supports operation across different operating systems, ensuring versatility in usage.

Future research will focus on exploring the potential use of open web GIS and spatial databases in the educational process. A study comparing the functionalities of proprietary and open desktop GIS would improve the quality of teaching the discipline "GIS for RER specialists".

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References

[1] Marín-Beltrán I, Demaria F, Ofelio C, Serra L M, Turiel A, Ripple W J, Mukul S A and Costa M C 2022 *Science of The Total Environment* **811** 151359 URL https://doi.org/10.1016/j.scitotenv.2021.151359
[2] Solarz J, Gawlik-Kobylińska M, Ostant W and Maciejewski P 2022 *Energies* **15** 1351 URL https://doi.org/10.3390/en15041351
[3] Modlo Y O, Semerikov S O, Bondarevskyi S L, Tolmachev S T, Markova O M and Nechypurenko P P 2019 *CEUR Workshop Proceedings* **2547** 217–240 URL https://ceur-ws.org/Vol-2547/paper16.pdf

[4] National Technical University of Ukraine “Kyiv Polytechnic Institute named after Igor Sikorsky” 2022 Educational program “Unconventional and Renewable Energy Sources” URL https://osvita.kpi.ua/sites/default/files/opfiles/141_OPPB_NVDE_2022.pdf
[5] Odesa Polytechnic National University 2022 Educational program “Renewable energy sources and energy complexes” URL https://op.edu.ua/kaf-tzne/education_programs
[6] National Technical University “Dnieper Polytechnic” 2022 Educational programs for specialty 141 “Electric Power, Electrical Engineering and Electromechanics” URL https://se.nmu.org.ua/ua/kafedra/normatyvne_z/
[7] Kharkiv National University of Municipal Economy named after O M Beketov 2022 Educational program “Unconventional and renewable energy sources” URL https://toe.kname.edu.ua/images/nvde-presentation.pdf
[8] National Aerospace University H E Zhukovsky “Kharkiv Aviation Institute” 2022 Educational and professional program “Non-traditional and renewable energy sources” URL https://drive.google.com/file/d/14Y5gWFDDAQhBhZ7qNm28I1VlyTftZOE3/view
[9] Kherson National Technical University 2022 Educational and professional program “Electrical Engineering and Electrical Technology” URL https://cutt.ly/WJL6SHm
[10] Chernivtsi National University named after Yuriy Fedkovych 2020 Educational and professional program “Electric Power, Electrical Engineering and Electromechanics” URL https://cutt.ly/lJL6MC4
[11] Ivano-Frankivsk National Technical University of Oil and Gas 2022 Curricula of the educational-professional program “Electric Power, Electrical Engineering and Electromechanics” URL https://cutt.ly/aJZqyIX
[12] Grishchenko S M, Morkun V S and Semerikov S O 2015 *Use of geoinformation technologies in the preparation of mining engineer* (Kryvyi Rih: Publishing Center of Kryvyi Rih National University)
[13] Syvyi M J, Mazbayev O B, Varakuta O M, Panteleeva N B and Bondarenko O V 2020 *CEUR Workshop Proceedings* **2731** 369–382 URL https://ceur-ws.org/Vol-2731/paper22.pdf
[14] Kholoshyn I V, Bondarenko O V, Hanchuk O V and Shmeltser E O 2019 *CTE Workshop Proceedings* **6** 403–412 URL https://doi.org/10.55056/cte.401
[15] Agapova O L 2016 *Cartography for the needs of alternative energy in Ukraine* (Kharkiv: V. N. Karazin Kharkiv National University) URL https://cutt.ly/SJZqNxs
[16] Zinovieva I S, Artemchuk V O and Iatsyshyn A V 2018 *Information Technologies and Learning Tools* **68** 87–99
[17] Iatsyshyn A, Iatsyshyn A, Kovach V, Zinovieva I, Artemchuk V, Popov O, Cholyshkina O, Radchenko O, Radchenko O and Turevych A 2020 *CEUR Workshop Proceedings* **2732** 893–908 URL https://ceur-ws.org/Vol-2732/20200893.pdf
[18] Cabinet of Ministers of Ukraine 2018 The concept of creating a national automated system “Open Environment” URL https://zakon.rada.gov.ua/laws/show/825-2018-%D1%80#Text
[19] Cabinet of Ministers of Ukraine 2021 On approval of the Concept for the development of digital competencies and approval of the action plan for its implementation URL https://zakon.rada.gov.ua/laws/show/167-2021-%D1%80#n13
[20] Verkhovna Rada of Ukraine 2018 Law of Ukraine “On National Infrastructure of Geospatial Data” URL https://zakon.rada.gov.ua/laws/show/554-20#Text
[21] Pomortseva E E, Masliy L A, Kin D A and Salnikov M V 2015 *Information processing systems* **2** 220–226
[22] Molikevych R S, Bohadorova L M, Kovalova K I and Okhremenko I V 2019 The use of geoinformation systems in educational and professional programs for the training of geographes *19th International Multidisciplinary Scientific GeoConference SGEM 2019* vol 19 pp 355–360 URL https://www.sgem.org/index.php/jresearch-article?citekey=Molikevych201922355360
[23] Volkov A I 2016 *Geoinformation models and decision support systems for assessing and controlling the level of man-made load on the environment* (Odesa: TEC)
[24] Zatserkovny V I, Tishaev I V, Poem I V and Demidov V K 2016 *Geoinformation systems in the Earth sciences* (Nizhyn: Nizhyn Mykola Gogol State University)
[25] Mokin V B, Kryzhanovsky E M and Botsula M P 2011 *Information technology of integration of mathematical models into geoinformation systems of surface water monitoring* (Vinnytsia: Vinnytsia National Technical University)
[26] Bielcheva G, Manakova N and Makogon N 2016 *Eastern-European Journal of Enterprise Technologies* **4** 38–45
[27] Pitak I V, Negadailov A A, Masikevich Y G, Plyatsuk L D, Shaporev V P and Moiseev V F 2012 *Geoinformation technologies in ecology* (Chernivtsi) URL https://geology.lnu.edu.ua/wp-content/uploads/2020/04/Ekolohichna-heoinformatyka_literatura-dlia-lektsiy.pdf
[28] Popov O O, Iatsyshyn A V, Iatsyshyn A V, Kovach V O, Artemchuk V O, Gurieiev V O, Kutsan Y G, Zinovieva I S, Alieksieieva O V, Kovalenko V V and Kiv A E 2021 *CEUR Workshop Proceedings* **2898**

230–254 URL https://ceur-ws.org/Vol-2898/paper13.pdf

[29] Gurieiev V, Kutsan Y, Iatsyshyn A, Iatsyshyn A, Kovach V, Lysenko E, Artemchuk V and Popov O 2020 *CEUR Workshop Proceedings* **2732** 693–708 URL http://ceur-ws.org/Vol-2732/20200693.pdf

[30] Semerikov S O, Chukharev S M, Sakhno S I, Striuk A M, Iatsyshin A V, Klimov S V, Osadchyi V V, Vakaliuk T A, Nechypurenko P P, Bondarenko O V and Danylchuk H B 2022 *IOP Conference Series: Earth and Environmental Science* **1049** 011001 URL https://doi.org/10.1088/1755-1315/1049/1/011001

[31] Anpilova Y, Yakovliev Y, Trofymchuk O, Myrontsov M and Karpenko O 2022 Environmental Hazards of the Donbas Hydrosphere at the Final Stage of the Coal Mines Flooding *Systems, Decision and Control in Energy III* ed Zaporozhets A (Cham: Springer International Publishing) pp 305–316 ISBN 978-3-030-87675-3 URL https://doi.org/10.1007/978-3-030-87675-3_19

[32] Myrontsov M, Karpenko O, Trofymchuk O, Okhariev V and Anpilova Y 2021 Increasing Vertical Resolution in Electrometry of Oil and Gas Wells *Systems, Decision and Control in Energy II* ed Zaporozhets A and Artemchuk V (Cham: Springer International Publishing) pp 101–117 ISBN 978-3-030-69189-9 URL https://doi.org/10.1007/978-3-030-69189-9_6

[33] Iatsyshyn A, Artemchuk V, Zaporozhets A, Popov O, Kovach V and Taraduda D 2021 Development of Teaching Methodology in the Field of Environmental Monitoring of Atmosphere *Systems, Decision and Control in Energy II* ed Zaporozhets A and Artemchuk V (Cham: Springer International Publishing) pp 307–317 ISBN 978-3-030-69189-9 URL https://doi.org/10.1007/978-3-030-69189-9_18

[34] Marcu C, Catita C, Crengăniș L and Stătescu F 2016 *RevCAD Journal of Geodesy and Cadastre* **20** 79–86 URL https://www.ceeol.com/search/article-detail?id=811627

[35] Jeong J S and González-Gómez D 2020 *Journal of Cleaner Production* **251** 119747 ISSN 0959-6526

[36] Avtar R, Sahu N, Aggarwal A K, Chakraborty S, Kharrazi A, Yunus A P, Dou J and Kurniawan T A 2019 *Resources* **8** 149

[37] Pavlenko L A 2013 *Geographic Information Systems* (Kharkiv: Simon Kuznets Kharkiv National University of Economics)

[38] Svitlychnyi O O and Plotnytskyi S V 2006 *Fundamentals of Geoinformatics* (Sumy: University Book) URL https://ktpu.kpi.ua/wp-content/uploads/2014/02/Svitlichnij-O.O.-Plotnitskij-S.V.-Osnovi-geoinformatiki.pdf

[39] Shipulin V D and Kucherenko E I 2009 *Planning and management of GIS projects* (Kharkiv: O.M. Beketov National University of Urban Economy in Kharkiv, Kharkiv National University of Radio Electronics)

[40] G2 2022 Best GIS Software. G2 Grid® for GIS URL https://www.g2.com/categories/gis#grid

[41] Gisgeography 2022 30 Best GIS Software Applications [Rankings] URL https://gisgeography.com/best-gis-software/

[42] QGIS 2022 QGIS A Free and Open Source Geographic Information System URL https://www.qgis.org/

[43] GRASS GIS 2022 GRASS GIS Bringing advanced geospatial technologies to the world URL https://grass.osgeo.org/

[44] Whitebox Geospatial Inc 2022 Innovative Geospatial Software URL https://www.whiteboxgeo.com/

[45] SAGA GIS 2022 Welcome to the SAGA Homepage URL https://saga-gis.sourceforge.io/en/index.html/

[46] gvSiG 2022 gvSIG Association URL http://www.gvsig.com/en/

[47] University of Twente 2022 ILWIS - Remote Sensing and GIS software URL https://www.itc.nl/ilwis/

[48] uDig 2022 uDig – User-friendly Desktop Internet GIS URL http://udig.refractions.net/

[49] MapWindow 2022 About the MapWindow GIS open source project URL https://www.mapwindow.org/

[50] SAGA GIS 2022 SAGA GIS tutorials URL https://sagatutorials.wordpress.com/about-saga-gis/

Journal of Physics: Conference Series

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Modeling training content for software engineers in parallel computing

To cite this article: Y O Sitsylitsyn *et al* 2023 *J. Phys.: Conf. Ser.* **2611** 012017

Modeling training content for software engineers in parallel computing

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Abstract. This study proposes a robust framework for the training of software engineers specializing in parallel computing. We first curated essential content for parallel computing education based on international standards and evolving recommendations from Computing Curricula. We then systematically structured the content and designed a well-defined learning pathway for aspiring software engineers. Concurrently, we conducted a comprehensive assessment of the current state of training for parallel computing in Ukrainian higher education institutions. We analyzed bachelor's programs in Information Technologies and scrutinized individual course syllabi to identify valuable insights. By merging our findings with the review of educational programs, we formulated a comprehensive model for training in parallel computing. We also examined the pivotal role of the course "Parallel and Distributed Computing" in the developed curriculum and identified essential tools and methodologies for developing parallel and distributed programs. Our research contributes to the advancement of parallel computing education and provides a valuable reference point for curriculum designers and educators.

1. Introduction

One of the methods of increasing the competitiveness of IT enterprises is to reduce the cost of software development and increase its efficiency. It should be noted that the development of programs that use only one processor core, relying on classic sequential algorithms, does not provide the necessary increase in productivity compared to those that use parallel multi-core solutions in their code.

The current level of development of supercomputer technologies based on parallel computing, the spread of multicore processors determines the relevance of studying parallel programming. Computational parallelism operates in various specific forms depending on the programming phase, the complexity of the parallel fragments, and the nature of the connections between them. Parallel programming includes all the features of classic serial programming.

In the process of studying parallel programming technology, a parallel style of thinking is formed, which implies the presence of abilities: to preliminary imaginary "parallelization" of the assigned task – its analysis with the aim of selecting subtasks that can be performed in parallel; to "parallelization" of data flows – selection of data flows that will be exchanged between subtasks performed in parallel; keeping in memory the actions of all subtasks in a certain period of time to properly manage their joint work.

With a sufficiently high level of development of the parallel style of thinking, a software engineer can foresee specific problems that arise during the operation of parallel algorithms, which do not appear every time and significantly complicate the debugging of programs [1]. Only the achievement of a certain level of development of a parallel thinking style will allow a software engineer to effectively implement parallel computing. Achieving success in mastering parallel programming hinges on a fundamental shift in cognitive processes, necessitating the cultivation of a parallel thinking style. This transformation, in turn, will facilitate the development of training for software engineers specializing in parallel and distributed computing.

In the pursuit of this objective, it is imperative to establish a structured curriculum tailored to the needs of aspiring software engineers entering the realm of parallel computing. This curriculum will serve as the foundational cornerstone upon which to construct a comprehensive model for the training of software engineers specializing in parallel computing. This model will not only prescribe the optimal sequence for their coursework but also outline the pivotal role and seamless integration of the "Parallel and Distributed Computing" course within the broader structural and logical framework of the bachelor's program in computer sciences.

Vakaliuk [2], Seidametova et al [3], Osadchyi [4], Varava et al. [5], Striuk and Semerikov [6] carry out fundamental research in the field of training of software engineers in HEIs. Scientists also highlight certain aspects of the mentioned problems, in particular: the issue of the quality of training of programmers [7]; requirements for professional qualities of software engineers [8]; organization of software engineering education in universities worldwide [9, 10]. Diaz et al [11], Sitsylitsyn [12] and other scientists are engaged in the review and selection of parallel programming tools. Marowka [13], Wilkinson et al [14], Capel et al [15] are explored teaching parallel programming.

Giacaman and Sinnen have delved into the nuances inherent in the conventional pedagogy of programming within higher education institutions, with a specific focus on preparing software engineers [16]. Furthermore, Vasconcelos et al. have conducted an insightful analysis of the temporal aspects involved in incorporating the knowledge grid related to "Parallel and Distributed Computing" [17].

Objective of the article: This article aims to formulate a training content model for software engineers in parallel computing.

2. Theoretical foundation of the study

To formulate a curriculum model for the training of aspiring software engineers with a specialization in parallel computing, the initial step is to establish the foundational content necessary for their education in this domain. To achieve this, we will reference established international standards, particularly the guidelines pertaining to computer science education [18–21].

The issue of parallel computing is primarily related to one of the constituent parts of computing – Computer Science [19,20]. Aspects of parallelism were first mentioned in the edition of Computing Curricula from 2001, but both in 2001 [18] and in 2008 [19] parallelism was not separated into a separate field of knowledge – the issue of parallel computing was included as separate sections in several different parts of the computer science study recommendations. And only in 2013, the first edition of the recommendations for the study of computer sciences was developed, where a separate branch of knowledge "Parallel and Distributed Computing" was created [20]. In the 2020 recommendations, there were significant updates made to the content within the knowledge domain of "Parallel and Distributed Computing".

To establish the content for the training of software engineers specializing in parallel and distributed computing, it is prudent to draw upon the following primary sources:

1. Recommendations outlining the composition of the subject area of parallel and distributed computing (referred to as Table of Contents 1), prepared as part of a collaborative effort between ACM and IEEE-CS within their curriculum development project [21].
2. Recommendations pertaining to the structure of the subject area of parallel and distributed computing (referred to as Content 2), developed within a project supported by the National Science Foundation (NSF) in the United States and in conjunction with the IEEE Technical Committee on Parallel Processing (TCPP) [22].

The fundamental approach to delineating the content for training in parallel and distributed computing adheres to the following principles:

1. The collection of knowledge and skills essential for effective professional practice is determined by distinct knowledge domains, each representing integral facets of the corresponding field of expertise.
2. These knowledge domains are further subdivided into smaller units known as sections, which serve as discrete thematic modules within the field.
3. Each section, in turn, is comprised of a collection of topics, representing the lower tier within this hierarchical structure within the respective field of expertise. Each topic is accompanied by an indication of its mandatory or optional status, along with the recommended amount of study time necessary for its comprehension.

It's essential to clarify that the structure of domains, sections, and topics is indicative of the essential knowledge required for proficiency in the relevant field of expertise, rather than an exhaustive list of educational courses. The curricula and corresponding training modules are subsequently developed based on this foundational content.

In our endeavor to shape the curriculum for the training of software engineers specializing in parallel computing, we will draw upon the aforementioned documents, denoted as Content 1 [21] and Content 2 [22], to define the subject domain of parallel computing. Additionally, we will incorporate insights from the seminal work in parallel computing, "Structured Parallel Programming: Patterns for Efficient Computation" by McCool [23], which we will refer to as Content 3.

At the highest level of this foundational content, we identify five primary knowledge domains, collectively spanning the entire spectrum of parallel computing topics:

1. Mathematical foundations for parallel computing.
2. Parallel computing systems (fundamentals of computing).
3. Parallel programming technologies.
4. Parallel algorithms for problem solving.
5. Parallel computing for large-scale tasks and specialized domains.

We present the curriculum content as a structured list of thematic sections (table 1). The right-hand columns of the table indicate the presence (+) or absence (–) of relevant Content topics in alternative developments, i.e., Content 1 [21] and Content 2 [22], respectively. The mark "+/–" means that the topic is presented to a large extent, the mark "–/+" says that the topic is revealed partially.

Let's examine the elements of the training content in parallel computing as outlined in Content 1 (ACM 2020 Recommendations) [21], Content 2 (NSF / IEEE-TCPP Project Recommendations) [22] and Content 3 (McCool et al) [23].

In content 3 [23], scientists highlight the following methods and technologies for developing parallel programs:

Journal of Physics: Conference Series **2611** (2023) 012017 doi:10.1088/1742-6596/2611/1/012017

Table 1. Summary of training in parallel computing.

No	Area of knowledge, section	Content1	Content 2
1	**Mathematical foundations for parallel computing**		
1.1	Graphs of program models	−	−
1.2	The concept of unlimited parallelis	−	−
1.3	Thin information structure of programs	−	−
1.4	Equivalent program transformations	−	−
1.5	Calculation models for computer systems	+	+
1.6	Mathematical models of parallel computing	+/−	+/−
2	**Parallel computing systems (fundamentals of computing)**		
2.1	Basics of machine computer	−	+
2.2	Basics of building computer system	−/+	+/−
2.3	Parallel computing systems	−/+	+/−
2.4	Multiprocessor computer systems	+/−	+/−
2.5	Multiprocessor computing systems with shared memory	−/+	+
2.6	Multiprocessor computing systems with distributed memory	+	+
2.7	Graphics processors	−/+	−
2.8	Computing systems of transpetaflop and ex-scale characteristics	−	−
2.9	Distributed computing systems	+	−/+
2.10	Challenges of supercomputers and data center	−	−
3	**Parallel programming technologies (fundamentals of software engineering)**		
3.1	General principles of parallel programming	−/+	−/+
3.2	Basics of parallel programming	−/+	+/−
3.3	Methods and technologies for developing parallel programs	−	+/−
3.4	Parallel problem-oriented libraries and software packages	−	−
3.5	Tools for parallel development of programs	−	−
3.6	Methods of increasing the efficiency of parallel programs	−	−
4	**Parallel algorithms for problem solving**		
4.1	General principles of parallel algorithm development	−/+	+/−
4.2	Educational algorithms of parallel programming	−	+
4.3	Parallel algorithms of matrix calculation	−	+/−
4.4	Parallel algorithms for sorting and searching data	−/+	+
4.5	Algorithms for parallel processing of graphs	−	+
4.6	Parallel algorithms for solving partial differential equations.	-	−
4.7	Parallel algorithms for solving optimization problems	−	−
4.8	Parallel Monte Carlo algorithms	−	−
4.9	Parallel algorithms for other classes of computationally intensive problems	−	−

1. Traditional programming languages and compilers that can parallelize. Vectorization of programs.
2. Software libraries for developing parallel programs: Intel TBB (Thread Building Blocks), Linda, Microsoft TPL (Task Parallel Library), MPI, PVM, Shmem.
3. Superlanguage tools for organizing parallelism: DVM, Cray Fortran, OpenMP, Cilk, HPF.

4. Parallel extensions of traditional programming languages: CAF, UPC.
5. Parallel programming languages: Occam, SISAL, NORMA.
6. Parallel programming languages for distributed shared memory systems in the PGAS model: X10, Chapel.
7. Parallel programming languages for graphic processors: CUDA, OpenCL.
8. Functional parallel programming languages: Parlog, Parallel Haskell, Erlang, T-System.
9. Tools and technologies to support metacomputing and distributed computing: Globus, UNICORE, gLite, X-Com, BOINC, MapReduce.
10. Programming technologies of FPGA computers.
11. Automation of parallelization and optimization of programs.
12. Elements of circuit engineering, languages for describing electronic circuits, VHDL.

List of sections of the field of knowledge “Parallel and Distributed Computing” based on research materials [23] and [21] are given in the table 2.

The performed comparison (table 1, table 2) shows that the recommendations of 2020 [21] almost completely overlap with options from the other two considered approaches. It can be noted that the sections related to distributed systems, cloud computing and formal models and semantics are more thoroughly disclosed in the recommendations [21].

Table 2. Sections of the field of knowledge “Parallel and Distributed Computing” (Content 1).

Section	Area of knowledge	Content 3	Content 1
A	parallelism fundamentals	+	+
B	parallel decomposition	+	+
C	communication and coordination	+	+
D	parallel algorithms, analysis, and programming	+	+
E	parallel architectures	+	+
F	parallel performance	+	+
G	distributed systems	−/+	−/+
H	cloud computing	−/+	−/+
I	formal models and semantics	+/−	−/+

The delineation of the subject domain of parallel and distributed computing was also undertaken as part of a project funded by the National Science Foundation (NSF) in the United States and facilitated by the IEEE Technical Committee on Parallel Processing (TCPP) [22]. The initial version of these recommendations was formulated in 2010, with the most recent working edition being published in 2020.

According to these recommendations, four areas of knowledge have been identified in the field of parallel and distributed computing:

1. Architecture.
2. Programming.
3. Algorithms.
4. Additional sections.

As you can see, the selected areas of knowledge largely repeat the content structure of training proposed in Contents 3. Along with this, two areas of knowledge ("Mathematical foundations" and "Parallel computing for large-scale tasks and specialized domains") are available in Contents 3, absent from the NSF / IEEE-TCPP recommendations. On the other hand, the area "Additional sections" of the considered recommendations as such is absent and distributed in other areas of knowledge of Content 3.

In the recommendations of the NSF / IEEE-TCPP project, structural elements of the second level – sections – are not explicitly highlighted. In fact, the composition of the areas of knowledge is determined immediately in the topics, which complicates the use of such a definition of the subject area. In some cases, the proposed topics are combined into groups.

Table 3. Sections of the field of knowledge "Parallel and Distributed Computing" (Content 2).

No	Area of knowledge, section	Content3	Content 2
1	**Architecture**		
1.1	Data and control parallelism	+	−/+
1.2	Shared and distributed memory	+	−/+
1.3	Memory hierarchy	+	−/+
1.4	Performance indicators	+	−/+
1.5	Floating point representation	+	−
2	**Programming**		
2.1	Parallel software paradigms	+	−/+
2.2	Problems of semantics and correctnes	+	+
2.3	Performance issues	+/−	−/+
3	**Algorithms**		
3.1	Models and complexity estimates	+	+/−
3.2	Algorithmic paradigms	+	−/+
3.3	Algorithmic problem	+	−/+
4	**Additional topics (no topic groups)**	−/+	−/+

By analyzing the key insights from the seminal works cited above, we can develop a comprehensive curriculum for software engineers who specialize in parallel computing, including a recommended sequence for their coursework (figure 1).

Based on our analysis of the training curriculum for software engineers in parallel computing, we identified the following goals for the course "Parallel and Distributed Computing":

1. Study of parallel computing systems, their programming methods, principles, and phases of software development using MPI and OpenMP technologies; formation of abilities to apply parallel programming technologies, as well as the main functions of these libraries.
2. Formation of parallel algorithm compilation skills for solving professional tasks, in particular: dividing a task into subtasks, identifying, and analyzing information dependencies between subtasks, information interaction between subtasks within MPI and OpenMP technologies.
3. Formation of a method of algorithmic actions, in which the well-thought-out process of compiling an algorithm naturally fits into the stages of development of a parallel algorithm, that is, the formation of a parallel style of thinking.

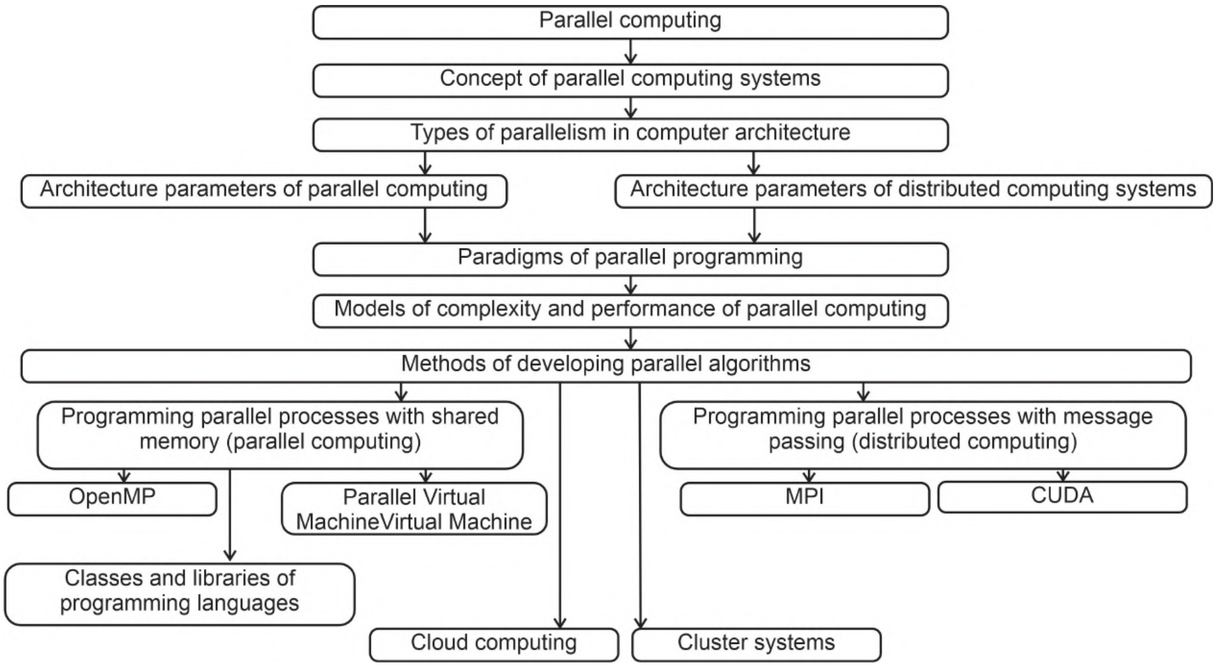

Figure 1. The trajectory of learning parallel computing.

4. Gaining experience in programming parallel computing systems, applying the principles of parallel algorithms, organizing information interaction between individual subtasks, applying parallelism to planning one's activities.

In addition to examining the curriculum for prospective software engineers in parallel computing, a thorough evaluation was conducted to assess the current state of such training in Ukrainian HEIs.

The instruction of the "Parallel and Distributed Computing" course is primarily aimed at instilling specific professional competencies in students pursuing higher education, as defined by the standards set forth in Ukraine for bachelor's programs in Computer Science [24]. Our analysis encompassed various HEIs in Ukraine, specifically within the domain of Information Technologies, and included a detailed review of individual course outlines [25–28].

Due to variations in course nomenclature across different institutions, our evaluation considered course outlines under diverse names such as "Parallel and Distributed Computing", "Technologies of Distributed Systems and Parallel Computing", and "Parallel Programming".

Our exhaustive review leads us to a compelling conclusion: parallel computing holds an indispensable place within the mandatory curriculum for software engineers pursuing bachelor's degrees in Information Technologies across HEIs in Ukraine.

By systematically applying the stages of system modeling to the course "Parallel and Distributed Computing", we have developed a comprehensive model, as shown in figure 2.

The model is structured as a cylinder with layers that represent different levels of semantic value. The foundational layer provides supporting knowledge, including essential concepts and their interconnections, which are essential for understanding the theoretical content.

The subsequent layers of the "concept cylinder" are arranged hierarchically. The first-level concepts are formed on top of the foundational layer. The third-level blocks help students learn MPI and OpenMP programming concepts.

The fourth-level layer of concepts and connections deepens understanding of previously learned material by helping students develop more abstract ideas, such as:

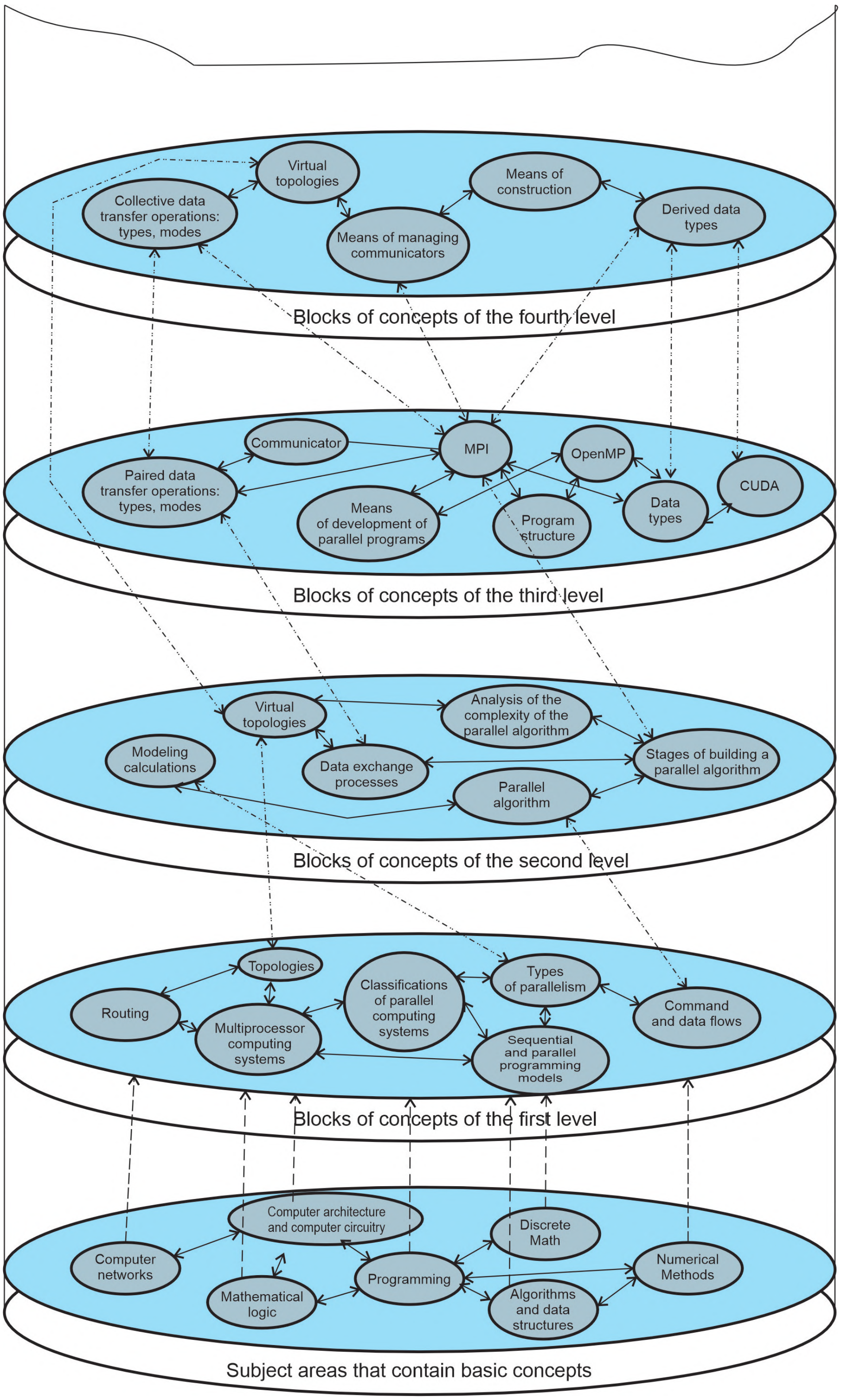

Figure 2. Training content model for software engineers in parallel computing.

- raw data types and their projection;
- controlling communicators and utilizing virtual topologies (linked to level 2).

This level of knowledge is applied to solve more complex problems in linear algebra, numerical methods, and graph theory.

It's important to note that the "concept cylinder" doesn't have an upper limit, signifying that the study of parallel computing shouldn't be confined to a single course. Relationships within the model aren't limited to adjacent levels, hence there's a direct connection between graph theory and parallel computing modeling, and algorithm theory with the analysis of parallel algorithm complexity.

Let's consider the elements of the model in more detail. Blocks of concepts of the first level are a set of basic concepts necessary for mastering the concepts of the following levels. They reflect the main blocks of the level, each of which can be represented by a separate logic-semantic scheme.

Blocks of concepts of the second level serve as a support for building the content part of the next section of the curriculum. These blocks also contain concepts, some of which were included in lectures and laboratory works, and others served as material for projects.

The blocks of concepts of the third level contain the material of the next chapter, within which the study of MPI and OpenMP technologies begins. These blocks of concepts are almost completely included in the classroom part of the course. When technical possibilities appear, the content of this level can be replaced by another programming technology, provided that its concepts are developed accordingly.

The fourth level of the model is the basis for processing the content of the next section of the module. The educational material of this level of the model includes only the basic concepts: creation of communicators, description and construction of data types intended for the user, etc. On the basis of blocks of this level, simple projects aimed at software implementation of mathematical models can be proposed.

By implementing the training content model for parallel computing software engineers into the curriculum, we can better understand the role of the course "Parallel and Distributed Computing" and the tools and methods used to develop parallel and distributed programs.

The model reveals that studying parallel computing necessitates gaining knowledge and skills in areas such as algorithmization, object-oriented programming, operating systems, computer circuitry, and computer architecture. These foundational knowledge and skills underpin the first and second level concepts of the model, enabling effective use of existing parallel libraries situated at the third level.

It's worth noting that the Modeling and Control of Students' Learning Pathways, particularly in terms of acquiring key competencies, should be conducted in a Cloud Service [29–31].

By analyzing the model of training content for software engineers in parallel computing, we can draw the following conclusions:

1. It is possible to choose a programming language for working with parallel libraries only after students have mastered the basics of algorithmization and the basics of object-oriented programming, that is, not before the third training.
2. The development of parallel computing programs will be effective only after students have mastered the basics of computer architecture, that is, not before the second year of study.
3. The development of distributed computing programs will be effective only after the applicants study the course of computer networks, that is, not before the third training.

Given the above, it can be concluded that the optimal time for teaching the courses of parallel and distributed computing would be no earlier than the third year of study for effective comprehension.

3. Conclusions

We conducted an analysis to construct a training content model for software engineers in parallel computing. This comprehensive analysis drew upon the multi-year paradigms of global computer education set forth by ACM, as well as insights gleaned from fundamental works authored by international experts in the field. The result of this endeavor was the formulation of a curated list of topics intended to shape the education of software engineers in parallel computing, complete with a recommended sequence to chart their learning journey.

Our investigation included an assessment of the current state of training for prospective software engineers in parallel computing within higher education institutions (HEIs) in Ukraine. This evaluation played a pivotal role in shaping our model. The model underscores that, prior to delving into the intricacies of parallel libraries (positioned as the third level in our model), students need to build a solid foundation in the first and second level concepts. This necessitates proficiency in algorithmization, object-oriented programming, an understanding of operating systems, familiarity with computer circuitry, and a grasp of computer architecture. As a result, a comprehensive study of the "Parallel and Distributed Computing" course is best undertaken in the third year of study. However, it is advisable to introduce certain elements of parallel programming during programming courses in the first and second years.

The formulation of this model provides a well-grounded rationale for positioning the "Parallel and Distributed Computing" course in the third year of the bachelor's program in computer science, within the broader structural and logical framework. The course curriculum, carefully designed to align with the third and fourth levels of the content model for training of software engineers in parallel computing, reflects this placement.

In the future, our focus will shift toward the development of topics that can be seamlessly integrated into programming language courses during the first and second years, thereby equipping students with the foundational knowledge necessary to excel in the "Parallel and Distributed Computing" course.

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References

[1] Striuk A M and Semerikov S O 2022 *Journal of Physics: Conference Series* **2288**(1) 012012 ISSN 17426588 URL `https://doi.org/10.1088/1742-6596/2288/1/012012`

[2] Vakaliuk T 2021 *Educational Technology Quarterly* **2021**(2) 257–273 URL `https://doi.org/10.55056/etq.17`

[3] Seidametova Z, Abduramanov Z and Seydametov G 2022 *Educational Technology Quarterly* **2022**(1) 20–34 URL `https://doi.org/10.55056/etq.5`

[4] Osadchyi V 2017 *Ukrainian Journal of Educational Studies and Information Technology* **5**(4) 89–99 URL `https://doi.org/10.32919/uesit.2017.04.08`

[5] Varava I P, Bohinska A P, Vakaliuk T A and Mintii I S 2021 *Journal of Physics: Conference Series* **1946**(1) 012012 ISSN 17426588 URL `https://doi.org/10.1088/1742-6596/1946/1/012012`

[6] Striuk A M and Semerikov S O 2019 *CEUR Workshop Proceedings* **2546** 35–57 ISSN 16130073

[7] Striuk A M, Semerikov S O, Shalatska H M and Holiver V P 2022 *CEUR Workshop Proceedings* **3077** 3–11 ISSN 16130073

[8] Ko Y, Burgstaller B and Scholz B 2013 *Proceeding of the 44th ACM Technical Symposium on Computer Science Education* SIGCSE '13 (New York, NY, USA: Association for Computing Machinery) p 415–420 ISBN 9781450318686 URL `https://doi.org/10.1145/2445196.2445320`

[9] Vakaliuk T A, Kontsedailo V V, Antoniuk D S, Korotun O V, Mintii I S and Pikilnyak A V 2019 *Proceedings of the 2nd International Workshop on Augmented Reality in Education, Kryvyi Rih, Ukraine, March 22,*

2019 (*CEUR Workshop Proceedings* vol 2547) ed Kiv A E and Shyshkina M P (CEUR-WS.org) pp 66–80 URL https://ceur-ws.org/Vol-2547/paper05.pdf

[10] Zahorodko P V, Modlo Y O, Kalinichenko O O, Selivanova T V and Semerikov S O 2020 *CEUR Workshop Proceedings* **2832** 94–103 ISSN 16130073

[11] Diaz J, Muñoz-Caro C and Niño A 2012 *IEEE Transactions on Parallel and Distributed Systems* **23** 1369–1386 URL https://doi.org/10.1109/TPDS.2011.308

[12] Sitsylitsyn Y 2020 *SHS Web of Conferences* **75** 04017 URL https://doi.org/10.1051/shsconf/20207504017

[13] Marowka A 2008 *IEEE Distributed Systems Online* **9** 1–1 URL https://doi.org/10.1109/MDSO.2008.24

[14] Wilkinson B, Villalobos J and Ferner C 2013 *Proceeding of the 44th ACM Technical Symposium on Computer Science Education* SIGCSE '13 (New York, NY, USA: Association for Computing Machinery) p 409–414 ISBN 9781450318686 URL https://doi.org/10.1145/2445196.2445319

[15] Capel M I, Tomeu A J and Salguero A G 2017 *Journal of Parallel and Distributed Computing* **105** 42–52 ISSN 0743-7315 Keeping up with Technology: Teaching Parallel, Distributed and High-Performance Computing URL https://doi.org/10.1016/j.jpdc.2017.01.010

[16] Giacaman N and Sinnen O 2018 *Journal of Parallel and Distributed Computing* **118** 247–263 ISSN 0743-7315 URL https://doi.org/10.1016/j.jpdc.2018.02.028

[17] Vasconcelos L B A, Soares F A L, Penna P H M M, Machado M V, Góes L F W, Martins C A P S and Freitas H C 2019 *2019 IEEE Frontiers in Education Conference (FIE)* pp 1–8 URL https://doi.org/10.1109/FIE43999.2019.9028566

[18] The Joint Task Force on Computing Curricula 2001 *J. Educ. Resour. Comput.* **1** 1–es ISSN 1531-4278 URL https://doi.org/10.1145/384274.384275

[19] Cassel L, Clements A, Davies G, Guzdial M, McCauley R, McGettrick A, Sloan B, Snyder L, Tymann P and Weide B W 2008 Computer Science Curriculum 2008: An Interim Revision of CS 2001 Tech. rep. New York, NY, USA URL https://doi.org/10.1145/2593246

[20] Joint Task Force on Computing Curricula, Association for Computing Machinery (ACM) and IEEE Computer Society 2013 *Computer Science Curricula 2013: Curriculum Guidelines for Undergraduate Degree Programs in Computer Science* (New York, NY, USA: Association for Computing Machinery) ISBN 9781450323093

[21] Clear A and Parrish A 2020 Computing curricula 2020: Paradigms for global computing education Paradigms for global computing education Association for Computing Machinery URL https://dl.acm.org/citation.cfm?id=3467967

[22] Prasad S K, Estrada T, Ghafoor S, Gupta A, Kant K, Stunkel C, Sussman A, Vaidyanathan R, Weems C, Agrawal K, Barnas M, Brown D W, Bryant R, Bunde D P, Busch C, Deb D, Freudenthal E, Jaja J, Parashar M, Phillips C, Robey B, Rosenberg A, Saule E and Shen C 2020 NSF/IEEE-TCPP Curriculum Initiative on Parallel and Distributed Computing - Core Topics for Undergraduates, Version II-beta Tech. rep. URL https://tcpp.cs.gsu.edu/curriculum/

[23] McCool M, Robison A D and Reinders J 2012 *Structured Parallel Programming: Patterns for Efficient Computation* (Morgan Kaufmann)

[24] 2019 Standart vyshchoyi osvity Ukrayiny pershoho (bakalavrs'koho) rivnya stupenya "bakalavr" za haluzzyu znan' 12 "Informatsiyni tekhnolohiyi" spetsial'nistyu 122 "Komp'yuterni nauky" URL https://mon.gov.ua/storage/app/media/vishcha-osvita/zatverdzeni%20standarty/2019/07/12/122-kompyut.nauk.bakalavr-1.pdf

[25] Dobrovol's'kyy H A 2020 Robocha prohrama navchal'noyi dystsypliny "Paralel'ni ta rozpodileni obchyslennya" URL https://moodle.znu.edu.ua/mod/resource/view.php?id=152709

[26] Khylenko V V 2020 Robocha prohrama navchal'noyi dystsypliny "Tekhnolohiyi rozpodilenykh system ta paralel'nykh obchyslen" URL https://nubip.edu.ua/sites/default/files/u286/kn_rp_tehnologiyi_rozpodilnih_sistem_ta_paralelnih_obchislen_rp_2021.pdf

[27] Oksiyuk O H 2020 Robocha prohrama navchal'noyi dystsypliny "Suchasni tekhnolohiyi bahatoprotsesornykh obchyslen"

[28] 2020 Robocha prohrama "Tekhnolohiyi rozpodilenykh system ta paralel'nykh obchyslen"' dlya studentiv za spetsial'nistyu 122 "Komp'yuterni nauky" osvitn'oyu prohramoyu "Komp'yuteryzatsiya obrobky informatsiyi ta upravlinnya"

[29] Pavlenko V, Prokhorov A, Kuzminska O and Mazorchuk M 2017 *CEUR Workshop Proceedings* **1844** 257–264 URL https://ceur-ws.org/Vol-1844/10000257.pdf

[30] Popel M, Shokalyuk S V and Shyshkina M 2017 *CEUR Workshop Proceedings* **1844** 327–339 URL https://ceur-ws.org/Vol-1844/10000327.pdf

[31] Vlasenko K, Chumak O, Bobyliev D, Lovianova I and Sitak I 2020 *CEUR Workshop Proceedings* **2740** 278–291 URL https://ceur-ws.org/Vol-2740/20200278.pdf

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Anthropologically oriented strategies of interaction in the Human-Computer system

To cite this article: O V Klochko *et al* 2023 *J. Phys.: Conf. Ser.* **2611** 012018

Anthropologically oriented strategies of interaction in the Human-Computer system

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Abstract. The article, based on the application of anthropological methodology, reveals the phenomenology of the physical-mental interaction between a person and a computer. Ways of integrative use of the concept of Umwelt by J. J. von Uexküll and the theory of movements construction are represented, and Umwelt-oriented strategies for improving computer technologies are presented. The Umwelt, as the world of perception and the world of human activity (in particular, cognitive), can be represented as an anthropo-computer world. On the basis of the current features of the body-mental Umwelt, ways of anthropologically directed improvement of HCI are determined. Using the questionnaire developed by the authors and applying cluster analysis, a survey of students of higher education institutions was conducted in order to determine the physical and mental orientation in Umwelt oriented interaction in the human-computer system. The interpretation of the research results indirectly indicates the systematicity, equality of interaction in the human-computer system. This determines the possibility of distinguishing typical ways of interaction in the human-computer system, among which the bodily and mental-psychological ones are significant, which correspond to certain levels that characterize the systemic, spatio-temporal and structural-functional organization of motor activity in the theory of movements construction.

1. Introduction

The problem of human-computer interaction is relatively traditional and established. This permanently relevant problem is presented as a through-and-through and constant, first of all, in connection with the co-evolutionary (for now) development of information technologies and, so far, the relative transformation of the person himself and his adaptation to the "Digital World". Accordingly, consideration of the specified problem in the direction of both sociocultural and technical-technological understanding is significant, systematic and multidimensional, which includes an anthropologically oriented interpretation of it. This is due, first of all, to the global trend of digitization of both technology, education and science, as well as socio-cultural and industrial spheres in general, as well as trends in the humanization and greening of earthly civilization. This is also determined both by requests aimed at constant technical, software and intellectual improvement of the digital sphere, and by issues of effective use of computer technology, which in turn are determined by the specifics of interaction in the human-computer system. Currently, there is a significant variety of ideas, visions, approaches and models presented in the scientific literature, which reveal the specifics of interaction in the human-computer system, both in specific technological and problem-oriented issues, and at the level of theoretical reflections and futuristic forecasts.

Interesting in this direction are the studies of recent years, which we will briefly present (figure 1, figure 2, figure 3).

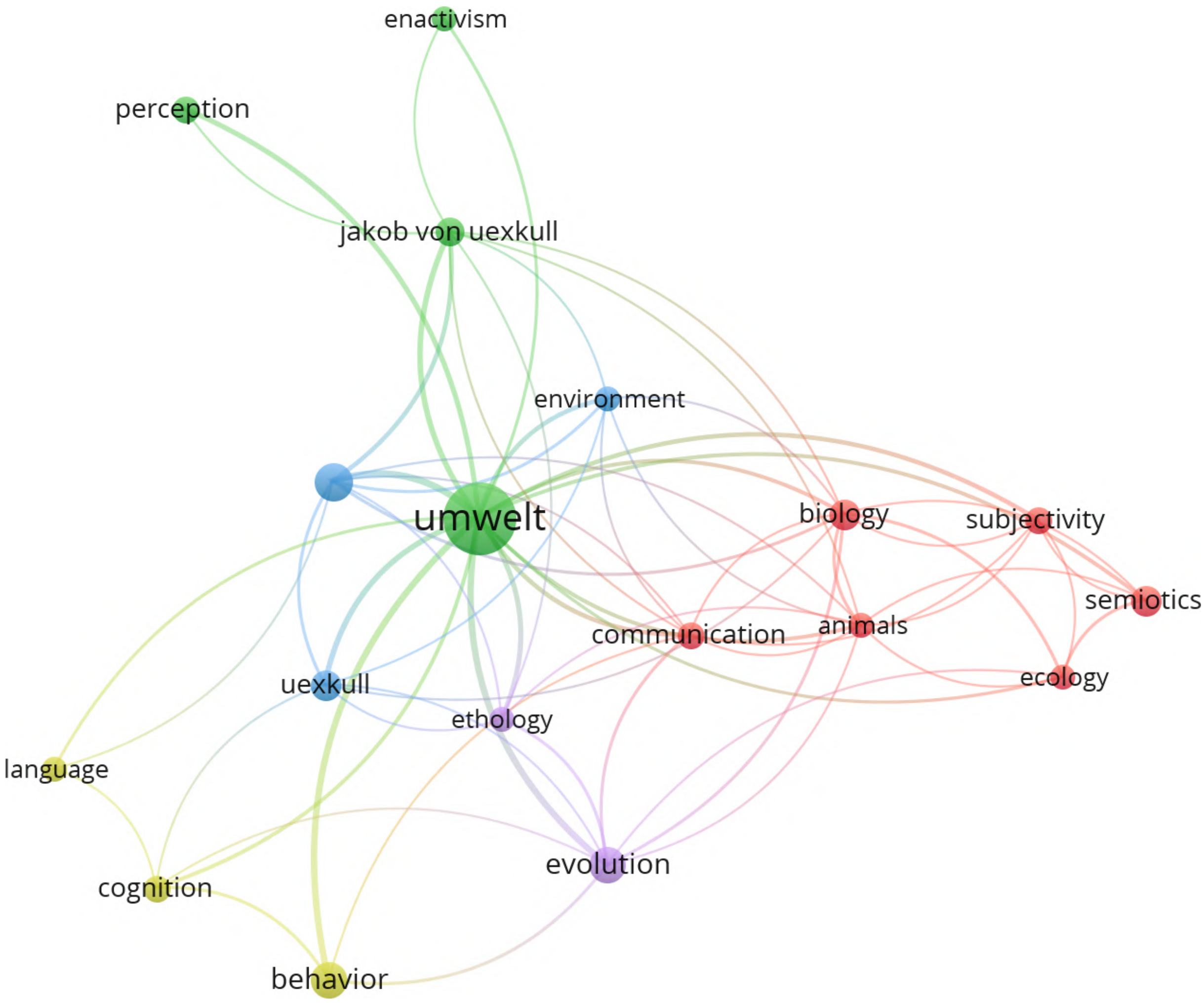

Figure 1. Connection map of thematic categories of research by scientists for five years (2018-2022) related to the topic "Umwelt", which are placed in the database of the multidisciplinary scientific platform Web of Science [1, 2].

In the study by Saeed et al. [4], having conducted an analysis of articles from 2017 to 2022 devoted to the problem of using gestures for human-computer interaction (HCI) using Sensory Gloves, comes to the conclusion that one of the directions for solving this problem is the improvement of the relevant deep learning algorithms and the decision to reduce the size of the equipment for greater compatibility and mobility of the system, as well as the search for compromises between robustness and sensitivity of the system. The system-organizing factor in this study was the dominance of technical solutions over anthropological solutions.

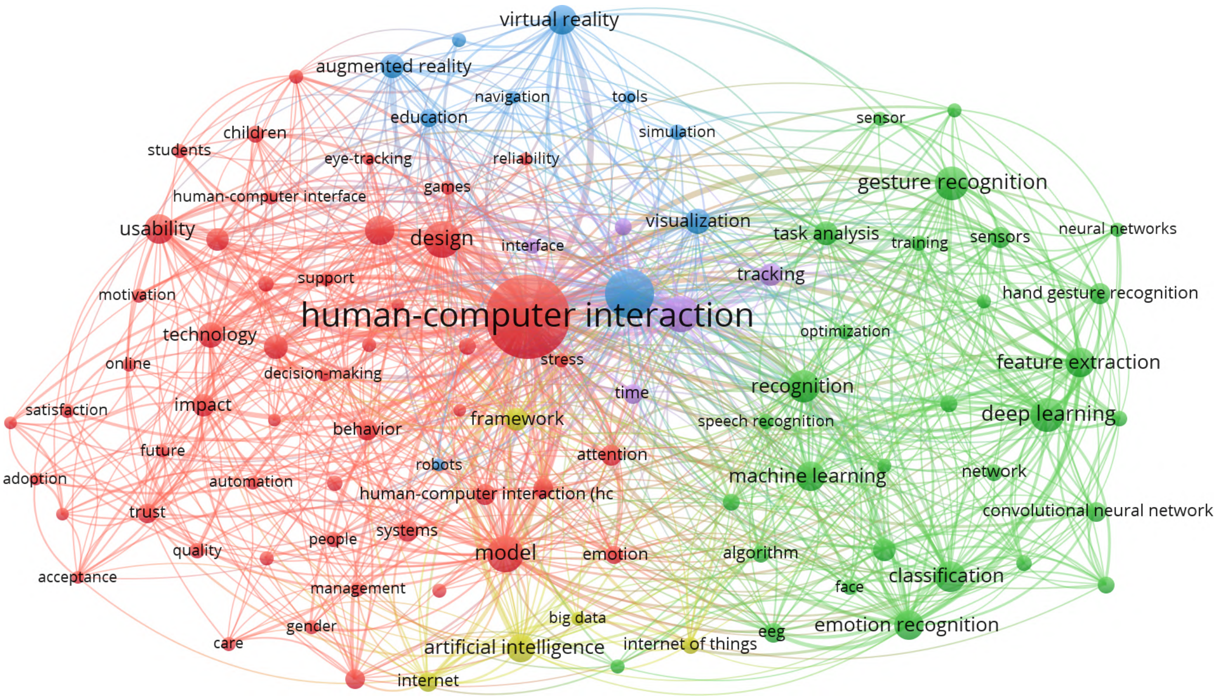

Figure 2. Connection map of thematic categories of research by scientists for five years (2018-2022) related to the topic human-computer interaction, which are placed in the database of the multidisciplinary scientific platform Web of Science [1, 2].

The analysis of the user experience in the design of the interface of human interaction with the computer was investigated by Xiong and Hou [5]. To create a more personalized interface design in order to meet the needs of the user, they used an optimized Kalman filter, which provides higher speed and accuracy of recognition of the gesture function [5].

Burrows et al. consider the issue of a mental model of HCI based on deep learning using convolutional neural networks and generative adversarial networks, offer solutions for solving the problems of stress and negative mood detection, defining strategies to counteract these negative phenomena [6]. The authors update attention to the problems of emotional intelligence, real-time design of HCI.

Sun et al. [7] made a “dispersion theory-based redundant electrode detection method” to optimize thumb motion-based gesture recognition using sEMG signals, thus addressing a specific “bodily-motor-mental-technical” a problem aimed at optimizing and increasing the efficiency of HCI.

Yun et al. [8] develops the problem of decision-making using visual HCI. The architecture of the visual decision-making system is developed on the basis of intelligent data analysis. In this way, the spatial-visual-intellectual dimension of the problems of interaction in the human-computer system is practically revealed.

Tarasenko et al. [9] consider the phenomenon of HCI in a practical way with the aim of improving simultaneous translation skills.

Robinson et al. [10] conducted a comprehensive analysis of articles on robotic vision over the past 10 years. According to the results of the study, it was found that the issues of robotic vision for recognizing actions, gestures and moving them in the space of human movement, as well as for ensuring interaction between a robot and a person, demonstration of actions to a person, training and social communication [10] were most often investigated.

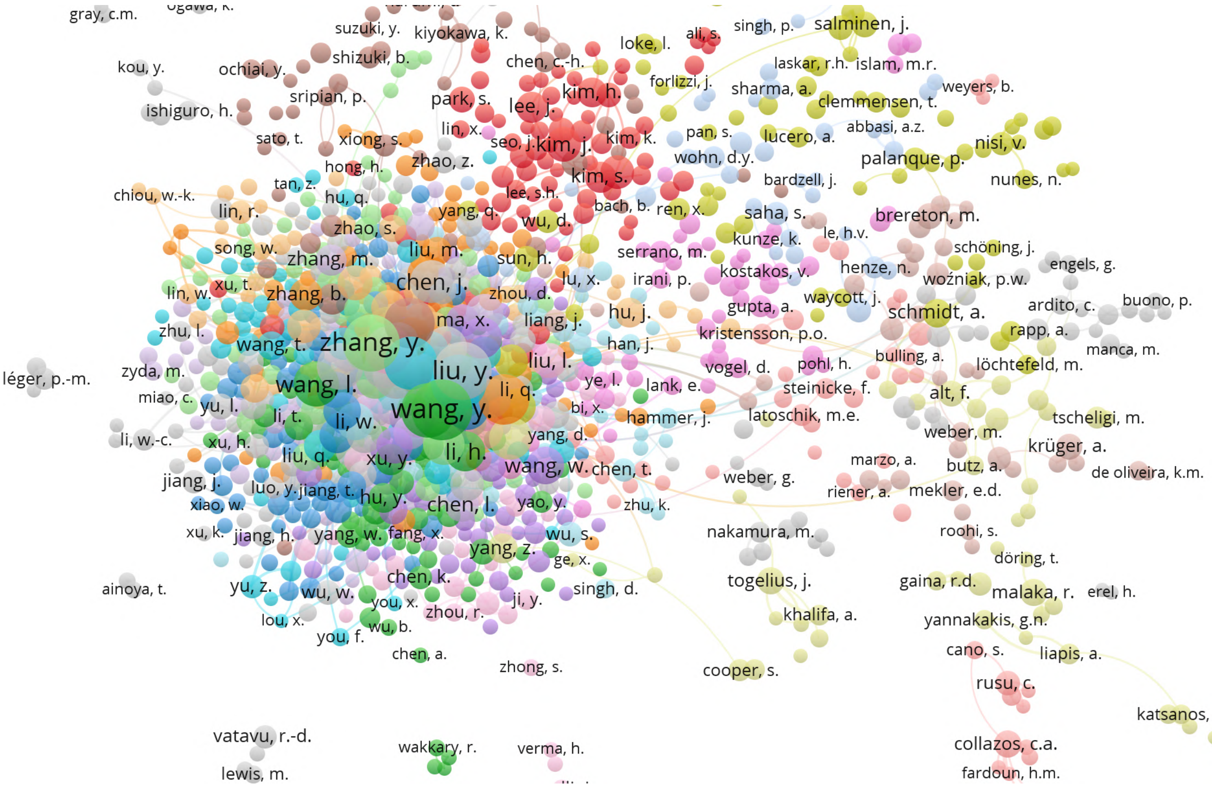

Figure 3. Connection map, created on the basis of the data of joint citations of authors in the field of human-computer interaction for five years (2018-2022), whose scientific works are placed in the abstract and citation database Scopus [2, 3].

The scientific interests of researchers are increasingly correlated with issues of health problems related, in particular, to the mental state of a person in the process of HCI, the emergence of computer addiction [11, 12].

The use of immersive technologies in e-learning, in particular game technologies based on virtual/augmented reality, are important issues of HCI research [13–19]. The results of many studies have shown that the balanced and appropriate use of these technologies in e-learning provides an opportunity to increase the educational achievements of students.

The growing role of the use of computer systems for health preservation, monitoring systems of the state of the surrounding environment actualizes the issue of digital literacy for effective and adequate use of providing HCI [20, 21]. Research by scientists shows that the issue of digital literacy of users of technological services in the health care system is a key component of their use.

At the same time, despite a significant amount of work in this direction, the insufficiently disclosed anthropocultural and psychological aspects of the problem, namely the correlation and correspondence of computer tools (technical, software, etc.) to the nature of man and his culture, are significant. In clarification, let's point out some significant specific issues of interaction in the human-computer system. These include human-oriented and interdependent issues of existence, integrity, harmony, corporeality, emotionality, formation of meanings, conjunctiveness, corporeal mind, sensory and motor interaction, etc. [22]. Summarizing, we can say that a person, due to his "anthropo-bio-psycho-cognito-socio-cultural" nature, needs a systemic, multidimensional and multichannel (polyfunctional) and human-dimensional interaction with the computer, which is implemented through a special "contact" interaction environment. That is, the currently dominant semiotic-symbolic, digital screen and partly figurative-semantic interaction needs a certain expansion and addition. This includes the imitation of human existence, presented in the format of Lebenswelt (Life World according to E. Husserl) [23]. Methodologically significant in this direction can be the application of concepts that holistically, systematically, autopoietically and in relationship and through the meanings of harmony with the environment reveal the "body-cognitive" nature of a person, namely: the embodied mind J. Lakoff [24, 25], enactivism, biomechanics – in particular, theories of movements construction [26], functional systems (physiological theory), Umwelt [27,28], functional circle (German: Funktionskreis) [28], concept of autopoiesis by H. Maturana and F. Varela [29] and others.

Human nature is characterized by "expansion", knowledge and expansion directed both outward into the "visible" world – the Macrocosm (Greek: $M\alpha\kappa\rho o\kappa o\sigma\mu o\zeta$), and immersed in its own special world – the Microcosm (Greek: $M\iota\kappa\rho o\kappa o\sigma\mu o\zeta$), through self-knowledge. According to the peculiarities of biological and mental human nature, within which the "expansion" of a certain part of both the environment and the inner world is relevant, it is the "creation" and existence of a person in the special realities generated by it – social, cultural, digital, mental-psychic. In the anthropocentric understanding and solution of the problem, a person, according to his essence, aims to "include" the computer in his anthropic world and transform it into an acceptable, understandable, predictable phenomenon – an object, a semiotic system or a part of this world. Another (unacceptable and opposite) to the indicated human-centric technocentric way of interaction in the human-computer system is also possible, in the implementation of which a person will be included in the world of the computer, adapting to it.

Summarizing the above, we actualize the need for anthropologically oriented studies of the problems of human-computer interaction, first of all, from the standpoint of systems theory. This approach is based on the integration of: human psychology, ergonomics, the need for multi-channel interaction; human morphophysiology (structure and function); bodies and physicality (social and psychological representation of the body); specifics of motor activity; speech; general and specific features of activity. We use the concepts of Umwelt as a methodological way to a multi-faceted systemic and holistic description of interaction in the human-computer system.

So, guided by the ideas of systematicity, integrity, expansive character and multidimensionality of the nature of the living and, above all, spiritual-mental, epistemological and activity-praxic and sensory-motor entities of man, we actualize the idea of considering the interaction in the human-computer system on based on the application of the Umwelt concept of the human cognitive and activity world [15]. Unlike other living organisms, the Umwelt of a person is presented as multidimensional and one in which intellectual and semiotic-symbolic aspects are decisive. The idea of Umwelt is interesting primarily because it represents a living organism not only and not so much as an isolated object, but as a systemic, multifunctional, multifaceted interaction of man and the environment, or, more precisely, as a special world that is formed by interaction with the environment, the Umwelt concept also effectively, systematically and variably reflects the phenomenon of the boundary-contact between a person and the environment, which is emphasized in Gestalt psychology. In the idea of Umwelt, as well as in the concept of the boundary-contact, the diversity and specificity of the cognitive and active nature of a person is manifested in the context of considering it in temporal and spatial aspects. To analyze the interaction in the human-computer system, we suggest using another component – the Human Umwelt. Then the human-computer system will be represented in an extended, complementary and variable manner as "Human – Human Umwelt – Computer". Human Umwelt in the specified system is considered at the same time: as a method of description and interpretation of interaction, as a boundary-contact determining the limits, dimensions and intensity of interaction, as a semantic-meaning field of sensory-motor-cognitive-activity interaction. As a model of Umwelt, which systematically and holistically represents human nature, we propose to consider the theory of movements construction. The specified theory describes the nature of motor activity taking into account the sensory-analytical, existential and spatial components, and also reveals the nature of cognitive and object-activity transformation of motor activity. Man, as a "bodily-motor-mental" being, within the framework of this theory, is consistently, integratively and systematically represented as vital-existential-sensual-motor, as bodily-synergistic-motor, as motor-spatial-cognitive, as object-activity-cognitive, as a physical-speech-intellectual and as an intellectual-spiritual phenomenon.

In the scientific literature, the problem of HCI in the context of the actualization of the phenomenology of the human Umwelt and its purposeful application for the development of software and computer equipment is not disclosed. This study is relevant to the current socio-cultural and scientific-practical trend of NBIC convergence. Accordingly, taking into account the significance of the indicated direction of research for humanizing and anthropologizing interaction in the human-computer system and further anthropocentric, ecocentric and "biocentric" directions of development of computer technologies, including robotics, virtual/augmented reality, development of smart environments (educational environments, smart houses, smart cities, etc.), we present this research as relevant.

Purpose. To conceptualize anthropologically oriented strategies of interaction in the human-computer system based on considering it as a spatial sensory-activity-cognitive reality.

2. Selection of methods and diagnostics

The research used a system of methods and approaches: systemic, ontological; hermeneutic; phenomenological [23]; biosemiotic (R. Millikan [30]); anthropological; cluster analysis. Methodical approaches developed in the system of digital anthropology, embodied cognitive science (L. Shapiro) [31], enactivism (F. J. Varela, E. Thompson, E. Rosch [31,32], biomechanics [15, 26], pedagogy [13–15] were applied.

Theories and concepts were applied: Umwelt (J. J. von Uexküll, [27,28]; of a functional circle (German: Funktionskreis) (the concept of J. J. von Uexküll) [27, 28]; the life world (German: Lebenswelt) of E. Husserl [23]; autopoiesis (H. Maturana and F. Varela) [29]; embodied mind J. Lakoff [24, 25]; muscle clamps and "character armor" [33] rhizomes (according to J. Deleuze and F. Guattari) [34]; archetypes and the collective unconscious of C. Jung [35,36]; the boundary-contact developed in Gestalt psychology [37, 38], the psychological field of K. Levin, functional systems. The applied ancient Greek concepts of Kairos (Greek: $K\alpha\iota\rho o\zeta$), Chronos (Greek: $X\rho o\nu o\zeta$).

Own methodological developments. In the study, the "Fedorets-Klochko Questionnaire was used to determine the body-mental orientation in the Umwelt oriented interaction in the human-computer system". The purpose of using the specified questionnaire was the primary diagnosis of interaction in the human-computer system is presented in the format of a physical-mental-spatial phenomenon – *anthropo-computer Umwelt.* The specified interaction was considered as a manifestation of the human Umwelt, which covers both sensory-cognitive and sensory-perceptive as well as mental and activity dimensions of the human.

Fedorets-Klochko Questionnaire was used to determine the body-mental orientation in the Umwelt oriented interaction in the human-computer system

1. Are you comfortable in the environment where the computer is located?
2. Do you have unpleasant physical and mental sensations when you are near a computer?
3. Do you feel fear, dislike, discomfort if there is a computer nearby?
4. Do you have positive physical and mental sensations when you are near a computer?
5. Are you interested in looking for and viewing on the computer screen the images of the elements and the world's primordial foundations, for example, fire, water, sky, sun, stars, outer space?

6. Is it interesting and important for you to perform similar and repetitive actions while working at the computer, for example, frequently checking mail, visiting familiar sites without special need?
7. Do you often listen to music while working at the computer?
8. Are you interested in working on a computer/tablet/smartphone on the road while walking or while waiting?
9. Do you often feel a sense of rhythm, peace and harmony while working at the computer?
10. Are you interested in looking at pictures of nature or natural artifacts, for example, trees, stones, animals, insects, etc. while working at the computer?
11. How often or systematically do you observe pictures of nature as landscapes and isolated artifacts of the process of working at the computer?
12. Do you often have a desire to immerse yourself in fantastic worlds and corresponding spaces created with the help of computer graphics?
13. Are you interested in artistic paintings, films and games where there are images of landscapes and earthly spaces, for example, the sea, forest, mountains, steppe, etc., while working at the computer?
14. When working at the computer, are you interested in graphic images, movies, and games in which movement in space is available?
15. Are you interested in images, movies and games that contain images of architectural buildings and cities while working at the computer?
16. Are you interested in observing the work of people and mechanisms/machines while working at the computer?
17. Are you interested in finding and looking at different interiors and things created by man while working at the computer?
18. Are you interested in images, movies and virtual games that contain images of architectural buildings/cities when working at the computer?
19. Does working at the computer help reveal your intellectual potential?
20. Does working at the computer contribute to the disclosure of your spiritual, mental and emotional potential?
21. Does working at the computer increase your interest in certain professional and life spheres?
22. Have you become smarter as a result of working at the computer?

Variants of answers: “No”, “Can’t decide”, “Yes, to a small extent”, “Yes”, “Yes, to a large extent”.

Let’s consider the conceptual and semantic bases of the questionnaire. The understanding of “Umwelt-interaction” in the system “Human-Umwelt-Computer” is based on the theory of movements construction. The system-organizing methodological factor that determines the application of the specified theory is the systemic, multidimensional, holistic and “anthropic” nature of motor activity, which reflects the nature of man as a sensory-perceptive, active, and mental being and as a “motor-activity-mental” way of interacting with the environment. In the content-semantic framework of the theory of movements construction, motor activity is considered multidimensionally as: existential-bodily, sensory-perceptual, sensory-motor, spatial-motor, activity-praxis (working with objects and tools), body-motor-mental, speech-mental and mental phenomena. The phenomenology of the motor sphere presented in the theory of movements construction reveals the essence of man and his interaction with the environment as a special harmonized motor-praxical-mental world. Accordingly, a person and his “world of interaction” with the environment is represented in sensory-perceptual, spatial-temporal, activity-motor (praxis), activity-cognitive, speech-mental formats. It is methodologically significant that a person's perception and cognition of the world and its activities are considered as defining aspects of the Umwelt. To clarify, we note that the Umwelt is a sensory-perceptual-cognitive-active world. According to J. J. von Uexküll [27, 28], the Umwelt is the world of Perception and the world of action.

It is decisive that the nature of a person, which is revealed through interaction with the environment, manifests itself in praxis (the ability to work with objects and tools is inherent only to a person) and in speech, communication and intellectual activity. The theory of movements construction are represented systematically, interdependently, multidimensionally, holistically, intentionally, which can be represented as special "worlds of interaction" (the world of Perception and the world of Action) – Umwelt. Thus, according to the ideas about a person as a multidimensional being – "existential-bodily-motor-spatial-praxis-speech-mental" and on the basis of understanding the peculiarities of his motor and mental and praxis-activity spheres, the questions of the questionnaire were formed. The group of questionnaire questions reflects the interaction of the corresponding level, which in the theory of movements construction has a certain degree of autonomy and systematicity and represents a "part" of the human Umwelt as a "perceptual-motor-active-mental" world.

The theory of movements construction presents motor activity, praxis (work with objects and tools) and speech-intellectual activity as a system in which 5 levels are distinguished (A, B, C, D, E). Each of the 5 levels is part of the following, although there is also a certain autonomy. Let's present the questions of the questionnaire in accordance with their certain levels. It is clear that it is not possible in a "pure" form or separately, by considering certain questions of the questionnaire, to reflect and characterize the state of each of the levels due to their interdependence and interpenetration. Questionnaire questions represent a mental-speech projection of a certain level of motor activity, perception, praxis and intellectual activity in the context of probable interaction with a computer.

The level of tonic movements (level "A") is revealed in the first 5 questions of the questionnaire (from the 1st to the 5th question). In the specified questions, the problem of sensory-perceptual and vital phenomenology of a person is actualized as a determining factor, which is revealed and interpreted in polar questions. In the questions of the questionnaire, the polar questions of comfort/discomfort, fear/absence of fear, pleasant/unpleasant sensations are actualized. But, first of all, the issues of positive sensations, sensory and perceptual images and reflections and their interpretations are considered as reflecting the state of this level "A". The cognitive aspect of the specified level is revealed through the actualization of the images of the elements and the world's primordial foundations – fire, water (sea, ocean, etc.), stones of the sky, sun, stars, outer space, etc. The questions conceptualize the problems of "simple" and not sufficiently differentiated sensations and sensory and perceptual images, which can be perceived, interpreted and represented as acceptable for the individual as well as antagonistic or polar. Such sensory, perceptual and partially emotional phenomena are simply presented as "positive" ("+") or "negative" ('–"). In the specified sensory and perceptual phenomena and partially in the emotional sphere, the primary biological and vital meanings associated with the basic existential and vital directions of a person are manifested. Emotions that can be manifested at the same time are close to thalamic ones. Such thalamic emotions, when considered in an evolutionary aspect, are ancient and close to pathological. They are undifferentiated and do not have a certain specific modality (visual, auditory, etc.) and primarily signal to the organism about two aspects of its existence – "good"/"safe" ("+") and "not good"/"dangerous" (bad "–") In the indicated sensory, perceptual and emotional phenomena, human vitality is reflected, as well as "sensory-perceptual" and "sensory-motor" ways of understanding or, more precisely, awareness of one's existence, which manifests itself as givenness and presence, which is expressed succinctly as "I" and "am".

In the questions of the questionnaire from the 6th to the 9th, the level “B” – “Synergistic movements” is reflected. This level in the context of HCI is interpreted somewhat more broadly, namely in the form of synergistic actions. To clarify, let’s point out that the action has a relatively complex algorithm, often stages, sequence and a certain purpose and meaning, while the synergistic movements is quite simple, rhythmic in its biomechanical implementation. Thus, through the levels “B” and “A”, the phenomenology of the rhythm that permeates the entire cosmos and manifests itself in human nature is manifested. Accordingly, rhythm is manifested in human temporality and is reflected in synergies, that is, in repetitive, rhythmic, oscillating, balancing movements. This level reveals the phenomenology of body space and the space near the body, the limits of which are the dimensions of the limbs and the body itself. Essentially, the contact between the body and the computer is within these dynamic limits. An imaginary zone in space that corresponds to this level “B” can be outlined as a sphere or an egg, where the boundaries are defined by limbs describing arc movements. Repetitiveness and rhythmicity of this level, which reflect the deeper rhythms of both the body and the cosmos and are manifested in the harmony of sounds – music and dance. Thus, the problems of repetition, rhythm, musicality, harmonization with oneself and with the world are embedded in the question of this level. Accordingly, in the system of this level, the computer and work on it can be considered in the semantic framework of promoting the manifestation of rhythm, harmony, as well as revealing the musical and poetic aspects of human nature. In this case, there will be a synergistic, complementary interaction, which should not only include synergistic effects, but be formed on the basis of them and thanks to them. Man in his biomechanical essence and by his human nature is harmonious. One of the ways of harmonization is the rhythm that manifests itself in the synergy of both movements and actions and interactions. It is also possible to have a polar or opposite interaction, which will manifest itself as ignoring rhythm and harmony.

Six questions from the 10th to the 15th reflect the level “C” – “Spatial movements”. The indicated level “C” manifests itself in a person through the implementation, first of all, of movements in space – walking, running, jumping. Thanks to this level, the spatiality and visuality of a person is revealed and formed. Space and movement in it reveal and form the corresponding sensory, perceptive and cognitive spheres in a person (for example, spatial perception, thinking, imagination, etc.). Therefore, the questions of the questionnaire concern the actualization of landscapes and landscapes, which are considered as real natural and anthropogenic, as well as “constructed” in the imagination of the artist, or virtual spatial phenomena. Also important are natural and anthropogenic spatial artifacts – stones, trees, animals, houses, objects, etc., which are represented both separately and as included in a certain spatial system – city, forest, steppe, house, interior, etc. The computer in the system of this level is displayed simultaneously as: a spatial object; as a “spatial-techno-instrumental” phenomenon.

Functional features of level D – “Object actions” are revealed in 3 questions, from the 16th to the 18th. In the questions of the questionnaire, which reflect the indicated level, the phenomenology of praxis is updated, that is, purposeful algorithmized object actions or work with objects, things, tools. Accordingly, the questions of the questionnaire are updated, which relate to observations of the work of people, mechanisms, machines, as well as the results of activities – objects, architectural structures, that is, the object and machine-technological environment. The computer in the system of meanings of this level is considered as a significant component of the object-instrumental environment.

The functional features of level “E” – “Intellectual (speech) movements” in the context of HCI are revealed in 4 questions – from the 19th to the 22th. In the questions of the questionnaire, which reflect the indicated level, the phenomenology of body language, speech and, to some extent, intellectual activity is considered. That is, in the questions of the questionnaire, in which the indicated level is reflected, first of all, the meanings, values, intentions of cognition are revealed, as a manifestation of intelligent human nature and mind as the highest result of the development.

In order to determine the groups of respondents according to the body-mental orientation in the Umwelt of oriented interaction in the human-computer system, the SimpleKMeans cluster analysis method was applied using the Weka platform [39, 40]. The number of clusters was determined taking into account the results of data preprocessing [41] (table 1). Analyzing the obtained results, it was decided to divide the respondents into three groups with characteristic features according to the research topic.

Table 1. The number of clusters, determined by quality indicators.

Index	Number of clusters
Dunn	4
DB	4
SD	3
CDbw	3
S_Dbw	3

3. Results and discussion

Let us consider the theoretical and conceptual understanding of the problem of HCI based on the integrative use of the concept of Umwelt by J. J. von Uexküll [27,28], the doctrine of autopoiesis by H. Maturana and F. Varela [29], the theory of movements construction [26] and the concept of boundary-contact [37, 38]. The specificity of these concepts is that in them the interaction between man and the environment is revealed holistically, systematically, and structured. These concepts represent the specified interaction between human and the environment as a special "human-environmental" reality (world), which can also be considered as a boundary (or zone) of their active contact, which includes mutual penetration. Accordingly, to consider the interaction in the human-computer system, the specified concepts can be applied integratively and mutually complementary, which reveals and actualizes their methodological and application potentials.

To understand the interaction in the human-computer system, we apply the idea of the boundary-contact [37, 38] on Gestalt psychology. The boundary-contact is a place (zone) of interaction between a person and the environment and is presented as a primary psychological reality. Accordingly, we can suggest that one of the aspects of effective interaction in the human-computer system should be the finding of electronic devices or their sensory, cognitive, autopoiesis or other effects in the "boundary-contact" between the person and the environment. The specified boundary-contact can be not only determined ("found") but purposefully constructed. The above-mentioned concepts present us with options and opportunities for consideration and selection of such contact boundaries (zones), which can be considered both relatively constant and dynamic. This is relevant even if special devices or their effects are localized in the human body itself.

We consider HCI as a special reality. In this reality, the nature of man is revealed as a system-organizing and leading one, which, according to the concept of H. Maturana and F. Varela, is cognitive and autopoiesis (the ability to self-form and self-develop). Autopoiesis as a special quality of the living, within the framework of this study, is interpreted by us, first of all, as the ability to form an effective boundary-contact between a person and the environment and to build one's Umwelt [27, 28]. In this aspect, computer cognition, regardless of autonomy, is considered as a manifestation of the human cognitive nature transformed into a technical tool. Therefore, human cognition in the specified interaction, despite the presence of elements of dialogical interaction, we present as leading and primary. Cognition, as a special human quality, and as a way of contact with the environment [37, 38] has various manifestations – sensitive, perceptive, motor, activity, verbal, etc. It is both formed and implemented through the actualization, first of all, of sensory systems and the motor sphere, which are the basis of locomotion, speech, and activity. Therefore, human cognition in its bodily basis is sensorimotor (sensorimotor intelligence and bodily mind), which has distinct spatial and motor dimensions [37, 38]. Another defining feature of human cognition is that it is verbal, which reflects a person's special ability to create symbolic realities. The specified aspects of the human mind as a sphere in which, first of all, the inner reality is reflected, reveal it as a spatial and activity phenomenon. Human sensory systems, which, perceiving the inner reality of a person or the external world, function within certain spatial boundaries. The specified limits can be considered in the format of spatial structuring of human cognition, which can be presented layer by layer according to the specified functional specificity of sensory systems. Thus, the spatial structuring of cognition is primarily determined by the spatio-temporal specificity of the functioning of sensory systems (proprioreceptive, visual, audio, etc.). It is important that sensory systems, having a certain degree of autonomy, integrate and reveal their cognitive potential during motor activity and other activities, forming special typical "sensory-motor zones" and "sensory-motor-activity zones", which, accordingly, have their own spatial specificity. The above-mentioned features of human cognition as sensory-spatial, perceptual-spatial, motor-cognitive, neuro-cognitive-spatial, cognitive-spatial phenomena are systematically revealed in the concept of building movements [26].

According to the ideas of J. J. von Uexküll, in humans, as in any living being, there is a sensory component in the form of a receptor system (German: *Merknetz*) and an active component (which is primarily realized due to the presence of motility), which considered as a system of effectors (in the sense of active "tools") (German: *Wirknetz*). The specified systems (sensory and effector, primarily motor) are not isolated, but exist interconnected, interdependent and complementary, adjusting to each other, forming a functional circle (German: *Funktionskreis*) (the concept of J. J. von Uexküll) [27, 28]. The functional circle essentially "integrates" the organism and the environment, including its artifacts and parts. A living being figuratively speaking is in a system of functional circles that construct its interaction with the environment.

In this study, we point out that the functional circle integrates a person and a computer, which is considered in many ways – as a thing, as a special world, as a tool, as a machine and technology, as a special cognitive and emotional. Accordingly, the *Funktionskreis* can be represented as one of the aspects of structuring the Umwelt of a person, in which a computer can be present – as a "thing-instrument" (structure), as a function (cognitive, image-forming, etc.) and as a special reality, including virtual and supplemented.

The application of the concept of Umwelt [27, 28] and *Funktionskreis* [27, 28] reveal to us the possibility to understand and represent the interaction of a person and a computer as a special multidimensional, dynamic and systemic integrity. The indicated integrity can be understood and varied and described as a system of "circles of interactions" – functional circles (*Funktionskreis*). The specified *Funktionskreis* can be represented as: levels; communication channels; flows of energy, matter, information; structural and functional fragments that integrate both the components of a person (or/and a person) and the environment (including a computer, augmented reality, etc.). Thus, the concepts of Umwelt and functional circles of J. J. von Uexküll are at the basis of methodological strategies aimed at considering Umwelt-oriented interaction in the "Human – Computer" system constructively, necessarily, purposefully, which determines the variability of representations. This, accordingly, conditions the strategies of applying existing ideas and theories (and their systems) in which man and his interaction with the environment are represented systematically, spatially and multidimensionally.

One of such anthropologically and spatially oriented, intellectually refined and deep in its meanings concepts that systematically reveal the interaction of the human Microcosm (Greek: $M\iota\kappa\rho o\kappa o\sigma\mu o\zeta$) and the world of the Macrocosm (Greek: $M\alpha\kappa\rho o\kappa o\sigma\mu o\zeta$) through consideration of the "mystery of movement" (according to the theory of movements construction). We interpret this theory more broadly as a theoretical system that represents the structural and functional foundations of the human motor and partially sensory sphere. This is due to the fact that the phenomenology of the sensory sphere, without which it is impossible to understand motor activity, as well as the movement itself, which is the basis of human activity, can be represented as Umwelt. According to J. J. von Uexküll, Umwelt is a sensory-perceptual-active world. In essence, in the theory of movements construction presented one of the system options for describing the human Umwelt, in which the motor component is system-organizing and leading.

In the theory of movements construction, movement is represented: systemically – as a system represented by 5 levels (A, B, C, D, E); purposeful – that is, motor activity of each level has a purpose, including self-maintenance; hierarchical – which is reflected in the allocation of lower and higher levels (the hierarchy starts from level A in the direction to E); ontogenetically – movement can be represented as the development of the motor system in the process of individual development (ontogenesis); phenomenologically and anthropologically – with the disclosure of the anthropological specificity of the movement and the phenomenology of each level. For Umwelt's oriented examination of the interaction in the "Human – Computer" system, the contextual meanings embedded in the theory of movements construction are important. This theory reveals the spatial, temporal, regulatory, pathological, health-preserving, communicative, and existential aspects of motor activity as a cybernetic system in interaction with the environment.

We will present the understanding of HCI according to the essential characteristics of each of the 5 levels (A, B, C, D, E).

The level of tonic movements – "A" is basic (it is the basis of the "movement" hierarchy) for all other movements. Accordingly, it is present in all movements. When considering "Level A" as a *Funktionskreis* (functional circle), it will be represented as a sphere and/or circle that encompasses a person both within his body and at a relatively short distance from the body. This level integratively represents many human spheres, systematically revealing human nature, namely: existence as a bodily given; the connection of the body and motor activity with the archetypal level of consciousness, including the collective unconscious; vitality manifested in tonic movements both in statics (sitting, standing) and in dynamics; thalamic emotions (including emotions close to pathological ones), which are mainly interpreted as positive "+" or negative "–" and reflect the state of health, vitality and to some extent can signal the future; anticipation (prediction of the future), which is manifested in a barely noticeable change in tone, in thalamic emotions; state of vital organs and systems; sensors and perception (including the level of sensations and integral sensory and perceptual images of images) in the formation of which participate – proprioceptors (located in muscles and their tendons), interoreceptors (localized in internal organs); noceoreceptors (pain); skin receptors. The functional purpose of the indicated level "A" is to maintain the organism itself in a biologically "optimal" state. This is realized by ensuring the regulation of muscle tone, which we can feel during palpation in any area of the body where there are muscles, including facial muscles. Muscle tone, which is present in the entire body where there are muscles, in the absence of pathology is regulated automatically, representing one "tonic" integrity. A person's understanding of himself as a special integrity and continuity can be represented as the self, which is perceived as "higher integrity" we believe is connected with the state of level "A". This level is continuous in time – it is always there, and it is also unbreakable in its inner space.

We present the interaction between a computer and a person at the "A" level as *existential-bodily-motor-tonic*. A computer at this level can be perceived and interpreted neutrally ("invisible"), positively ("+") or negatively ("–"). An ambivalent "mixture" of the specified response options is possible. Accordingly, this will also manifest itself in an increase in the risks of computer addiction formation, if there is a "totally" positive "+" perception. Because the entire "inner world" of thalamic emotions and deep (in the sense of interoceptive) sensors and perception due to the potential of plasticity (including the ability to adapt) is accordingly modified under the influence of "computer connotations" (in the sense of long-term but weak influences). A negative "–" perception of a computer can be formed due to the fact that at the subconscious level it can be perceived as a "non-living entity with signs of a living one". The body will perceive it ambivalently as "+" and "–", respectively, which can generate tension, fear and anxiety, respectively. Negative emotional states that cannot significantly affect mental reality are indicated. Accordingly, as a result of hypercompensation and psychological defense mechanisms, such weak effects of the "computer" on the subconscious can transform into a tendency to addiction and a "hyperpositive" attitude towards the computer. Drawing analogies, we can say that at the level of cell biology, a virus acts in a similar way, which is often incorporated into the cell's genome.

This level "A" is the most "true", it is the "level of alateia" – truth (Greek: $\alpha\lambda\eta\upsilon\varepsilon\iota\alpha$) and being. It accurately reflects the state of the body and, above all, of the nervous system and psyche, including hidden problems. Psychological and other life problems can be transformed into physical problems, a typical variant of which is muscle clamps, which can collectively form the so-called "character armor" [33]. Muscle clamps are formed primarily at level "A". As an example, we note that interaction with the specified level is used when working with a polygraph. Level "A" mainly determines the individual specificity of handwriting, gait, and voice. Purposefully changing these phenomena (for example, handwriting) is quite difficult, and in most cases it is not possible. If the handwriting changes, the intonation of the voice changes, then mostly the person changes deeply and totally.

We will present one of the variants of the spatial structuring of level "A". The specified structuring is carried out on the basis of a structural-functional approach, which includes, first of all, integrative consideration of morpho-physiological characteristics and spatial factors. In the spatial aspect, level "A" has several boundaries, which can be represented as the boundaries and/or zones of reception and contact between the body and the computer. These boundaries can also be represented as anthropomorphic stereometric figures, "spatial spots", or within the framework of a mathematical model as clusters. The indicated boundaries/zones, which cover both the whole body and partially the environment, reveal the anthropic-computer-environmental specificity of the functional circle that corresponds (more precisely, it is formed with the participation of this level) to this level "A". The presented boundaries/zones accordingly structure this level, "immersing" both in the "organism-body" and "spreading" into the environment. That is, under this consideration, the body is not rigidly limited by the surface of the skin. We distinguish the following boundaries/zones ("clusters of reception and interaction"): 1) the zone close (*of electromagnetic and field interactions*) to the body and located at a relatively short distance from the body surface and represented by electromagnetic radiation, which accordingly also has its own spatial specificity, which is determined area, time and state of the body, as well as to a certain extent it is "constructed" by the psychological field as a manifestation of human nature (according to K. Levin's concept); 2) limited to the surface of the human body (skin surface) (*superficial*); 3) the border (*of skin sensitivity*) is formed by skin receptors located in the skin itself; 4) border (*proprioceptive*) (in essence, a receptor shell or space), which is formed by proprioceptors of the muscular system; 5) border (*interoreceptor*), formed by receptor systems of internal organs and vessels. Interaction with the computer is carried out both according to the presented sequence (from the 1st to the 5th border) and in any other. "Body-computer interactions" are relevant, which can be revealed with the integrative use of K. Levin's concept of the psychological field and the above-mentioned borders/zones (levels), which we consider as anthropobiologically determined "matrices and/or typical ways of interactions".

Level "A" is also characterized by certain vibrations with corresponding rhythms, which are mostly low-amplitude and relatively high-frequency. Due to the specified outwardly imperceptible "vibrations" of the muscular system as well as the body itself, a relatively stable state of a person is maintained at rest (static movements – sitting, standing) and during dynamic movements. That is, barely noticeable muscle oscillations, which are caused by constant harmonized and relatively rhythmic switching of individual muscle fibers, form dynamic balance, for example, when standing or sitting, which are one of the manifestations of level "A". You can also notice the manifestation of this level when a person shivers in the cold, when the structure of vibrations changes with increasing amplitude. These automatic neuromuscular processes aimed at maintaining tone are mostly not realized by a healthy person. The understanding of the importance of this level as a vital problem appears when violations occur in the indicated "level A", for example, in Parkinson's disease, cerebral palsy, etc. Rhythms and vibrations of the level of tonic movements "A" can form their "imperceptible" interactions with the computer as a technical system, including synergies, adjustments, violations of certain rhythms, etc. This is due to the presence in modern computers as complex technical systems of their specific vibrations and rhythms both at the level of electrical, electromagnetic and mechanical processes.

Temporality of the indicated level is understood as temporal continuity and givenness, which determines the understanding of time as eternal, forming the effect of integrity in time and as its own time (subject time) acceptable and "comfortable" for a person. This understanding of time among the ancient Greeks was defined as Kairos (Greek: $K\alpha\iota\rho o\zeta$ – favorable time), it is perceived as a harmonious temporal existence. A similar understanding of time is defined in the format of existential temporality. Time becomes noticeable and understood as an existential issue when problems arise in the indicated level "A", before that it is not "noticed". The rhythms that are formed during the interaction in the human-computer system can enhance the effect of temporal well-being – the perception of time as Kairos, or transform it into linear temporality – "Time-Chronos", which can subjectively be perceived as a threat to the reduction of "time-resource", loss of existence and threat to existence.

The indicated level "A" is also connected with the understanding of one's "I" as an individuality, as a given, as existence (in particular, existential corporeality) and physicality. According to this interpretation, it is important that this level is quite closely connected with the collective unconscious. To clarify, let us recall that the collective unconscious is, first of all, a connection and some kinship between people at a deep subconscious level, which can be manifested in typical stereotyped formats of perception, understanding, action and behavior – archetypes (according to C. Jung) [35, 36]. The specified archetypal dimension of the psychic, which is manifested to a certain extent through the "A" level (tonic movements) can also be presented as a specific feature of the human Umwelt, which spreads like a rhizome (mushroom) (according to J. Deleuze and F. Guattari) [34] for a significant part of humanity, while having typical manifestations in each individual – archetypes.

A computer can be a significant and positive, neutral or, conversely, negative artifact, a part of the human, an archetypal phenomenon, a "living" or a dangerous "inanimate" object. A similar perception and understanding of reality, which is defined by bodily-existential, bodily-tonic and vital levels, exists in childhood and is often manifested in extreme and pathological conditions. This interaction between a computer and a person, which is realized through the level of tonic movements ("A"), we define as *existential-bodily-motor-tonic*.

The state of the specified level, including manifestation through the unconscious dimension of mental reality, can transform into higher levels (B, C, D, E), manifesting in them. Accordingly, for the synergistic or antagonistic interaction of the computer with the "A" level, we can use the effects on various sensory-receptors and sensory-perceptive systems. The influence of technical means on receptors and analyzers can be relevant: tactile, vibration, stereognosis, noceoception, temperature, proprioceptive. It is also possible to influence the auditory analyzer (music, conversation, isolated sounds and sound backgrounds) and, to a lesser extent, through the visual analyzer (visual images – pictures, landscapes, images of things and structures). The impact on sensory-perceptual processes can be implemented based on the use of relatively simple, primary, "elementary" images (audio, visual), colors, signs, symbols, rhythms and their combinations, as well as archetypal images, influences and figures. What is relevant is that this level is constant, and the neurophysiological and neurohormonal processes that largely determine it (at the level of biology) determine its inertia. Therefore, external influences have an inertial and delayed character in various terms, manifesting themselves after some time. This level is "closed" to direct influences, it reflects the constancy of life itself and its self-sufficiency.

We have presented in general terms one of the variants of the layered, multidimensional, spatial and partially temporally oriented structuring of the level of tonic movements as a special Umwelt (which is a structural-functional and spatial-temporal and sensory-perceptual-cognitive-activity structuring of human interaction with the environment) and as a functional circle (functional sensory-perceptual-activity structuring) in order to take into account the specified features in the design and operation of computers, as well as in the development of software and interfaces.

Level B – "Synergistic movements" reveals the phenomenology of motor activity based on typical patterns (patterns, patterns, "stamps") (according to the theory of movements construction) [26] and rhythm. The leading characteristics of the movements of this level are that they are: rhythmic (as if "pulsating"); repetitive, i.e. those that are accordingly reproduced as certain patterns ("stamps"); balancing; can create an effect of continuity; include mainly large areas of the body; those that are carried out without moving in space; reciprocal, which are implemented by successive and alternating contraction of muscles (for example, when walking), which forms a certain rhythm. The defining feature of level "B" movements is synergy, which is based on repetitive, interdependent, reciprocal and at the same time on multidirectional and ultimately harmonizing and balancing motor activity. An example of this level "B" movement is balancing, walking (meaning repetitive movements during walking).

These movements reveal to us the beauty, harmony of a person and the topological nature (as inseparability and plasticity) of his body, which, accordingly, has projections into mental reality. Due to its topological nature, the human body can change in space, remaining inseparable, whole and not losing its characteristics. In spatial terms, synergies occupy the space defined by the body itself. To some extent, an illustration of human interaction with space at this level "B" is the famous Virtulian man (Italian: *L'uomo vitruviano*) by Leonardo da Vinci (figure 4). In essence, the space delineated by the human body in the case of synergies is similar to a sphere, an egg, or, more precisely, to a certain spatial spot (closer to a sphere), which can change dynamically. We define the representation of this level of "B – synergistic movements" (according to the theory of movements construction) as a partial component of the human Umwelt as a synergistic-topological-fractal Umwelt. This understanding is due to the fact that, in addition to spatial continuity and inseparability as topological features, movements of a given level form not only movement patterns (in the sense of typical movements) but also, to a certain extent, repetitive and complex spatial movements that cannot be formally reduced only to typical sample More precisely, the sample has many variations in scale, amplitude, trajectory. In addition, the projection of this level into psychic reality, as well as the manifestation of the psychic through this level, manifests itself in rhythms and certain phenomena, which can be partially represented using the concept of fractals. In this way, the *synergistic-topological-fractal* Umwelt manifests itself as a spatial, temporal, vital continuity, rhythm and pulsation in the space close to the body. This includes "spontaneous" but at the same time expected structuring of space based on typical but variable movements, actions, images (visual, audio, motor). This level of human Umwelt can also be metaphorically represented as rhythmic-musical-choreographic or rhythmic because it is based on typical, repetitive oscillatory movements with a fairly significant amplitude. Synergies are the basis of dances, as well as moves – rhythmic, oscillating, balancing economical movements with a relatively simple algorithm.

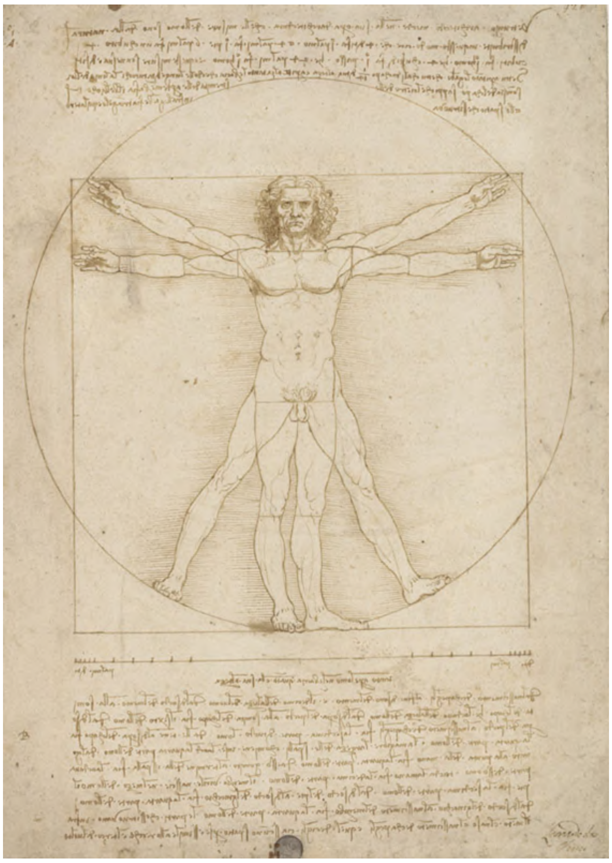

Figure 4. Vitruvian Man. Leonardo da Vinci, 1490. Gallerie dell'Accademia, Venice [42].

Thanks to this level "B", human temporality becomes "embodied", transforming into motor activity, which a person can comprehend in bodily-motor and visual-bodily images and rhythms. Time ceases to be only a "comfortable", "eternal" and "young" Kairos, reflecting the "Eternal" and relatively unchanging existential "Is", which is not sufficiently comprehended at the "A" level. The subjective time and temporality of this world is revealed simultaneously as Kairos (continuous, boundless and "eternal" time) and as Chronos (Greek: $X\rho o\nu o\zeta$) (as discrete time that can be structured into equal fragments and time that a person understands through rhythm).

The synergistic-topological-fractal Umwelt integrates space, time, vitality, corporeality, existence in human consciousness as a continuous rhythm and flow of life, manifested in synergistic movements ("level B") through which human nature manifests itself brightly and expressively. This fragment of the Umwelt is also reflective in its essence, it reveals a person's view of himself, his body, movements and being; looking at oneself; understanding oneself in the world. This is manifested through the "structuring of time through space" and "structuring of space", which is realized precisely thanks to "synergistic motor actions" (authors' interpretation) in which there is rhythm, repetition, reproduction of typical motor images, etc.

When structuring this synergistic-topological-fractal Umwelt layer by layer (as in the previous level "A") as a border/zone with the inclusion of body-receptive components, we define: 1) the space is limited by the surface of the body and the movements of the outstretched limbs (although usually this space is somewhat smaller because the larger part of the movements of the limbs is realized not in an extended, but in a slightly bent position), it partially coincides with the zone formed by electromagnetic radiation of level "A"; 2) the zone/boundary (more precisely, the body), which is represented by the proprioceptors of muscles, tendons and partially ligaments (almost corresponds to the 3rd zone of level "A") of the musculoskeletal system; 3) zone/boundary (body) (*vestibular-balancing*), which is determined by the vestibular analyzer and systematically interacts with "zone 2" represented by proprioception. To clarify, we note that the indicated 3rd *vestibular-balancing* border/zone has several localizations: in the format of the whole body as a "filled with weight" dynamic spatial object; parts of the body as "filled with weight" dynamic spatial objects; as body zones of "attraction", which can be represented in the form of limited localization – dots, spots, etc. For example, a person does not sufficiently differentiate and understand his general center of gravity, which can move during movement.

The level of synergistic movements due to vestibular perception actualizes and makes sense of the top/bottom relationship, which determines the vertical orientation of the body and, accordingly, the Umwelt. The top/bottom relationship becomes a significant bodily metaphor, which is a manifestation of both the human body and the Umwelt. This relationship contributes to the spatially oriented understanding of oneself as bodily reality, as bodily existence, the surrounding world and is transformed into culture as a significant indicator and "filler" of meanings, becoming an aspect of bodily cognition. These ideas about the role of the body in the formation of human cognition and speech are revealed by J. Lakoff [24, 25], focusing on bodily metaphors. In this way, the Umwelt acquires a spatial orientation based on the understanding of the top/bottom relationship. The specified aspect of spatial orientation and the "archetypal" (in the sense of deep) significance of the top/bottom relationship can be purposefully applied in the development of software and interfaces.

At this level "B", which determines the specificity of the synergistic-topological-fractal Umwelt, the receptor systems of internal organs (interoreceptors) and skin (skin receptors – tactile, pain, etc.) are not relevant. They can only partially determine the specificity of the synergistic-topological-fractal Umwelt, "helping" to realize proprioception. That is, this Umwelt is, as it were, a projection of the body in the narrow sense as a locomotor apparatus, "a body without organs." With some irony, we can also use J. Deleuze's metaphor – "bodies without organs" for its characterization (as well as the description of Umwelt).

The interaction between a person and a computer, which is implemented at the level of the synergistic-topological-fractal Umwelt (in the theory of movements construction, it corresponds to the "B" level and is mainly formed by it), will include, first of all, taking into account its specific characteristics. This means that the development of computer equipment, software, interfaces and modes of operation must take into account the phenomenology of: rhythm; topology as inseparability, continuity, plasticity and fluidity; repeatability; fractality; circular and rhythmic movements; temporality; harmonization with the environment.

We will present the theoretical understanding of the following levels C, D, E within the framework of this study somewhat abbreviated and generalized. Level "C – spatial movements" reveals to us the phenomenology of human motor activity through the realization of its spatiality and being in space through movement, visuality and audiality. Accordingly, metaphorically, a person (his spatial nature) who corresponds to this level "C" is represented as a Spatial Man (Latin: Homo Spatialis) and a Locomotor Man (Latin: Homo Locomotrius). Walking, running, jumping are the main movements realized thanks to this "C" level. Due to the fact that visual sensors and perception at this level are the determining spatiality of a person, it is manifested through interaction with spatial objects, landscapes, landscapes, both real and virtual. Level "C", together with the visuality and audiality of a person form a *special spatial Umwelt.* In this spatial Umwelt, the motor-visual and visual-spatial component may dominate, as for example in people with hearing impairments, or the auditory component may prevail as in people with visual impairments. With typical development, there will be harmonized, complementary synergistic interactions between the audio and visual components, which must be taken into account when developing and operating computer equipment and software.

The computer in the system of this level is displayed simultaneously as: a spatial object; as a "spatial-techno-instrumental" phenomenon that can shape ("generate") spaces and spatial things; as a way or "machine" to move in virtual spaces. Consideration of space (primarily virtual) in the format of instrumentality is emphasized – as "spatial-instrumental", which is both a manifestation and a result of the "human-spatial-computer" way of working (interaction) (formation, contemplation, interpretation) with spatial objects. Space (virtual and real) in the "C" level system acts as an effective way of integration, synergy, synchronization in "human – computer" systems. The spatial-instrumental nature of interaction in the human-computer system determines the actualization of the phenomena of spatial orientation, spatial thinking and perception, and will and intentionality. In the semantic framework of the phenomenology of the human Umwelt as a spatial phenomenon, the computer acquires the format of a "collapsed" "space-world", a tool-space that can variably unfold (install) forming various visual realities-spaces. Accordingly, the computer is considered as a special space-producing ("creative") thing or machine, which determines the "quasi-vital" (as an imitation or perception of a living) understanding of the computer by a person and reveals its "techno-creativity" and "techno-cosmism" (as the ability to generate harmonized and "completed" realities and spaces). Accordingly, it will be relevant to consider the computer as a phenomenon forming a dialogue in space, with space and thanks to space. This is realized, first of all, thanks to its "spatial-instrumental" capabilities of the computer as a machine "shaping" the existing spaces within the limits of the human Umwelt and consciousness.

Level D – "Object actions" reveals the phenomenology of praxis. The significance and essence of praxis can be metaphorically and systematically presented in the anthropological format as the Skilled Man (Latin: Homo Habilis). Praxis is purposeful, algorithmized, consistent in nature objective actions and/or work with object, hand tools, to some extent with the environment (materials, etc.). The computer in the system of meanings of this level is considered as a significant component of the object-instrumental environment, which we present in the Umwelt format. The computer in the system of this level will be presented as a special "multifunctional" activity tool. We define this Umwelt-oriented aspect of interaction in the human-computer system as a *constructive-praxical-instrumental Umwelt*. Due to the rapid evolution of technologies and equipment, including the technologization of all spheres of life and human activity, one of the manifestations of which is digitalization, the specified level will acquire "technological connotations" and will be presented as a *constructive-practical-instrumental-technological Umwelt*. Traditionally, this level is understood in the formats of ergonomics of computer equipment and as software design, although in its essence it is much broader, multifaceted and multidimensional.

Level E – "Intellectual (speech) movements" is represented by body language, language, and, to some extent, intellectual activity. Intelligence, despite its autonomy, is ontogenetically (in the sense that in a person, in the process of individual development, verbal intelligence is formed on the basis of sensorimotor) and partly functionally (as an example, the concept of the bodily mind of J. Lakoff) [24, 25] connected with the bodily-motor human dimension. In the theory of movements construction, cognition as an attributive and determining specificity of human nature has bodily-semiotic (for example, complex dances, body language), semiotic-semantic, communicative-cognitive (speech, communication, sign systems and thinking) and figurative-semantic representations. The computer in the meaning system of this level is considered as a significant component of the cognitive dimension of Umwelt-interaction in the human-computer system. Based on the consideration of its implementation and existence, we present the specified interaction mainly as instrumental and cognitive. Accordingly, we define it as the *instrumental-cognitive Umwelt* as the dominant one. The computer in the system of this level will be presented, first of all, as a special "multifunctional" tool of intellectual activity, although other aspects are also present. Traditionally, interaction in the human-computer system is mainly considered in the dimensions of cognition and/or as cognitive or cognitive-communicative interaction.

A study was conducted by surveying students and teachers of higher education institutions of Ukraine using the "Fedorets-Klochko Questionnaire was used to determine the body-mental orientation in the Umwelt oriented interaction in the human-computer system". Research was conducted in 2022 at: Vinnytsia Mykhailo Kotsiubynskyi State Pedagogical University; Public higher educational establishment "Vinnytsia academy of continuing education"; Communal Institution of Higher Education "Vinnytsia Humanitarian and Pedagogical College"; Berdyansk State Pedagogical University. 87 respondents took part in the study. The purpose of the study was to determine the physical-mental orientation in the Umwelt of oriented interaction in the human-computer system. The survey results were processed using cluster analysis, three clusters were obtained (table 2, figure 5).

Table 2. The cluster model to determine the groups of respondents according to the body-mental orientation in the Umwelt of oriented interaction in the human-computer system, built using the SimpleKMeans algorithm. (Correspondence of the markings of the vertical axis: "-1" corresponds to the answer "No"; "0" – "Can't decide"; "1" – "Yes, to a small extent"; "2" – "Yes"; "3" – "Yes, to a large extent".)

Question number	Cluster № 0, 28%	Cluster № 1, 35%	Cluster № 2, 37%
1	2	2	2
2	-1	-1	-1
3	-1	-1	-1
4	-1	0	-1
5	-1	0	2
6	-1	1	-1
7	-1	3	3
8	2	1	2
9	-1	1	1
10	-1	0	1
11	-1	0	1
12	-1	1	0
13	-1	1	2
14	-1	1	2
15	-1	0	2
16	-1	0	2
17	-1	1	2
18	-1	1	2
19	1	2	2
20	-1	2	0
21	-1	1	2
22	1	1	2

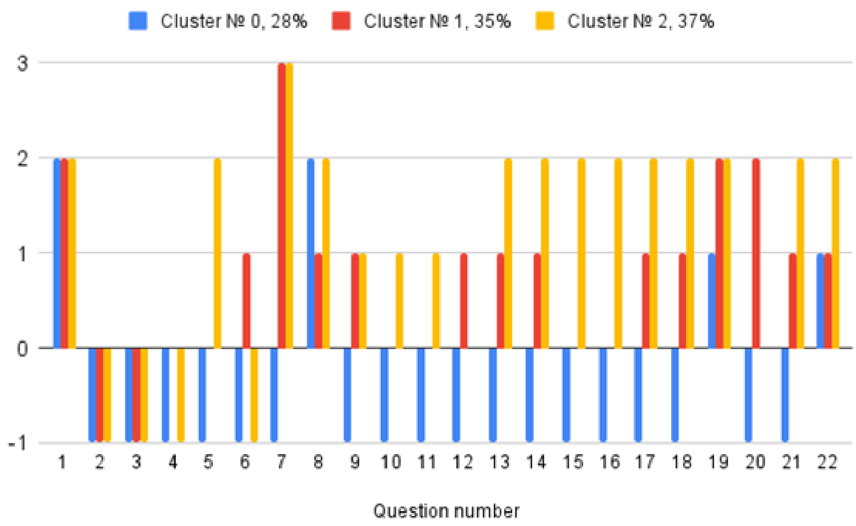

Figure 5. The value of the centroids of the clusters according to the question number "Fedorets-Klochko Questionnaire was used to determine the body-mental orientation in the Umwelt oriented interaction in the human-computer system", presented in the form of a bar chart (Correspondence of the markings of the vertical axis: "-1" corresponds to the answer "No"; "0" – "Can't decide"; "1" – "Yes, to a small extent"; "2" – "Yes"; "3" – "Yes, to a large extent").

Cluster 0, which is formed by 28% of the respondents, is mainly represented by negative answers. The answers to questions № 1, № 8, № 19, № 22 were positive. From Umwelt's point of view of oriented interaction in the human-computer system, the specified structure of answers, to a certain extent, indicates the dominance of interaction that is cognitive in nature. This corresponds to the level of intellectual movements "E" in the theory of movements construction.

Cluster 1 is formed by 35% of the subjects. The cluster is mostly dominated by positive answers. The presence of neutral answers to 6 questions is also relevant. № 4, № 5, № 10, № 11, № 15, № 16. These neutral answers are correlated with different zones of the body-mental Umwelt of a person, which is structured according to the theory of movements construction. The correspondence of neutral answers to the levels of movements according to the theory of movements construction will be as follows: № 4 and № 5 – level "A – tonic movements"; № 10, № 11 and № 15 – level "C – spatial movements"; № 16 – level "D – substantive actions". The specified distribution of neutral answers relative to the specified levels A, C, D indicates insufficiently actualized Umwelt-oriented interaction in the human-computer system at the specified levels. At the same time, compared to "Cluster 0", the specified interaction is formed at all levels, including A, C, D.

Cluster 2 is formed by 37% of the subjects. Cluster centroids are mostly positive answers. It is relevant to have neutral answers in 2 questions. The distribution of questions by levels (according to the theory of movements construction) is as follows: question № 12 corresponds to the level "C – spatial movements", and question № 20 – to the level "E – intellectual movements". In this cluster, there is a certain growth of Umwelt-oriented interaction in the human-computer system, which is relatively evenly distributed across all levels.

In clusters 0, 1, 2, the zone in which the Umwelt-oriented interaction in the human-computer system is not sufficiently updated is the "C – spatial movements" level. This indirectly indicates the perception of the computer, mainly as a thing, a tool and at the same time as a cognitive phenomenon, and not as a special space or "forming" virtual spaces of the tool.

In clusters 0, 1, 2, the zone in which the Umwelt-oriented interaction in the human-computer system is most actualized is the level "B – synergistic movements" and the level "E – intellectual movements". We interpret it in the following way – level "B – synergistic movements" – forms rhythms, rhythmic repetitive movements ("stamps" according to the theory of movements construction). This level, in our opinion, is connected with music and is manifested (according to the theory of movements construction) through dances and rhythmic movements (walking; working in a certain rhythm, for example typing). Rhythms and synergies of this level are synchronizing, harmonizing, integrating when interacting in the human-computer system.

The level "E – intellectual movements" is defining and system-organizing, in which there is the most intensive and constant Umwelt-oriented interaction in the human-computer system. Such interaction is consistent with the intellectual nature of man as a rational being (Latin: Homo Sapiens) and relative to the instrumental-cognitive "essence" and purpose of the computer.

4. Conclusion

The anthropologically oriented result of the methodological and conceptual reflection of the interaction in the human-computer system based on the integrative application of the concepts of the Umwelt of J. J. von Uexküll, the functional circle (German: Funktionskreis) and the theory of movements construction in general terms has been developed the concept of a person's bodily-cognitive Umwelt – the sensory-perceptual-cognitive-active world. When developing the model of the corporeal-cognitive Umwelt, concepts were used that reveal the "corporeal-cognitive" nature of a person holistically, systemically, autopoietically and in relationship and through the meanings of harmony with the environment. In addition to the above-mentioned theories, the following concepts were applied in the development of this model: body mind by J. Lakoff, enactivism, functional systems, autopoiesis by H. Maturana and F. Varela, body without organs by J. Deleuze, archetypes of C. Jung. The body-cognitive Umwelt of a person is structured according to the theory of movements construction into five levels, which are simultaneously considered as functional circles, as relatively constant flows of information and energy, as well as as topological and fractal structures.

The integrative use of the Umwelt concept and the theory of movements construction for the analysis of possible ways and features of interaction in the human-computer system represents one of the options for structuring the specified interaction. An important aspect of this is the selection of certain zones of such interaction, presented in the format of levels, which determine the specifics of the indicated interactions. Taking into account the specifics of each of the levels is the way to form the ergonomics of interactions in the human-computer system, taking into account human nature, including psychology. Integrative influence on levels is a way of organizing multi-channel human-computer system interaction (we consider the levels of the human Umwelt selected by us as zones of multi-channel system interaction between a human and a computer).

The body-cognitive Umwelt is structured according to the theory of movements construction into five levels, which are simultaneously considered as functional circles, as relatively constant flows of information and energy, as topological and fractal structures, as special spatial, temporal, sensory, perceptual, motor, cognitive and activity worlds of a person. Each level of the bodily-cognitive Umwelt has its own specific autonomy and system characteristics, the knowledge and understanding of which can be purposefully used for anthropically oriented improvement of interaction in the human-computer system. We consider the levels of the human Umwelt identified by us as zones of multi-channel system interaction between a human and a computer. The characteristics of the bodily-cognitive Umwelt, as well as its relatively autonomous levels, can be purposefully used in the development of: software, Umwelt-oriented digital technologies and interfaces, in the design and design of computers, robots, smart environments (educational, homes, cities) and also when organizing work and life in the new digital world. This becomes especially relevant in the conditions of the global Covid-19 pandemic, as well as in the implementation of: sustainable development goals, including greening; NBIC convergence and other challenges.

A study of Umwelt oriented interaction in the human-computer system was conducted. For this, the "Fedorets-Klochko Questionnaire was used to determine the body-mental orientation in the Umwelt oriented interaction in the human-computer system" was used, the results were processed using cluster analysis. The interpretation of the research results indicates the systematicity and level of interaction in the human-computer system. This determines the possibilities of distinguishing typical paths and spheres of interactions in the human-computer system, among which the bodily and mental-psychological ones are significant, corresponding to certain levels that correlate with the systemic, spatio-temporal and structural-functional organization of motor activity in the theory of movements construction.

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References

[1] Clarivate 2023 Web of Science URL `https://www.webofscience.com/wos/woscc/basic-search`

[2] Centre for Science and Technology Studies, Leiden University, The Netherlands 2023 VOSviewer - Visualizing scientific landscapes URL `https://www.vosviewer.com/`

[3] Elsevier 2023 Scopus URL `https://www.scopus.com/home.uri`

[4] Saeed Z R, Zainol Z B, Zaidan B B and Alamoodi A H 2022 *IEEE Access* **10** 123358–123377 URL `https://doi.org/10.1109/ACCESS.2022.3219430`

[5] Xiong X and Hou Y 2022 *International Journal of Advanced Computer Science and Applications* **13**(12) URL `https://doi.org/10.14569/IJACSA.2022.0131216`

[6] Burrows H, Zarrin J, Babu-Saheer L and Maktab-Dar-Oghaz M 2021 *Electronics* **11**(1) 118 URL `https://doi.org/10.3390/electronics11010118`

[7] Sun Y, Xu C, Li G, Xu W, Kong J, Jiang D, Tao B and Chen D 2020 *Alexandria Engineering Journal* **59**(3) 1149–1157 URL `https://doi.org/10.1016/j.aej.2020.01.015`

[8] Yun Y, Ma D and Yang M 2021 *Future Generation Computer Systems* **114** 285–289 URL `https://doi.org/10.1016/j.future.2020.07.048`

[9] Tarasenko R, Amelina S and Semerikov S 2021 Conceptual Aspects of Interpreter Training Using Modern Simultaneous Interpretation Technologies *Proceedings of the 17th International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer. Volume I: Main Conference, PhD Symposium, and Posters, Kherson, Ukraine, September 28 - October 2, 2021* (*CEUR Workshop Proceedings* vol 3013) ed Ermolayev V, Esteban D, Mayr H C, Nikitchenko M, Bogomolov S, Zholtkevych G, Yakovyna V and Spivakovsky A (CEUR-WS.org) pp 239–252 URL `https://ceur-ws.org/Vol-3013/20210239.pdf`

[10] Robinson N, Tidd B, Campbell D, Kulić D and Corke P 2023 *J. Hum.-Robot Interact.* **12** 12 URL `https://doi.org/10.1145/3570731`

[11] Jung S, Buruk O O and Hamari J 2022 Altered States of Consciousness in Human-Computer Interaction: A Review *Nordic Human-Computer Interaction Conference* NordiCHI '22 (New York, NY, USA: Association for Computing Machinery) ISBN 9781450396998 URL `https://doi.org/10.1145/3546155.3546667`

[12] Klochko O, Fedorets V, Klochko V and Kormer M 2020 The Use of Ensemble Classification and Clustering Methods of Machine Learning in the Study of Internet Addiction of Students *Proceedings of the 1st Symposium on Advances in Educational Technology - Volume 1: AET,* INSTICC (SciTePress) pp 241–260 ISBN 978-989-758-558-6 URL `https://doi.org/10.5220/0010923500003364`

[13] Behl A, Jayawardena N, Pereira V, Islam N, Del Giudice M and Choudrie J 2022 *Technological Forecasting and Social Change* **176** 121445 URL `https://doi.org/10.1016/j.techfore.2021.121445`

[14] Klochko O V, Tkachenko S V, Babiichuk I M, Fedorets V M and Galych T V 2022 Using Virtual Reality Technologies for Teaching Computer Science at Secondary School *ICTERI 2021 Workshops* (*Communications in Computer and Information Science* vol 1635) ed Ignatenko O, Kharchenko V,

Kobets V, Kravtsov H, Tarasich Y, Ermolayev V, Esteban D, Yakovyna V and Spivakovsky A (Cham: Springer International Publishing) pp 231–246 ISBN 978-3-031-14841-5 URL https://doi.org/10.1007/978-3-031-14841-5_15

[15] Klochko O V, Fedorets V M, Uchitel A D and Hnatyuk V V 2020 Methodological aspects of using augmented reality for improvement of the health preserving competence of a Physical Education teacher *Proceedings of the 3rd International Workshop on Augmented Reality in Education, Kryvyi Rih, Ukraine, May 13, 2020* (*CEUR Workshop Proceedings* vol 2731) ed Burov O Y and Kiv A E (CEUR-WS.org) pp 108–128 URL https://ceur-ws.org/Vol-2731/paper05.pdf

[16] Klochko O V and Fedorets V M 2022 *Educational Technology Quarterly* **2022**(4) 276–306 URL https://doi.org/10.55056/etq.431

[17] Lytvynova S H, Semerikov S O, Striuk A M, Striuk M I, Kolgatina L S, Velychko V Y, Mintii I S, Kalinichenko O O and Tukalo S M 2021 AREdu 2021 - Immersive technology today *Proceedings of the 4th International Workshop on Augmented Reality in Education (AREdu 2021), Kryvyi Rih, Ukraine, May 11, 2021* (*CEUR Workshop Proceedings* vol 2898) ed Lytvynova S H and Semerikov S O (CEUR-WS.org) pp 1–40 URL https://ceur-ws.org/Vol-2898/paper00.pdf

[18] Semerikov S O, Vakaliuk T A, Mintii I S, Hamaniuk V A, Soloviev V N, Bondarenko O V, Nechypurenko P P, Shokaliuk S V, Moiseienko N V and Shepiliev D S 2022 Immersive E-Learning Resources: Design Methods *Digital Humanities Workshop* DHW 2021 (New York, NY, USA: Association for Computing Machinery) p 37–47 ISBN 9781450387361 URL https://doi.org/10.1145/3526242.3526264

[19] Burov O Y and Pinchuk O P 2023 *Educational Technology Quarterly* **2023**(1) 58–68 URL https://doi.org/10.55056/etq.435

[20] Campanozzi L L, Gibelli F, Bailo P, Nittari G, Sirignano A and Ricci G 2023 *Frontiers in Public Health* **11** 506 URL https://doi.org/10.3389/fpubh.2023.1109323

[21] Klochko O V, Fedorets V M, Mazur M V and Liulko Y P 2023 *CEUR Workshop Proceedings* **3358** 87–101 URL https://ceur-ws.org/Vol-3358/paper15.pdf

[22] Pinchuk N, Pinchuk O, Bondarchuk O, Balakhtar V, Balakhtar K, Onopriienko-Kapustina N, Shyshkina M and Kuzminska O 2022 *Educational Technology Quarterly* **2022**(2) 129–142 URL https://doi.org/10.55056/etq.8

[23] Lobo C 2022 *Theory in Biosciences* **141**(2) 175–202 ISSN 1611-7530 URL https://doi.org/10.1007/s12064-021-00348-4

[24] Whiteford-Damerall A 2021 *The American Journal of Psychology* **134**(1) 13–29 ISSN 0002-9556 URL https://doi.org/10.5406/amerjpsyc.134.1.0013

[25] Cuccio V and Graziano M 2022 A Two-Level Model of Embodied Mathematical Thinking. Body Schema, Body Image and Language *Metaphors and Analogies in Sciences and Humanities: Words and Worlds* (*Synthese Library* vol 453) ed Wuppuluri S and Grayling A C (Cham: Springer International Publishing) pp 87–113 ISBN 978-3-030-90688-7 URL https://doi.org/10.1007/978-3-030-90688-7_5

[26] Yevtuch M B, Fedorets V M, Klochko O V, Shyshkina M P and Dobryden A V 2021 Development of the health-preserving competence of a physical education teacher on the basis of N. Bernstein's theory of movements construction using virtual reality technologies *Proceedings of the 4th International Workshop on Augmented Reality in Education (AREdu 2021), Kryvyi Rih, Ukraine, May 11, 2021* (*CEUR Workshop Proceedings* vol 2898) ed Lytvynova S H and Semerikov S O (CEUR-WS.org) pp 294–314 URL https://ceur-ws.org/Vol-2898/paper16.pdf

[27] Schroer S A 2021 *Ethnos* **86**(1) 132–152 URL https://doi.org/10.1080/00141844.2019.1606841

[28] Michelini F 2019 Introduction: A foray into Uexküll's heritage *Jakob von Uexküll and Philosophy: Life, Environments, Anthropology* ed Michelini B and Köchy K (Routledge) ISBN 9780429279096 URL https://doi.org/10.4324/9780429279096

[29] Rodríguez Gómez S 2022 *AI & SOCIETY* **37** 1307–1318 ISSN 1435-5655 URL https://doi.org/10.1007/s00146-021-01355-1

[30] Millikan R G 2021 *Biosemiotics* **14**(3) 581–582 ISSN 1875-1350 URL https://doi.org/10.1007/s12304-021-09468-2

[31] Privas-Bréauté V 2022 *Recherche et pratiques pédagogiques en langues de spécialité-Cahiers de l'APLIUT* **41**(1) URL https://doi.org/10.4000/apliut.9830

[32] Apostol P 2021 *Studia Universitatis Babes-Bolyai Philosophia* **66**(2 Suppl.) 15–24 URL https://www.ceeol.com/search/article-detail?id=992479

[33] Nilsen H F 2022 *International Body Psychotherapy Journal* **21**(1) 105–109 URL https://www.ibpj.org/issues/articles/Havard%20Friis%20Nilsen%20-%20The%20Origins%20of%20Body%20Psychotherapy.pdf

[34] León Casero J and Closa Guerrero I 2020 *Isegoría* (63) 387–406 URL https://doi.org/10.3989/isegoria.2020.063.06

[35] Major J C 2021 *Biosystems* **208** 104501 URL https://doi.org/10.1016/j.biosystems.2021.104501
[36] Martins A T 2021 *Echinox Journal* **40** 313–321 URL https://www.ceeol.com/search/article-detail?id=959696
[37] De Luca Picione R 2021 *Theory & Psychology* **31**(5) 729–745 URL https://doi.org/10.1177/0959354320947184
[38] Santos M A d, Silva P F A L, Nascimento L C and Farinha M G 2020 *Psicologia Clínica* **32**(2) 357–386 URL http://pepsic.bvsalud.org/scielo.php?pid=S0103-56652020000200009&script=sci_abstract&tlng=en
[39] 2023 Weka 3: Machine Learning Software in Java URL https://www.cs.waikato.ac.nz/~ml/weka/
[40] Xin D, Jia-li X, Jia-jing W and Dong-ning J 2021 *Journal of Physics: Conference Series* **1948**(1) 012171 URL https://doi.org/10.1088/1742-6596/1948/1/012171
[41] Abdulrazzak H N, Hock G C, Mohamed Radzi N A, Tan N M and Kwong C F 2022 *Mathematics* **10**(24) 4720 URL https://doi.org/10.3390/math10244720
[42] Gallerie Dell'Accademia di Venezia 2023 Study of the proportions of the human body, known as the Vitruvian Man. Leonardo da Vinci URL https://gallerieaccademia.it/en/node/1582

Journal of Physics: Conference Series

PAPER • OPEN ACCESS

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To cite this article: N A Dotsenko *et al* 2023 *J. Phys.: Conf. Ser.* **2611** 012019

Technology of creating educational content for open digital resources in general technical disciplines

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Abstract. The article presents the technology of creating educational content for open digital resources in general technical disciplines that consist of the four stages: development, design, posting and final. There are proposed to create video, interactive and graphic educational content in the context of the proposed technology at the development stage. Video content is presented in the form of video lectures, video instructions for practical and laboratory tasks, video recording of the educational results. Interactive content is introduced by lectures and laboratory tasks with interactive elements, interactive posters or tests. Graphic content is provided by lectures with graphic models of the technical objects, practical tasks with the use of modelling and design programs, creation of 3D models for laboratory works and performing engineering and technical projects. The design stage includes the selection of services for the specific type of content and creation the tasks for open digital resources. Educational content is implemented in an open digital resource by obtaining a link, QR or implementation code at the posting stage. The final stage of the application of the proposed technology involves the performance of tasks by higher education applicants, obtaining points, acquisition of competencies. The Pearson criterion was used to statistically verify the application of technology of creating educational content for open digital resources in general technical disciplines. The higher education applicants in the experimental group received higher results than in the control group which may indicate the effectiveness of the outlined technology.

1. Introduction

The main goal of modern education is to introduce new information technologies into the educational process and management of educational institutions, to create free access to cultural, educational and scientific information. Informatization of education contributes to the development of a system of lifelong learning, which provides an individual learning trajectory for each person. Access of higher education applicants to various sources of information develops critical thinking and independence, provides a creative approach to education. Integrating open education content into training in general technical disciplines is an effective way to overcome the higher education challenges posed by the pandemic.

Digital skills are based on digital information skills, they are an important aspect in acquiring subsequent professional skills [1]. The use of digital educational resources increases the impact of intrinsic motivation within the institution [2]. It is necessary to take into account the general principles of design the engineering and technological educational content and its updating to the requirements of time [3]. The effectiveness of the content of general technical disciplines and methods of teaching technology is determined by the execution of professional activity [4]. It was outlined the main features for the development and implementation of practice-oriented classes activating and stimulating students' cognitive interest in mastering the necessary professional competencies in the study of general technical disciplines [5].

Higher education applicants increasingly demand more constructive online courses that not only provide information but also facilitate studying experiences [6]. Higher education applicants proceeded with four interrelated steps when studying in the open digital resources: locating information, information use, remix and repurpose, and knowledge sharing [7]. Suggestions, based on the finding, are offered for institutions looking to pursue open educational resources programs on their campuses [8]. There is a need for digital repositories to reflect or make visible how resources corresponded to the particular instructional models [9]. So, it is necessary in the digital competence trainings for tutors to structure their courses so that pre-service teachers can see them as role models, as well as the theoretical and practical information should be offered [10]. There are a plenty of learning tools for using in general technical disciplines. It was investigated the use and benefit of an incentive system in a computer-based physics game on students' learning and efficiency of educational results [11]. It is important to understand YouTube EDU videos characteristics which can be used for making decisions for improving educational content and learning technologies [12]. Also using remote labs in higher education in the condition of open digital resources showed positive findings [13].

The cloud solutions for 3D modeling is used in technology education to create and visualize technical objects, 3D modeling is implemented in the educational process of documenting students' projects as architectural exercises [14]. Online meetings, distance learning and live streaming make the video content become more popular [15]. The investigation is dedicated to implementation of interactive educational content using 3D visualization technologies [16]. Methodological and technological aspects as well as architecture and elaboration algorithms of educational 3D visualization are considered [17]. However, wide spreading of interactive 3D content on the web requires efficient methods of content creation and it also should be competency-based [18]. Interactive and web-based content of simulation education may be an answer to deficit of professional tools and space and lack of teaching personnel [19]. It was investigated the potential of using Holograms as technology for delivering educational content to the audience [20]. It is determined the need in methodical support for the preparation of educational content on the basis of distance education platforms for higher educational institutions [21]. The study presents the possibilities of using augmented reality in the study of different fields [22]. In the investigation it is considered the study of application of Augmented Reality technology for mathematical disciplines [23].

The authors explored some aspects of engineering education, for example, it was presented the implementation of future agricultural engineers' training technology in the informational and educational environment [24] and the technology of application of competence-based educational simulators for learning general technical disciplines [25]. Also there is the investigation about technological model of training of Masters in Electrical Engineering to electrical installation and commissioning [26], but the learning content of open educational resources in general technical disciplines can be varied, including courses, course materials, learning objects, content of modules, collections, journals, etc. Creating media and interactive content of open digital resources is an effective way to prepare higher education applicants.

The aim of the article is to develop the technology of creating educational content for open digital resources in general technical disciplines, which includes the creation of video, graphic and interactive content and describe the stages of implementation of the proposed technology.

2. Methods

The assembly of methods of the research process is represented by: theoretical methods – categorical and logical analyses in order to development the technology of creating educational content for open digital resources in general technical disciplines, generalization of the results and experience; empirical methods – surveys, questionnaires, self-assessment, testing, observation of the learning process and educational results, pedagogical experiment; statistical methods – quantitative processing of indicators and verification of the reliability of the obtained empirical results using the Pearson criterion. The control group (CG) takes into account the comparison of self-assessment, and the experimental group (EG) – the results of the analysis of the quality of knowledge. The result of the experiment involved 227 higher education applicants. There were 115 people in the control group and 112 in the experimental group. The Pearson criterion [27] was used to compare the results of the experimental and control groups. In order to statistically verify the equality of use of educational content for open digital resources in general technical disciplines in control and experimental groups, there were formulated hypotheses: H0 – there are no significant difference in the level of application of educational content for open digital resources in general technical disciplines; H1– there are significant difference in the level of application of educational content for open digital resources in general technical disciplines in control and experimental groups.

3. Technology of creating educational content for open digital resources in general technical disciplines

There are presented the technology of creating educational content for open digital resources in general technical disciplines (figure 1). It includes the creation of video, interactive and graphic content. The outlined technology consist of the four stages: development, design, posting and final stage. The stages of creation of each of the specified types of educational content and its implementation into open educational resources have some peculiarities.

The development stage includes the creation of video, graphic and interactive content for the lectures, laboratory and practical classes and independent work. Lectures for open digital resources are recommended to be submitted in the form of video lectures, lectures with interactive elements and lectures with graphic models of mechanisms. Practical tasks in general technical disciplines are presented through the video instructions, interactive posters and practical tasks with the use of modelling and design programs. Laboratory tasks include the video instructions, laboratory works with interactive elements and creation of 3D models. The higher education applicants during their independent work in the conditions of open digital resources in general technical disciplines present the recording of their reports, the result of the engineering and technical projects and perform the interactive tests.

The design stage includes creation of materials on the basis of specified services. Video content can be designed through the selection of text and visual materials and be presented in the form of presentations with video elements or video recording of information. The interactive content is developed with the services for interactive tasks and posters, worksheets, dictionary cards and info-graphics. Graphic content is created on the basis of 3D models.

The features of the posting stage are conditioned by the type of the service used at the previous stage. Video content is downloaded on the YouTube channel and posted in the conditions of open digital resources through the implementation code. The access to the interactive content need to be set up in the previously selected service and placed in the open digital resources through the link, QR or implementation code. The graphic content at the following stage is presented in the form of 3D models of the technical objects, mechanisms and machines in the conditions of open digital resources.

The final stage it devoted to getting results. The result of using this technology is the performance of tasks by higher education applicants, obtaining points and acquiring

 2611 (2023) 012019 doi:10.1088/1742-6596/2611/1/012019

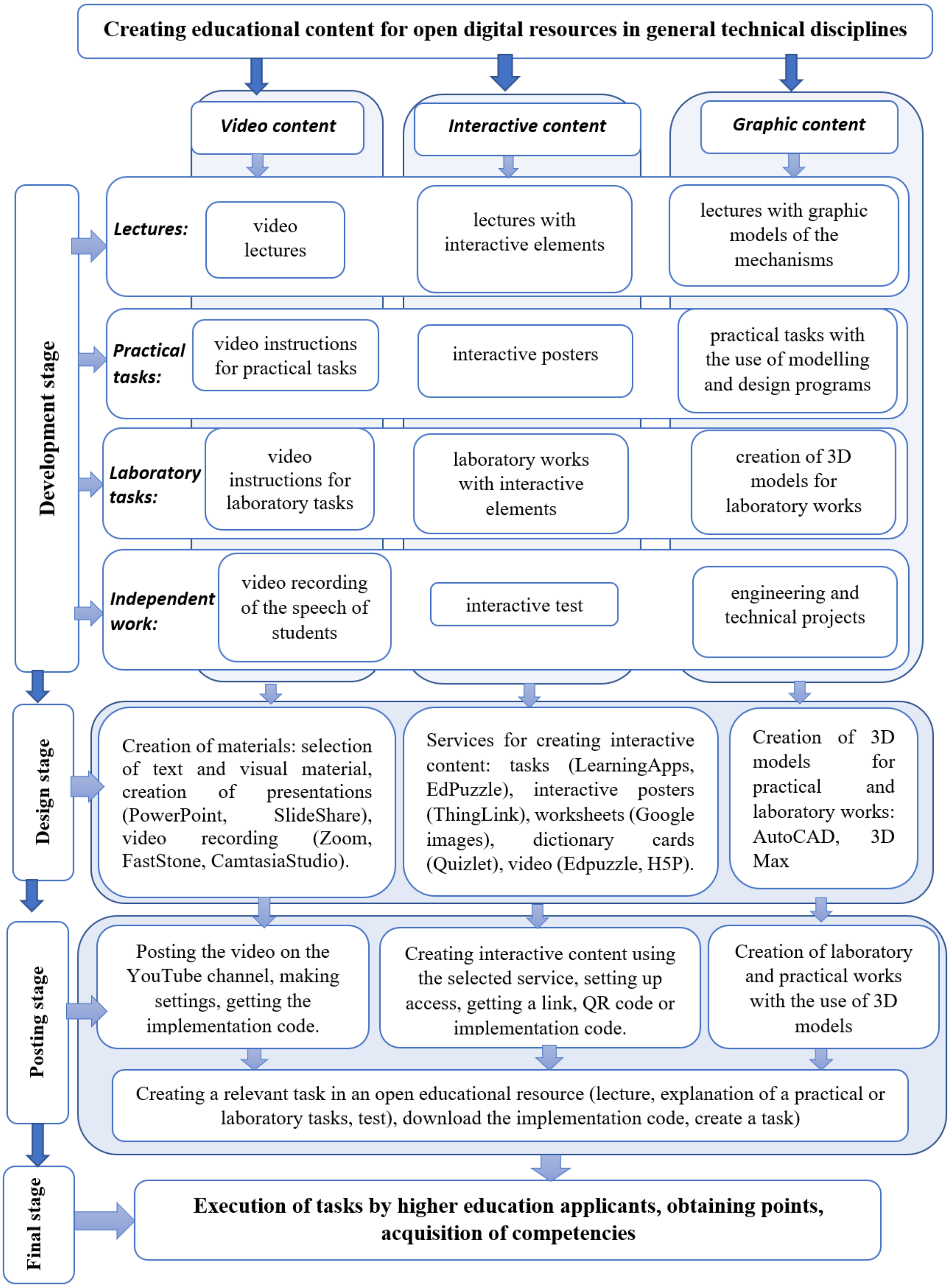

Figure 1. Technology of creating educational content for open digital resources in general technical disciplines.

competencies. The use of modern multimedia and interactive technologies allows to increase the clarity and ergonomics of the perception of educational material, which has a positive effect on learning motivation and efficiency. The research outlined the creation of each type of content for open digital resources in general technical disciplines.

3.1. Educational videos

Creating educational videos can increase higher education applicants' involvement in learning and significantly diversify the learning process in blended and online courses. It is possible to effectively integrate audio and visual elements to help students better understand complex concepts. Educational videos can have different purposes to achieve the educational goals of the course. This can be either a video lecture taken on camera or an explanation of educational material in a screencast format (video from the screen) using slides of presentations, diagrams or other graphic elements. In the context of preparing to record a training video, it is necessary to: review the syllabus of the course (expected results, goals, objectives, materials), choose digital tools for recording and editing video. There are considered some resources for recording video content. Zoom – a service for video conferencing, online meetings and distance learning, suitable for individual and group classes. The advantages when using this program are the ability to share the screen with the sound. FastStone Capture is a powerful, lightweight, but functional program for creating screenshots. It allows to record any action on the screen, including moving the mouse and voice from the microphone, in highly compressed video files. Camtasia Studio allows to edit a clip after creating it. The editor has all the necessary tools, such as slicing and adding various effects. There is an option to add audio and video tracks to the project, compile and edit them.

3.2. Interactive technologies

Interactive technologies enrich the learning process, involving in the process of perception of educational information most of the sensory components of learners. They integrate powerful distributed educational resources, can provide an environment for the formation of key competencies, which include primarily information and communication. The use of interactive technologies, in particular, interactive tasks and exercises allows to: individualize the learning process; organize educational material taking into account different ways of educational activity; compactly present a large amount of clearly structured and consistently organized educational information; strengthen the visual perception and facilitate the assimilation of educational material. With the help of a huge number of Internet resources, it is possible to create a collection of interactive tasks. These can be tasks of the following nature: correlation of concepts and definitions; insert a missing letter or word; crosswords, riddles, charades, puzzles; word search; quizzes with one and many correct answers; interactive games; construction of a timeline, etc.

The study considered services for creating interactive content: tasks (LearningApps, EdPuzzle), interactive posters (ThingLink), worksheets (Google images), dictionary cards (Quizlet), video (H5P).

The Learning Apps interactive task designer is created to support the learning process with the help of interactive modules (exercises). At the same time, both the learner and the tutor can create interactive modules based on templates.

The main idea of interactive tasks that can be created in this service is that students can test and consolidate their knowledge in the form of game, which contributes to the formation of their cognitive interest in a particular discipline. Edpuzzle is an online service for creating video clips with the ability to add voice comments and questions from the material. The tutor can take videos from YouTube, Vimeo, Khan Academy, TED-Ed, LearnZillio as a basis, as well as download them from the PC. EDpuzzle is integrated with Google Class. Based on one video, there is an ability to create an interactive quiz with open-ended questions or with the choice of one answer from several, give voice comments and explanations to the video or completely voice it. The Thinglink service is a tool for creating interactive infographics or interactive posters: interactive map, diagram, table. Furthermore, its capabilities extend to other methods of multimedia didactic. The interactive map avoids overloading with information, images, icons, inscriptions. The interactive table has the following features: cost-effectiveness and logical construction, readability, interactivity, visualization of table cells. The table can also be animated, with a minimal amount of printed text. In the case of working with an interactive reference scheme, by clicking on individual elements, there is a possibility to get more complete information or a visual image. An interactive worksheet in Google Docs is a digital tool for organizing student learning activities through cloud services and web tools. It may include: test elements, organization of work with the text, problem tasks with step-by-step execution, tasks for the ability to classify, compare. Feedback from a tutor in interactive worksheet technology in Google Docs often takes the form of comments in the margins of an already completed worksheet. The Quizlet service for creating dictionary cards allows to memorize information that can be presented in the form of training cards. It is enough to enter the basic concepts and definitions once, adding pictures and audio files to them, and the system itself combines different exercises and games. There are some ways to work in Quizlet: card mode - cards can be flipped over to repeat terms and definitions; memorization mode – it is necessary to answer each question correctly twice; letter mode – a definition or picture of the term will be given and it is assessed how well the student knows the material and makes mistakes in writing, it is necessary to answer each question correctly twice; spelling mode – it is necessary to write what is heard; testing mode – different versions of tests are automatically created (correlation, multiple choice, true / false, filling in gaps); two types of games. H5P is a handy designer for creating interactive tasks based on templates. All H5P components are made in a modern HTML5 format. It is possible to create interactive videos, assignments, skip items, questionnaires, quizzes, and more.

3.3. Graphic content
The proper graphic content is crucial to creating the perfect 3D model. 3D model depicts an object in 3D graphics mode. 3D modelling is used in industries such as 3D printing, interior design, architecture, film, games and animation, digital production. In 3D Max it is possible to make three-dimensional models, there is a built-in physics and kinematics, a system of particles, it is easy to build an animation and get a video. 3Ds Max is a commonly used visualizer for interior or exterior design. Advantages of 3Ds Max: many training materials, extensions and ready-made libraries; demand for specialists in the market. Autodesk AutoCAD is a more specialized environment that is used mainly by engineers, architects and other design professionals. AutoCAD has great potential for modelling technical processes. There are advantages of AutoCAD: a large number of training materials; ease of use; specialization in the technical field. Sketch-Up is a very easy-to-use program for simple modelling of buildings and interiors. It is designed for mass use, and therefore has a built-in training system and a minimum of tools, and to operate them is not difficult. It is integrated with the Google Maps service so that users can add to the map their three-dimensional models of houses and other attractions.

3.4. Educational content for open digital resources in general technical disciplines
The proposed technology of creating educational content for open digital resources in general technical disciplines is presented on the example of Mechanics of Materials and Constructions, Engineering and Computer Graphics and Theory of Mechanisms and Machines.

Lectures in training modules on Mechanics of Materials and Constructions are presented in the form of video lectures and recorded with Zoom.

There are designed the videos instructions for the calculation of practical works of the module “Geometric characteristics of flat sections”. The interactive posters for calculation the centre of gravity of the construction, the moment of inertia, the moment of resistance of the section and the radius of inertia were performed in the Thinglink service.

In the context of the studying modules “Central tension and compression of the rods”, “Torsion” there were developed the video instructions for practical works and interactive posters “Determination of longitudinal force in sections”, “Determination of total elongation or shortening of the rod” and “Determination of torque”, “Determination of twist angle”.

In the laboratory works “Tensile testing of steel sample”, “Testing of samples of anisotropic materials for compression” and “Testing of steel rod for torsion” used 3D models of these samples before and after deformation.

In addition to video lectures and instructions for practical work of the module “Bending” there are presented the interactive posters “Determination of transverse force and bending moment”.

Video lectures and video instructions for practical work increase the visibility while mastering the theoretical material. Interactive posters assigned to get acquainted with the sequence of practical work, make important concepts, reference tables, figures and more. 3D models in laboratory works form an idea of the course of deformation and its consequences. After each module, higher education applicants take an interactive test and consolidate their knowledge and skills.

In the mastering tasks for training modules “Point, line and plane on a complex drawing”, “The technical drawing” in the course of Engineering and Computer Graphics created video lectures on the basis of work with design and modelling programs Autodesk AutoCAD, 3D Max. The H5P module used to record the video lectures with interactive questions after each part of the material.

Also it was presented the explanation to the practical tasks with the modelling and design programs for the modules “Point, line and plane on a complex drawing”, “The technical drawing” for drawing in two-dimensional space and for the modules “Axonometry, sections cross-sections”, “Construction Drawing” for the creation of 3D models.

Exercises and tests that created in the Learning Apps application have been created to consolidate the skills acquired while performing graphic works.

In the context of studying Theory of Mechanisms and Machines, there were created the lectures with interactive elements on the basis of service the Camtasia Studio. Execution and discussion of practical work of the module “Structural analysis of mechanisms” need to be performed using an interactive worksheet in Google Docs.

Drawing of structural and kinematic schemes of mechanisms, construction of plans of speeds, forces and accelerations of modules “Kinematic analysis of mechanisms” and “Kinetostatic analysis of mechanisms” is carried out by means of modelling and designing programs. Thus, the creation of educational content in general technical disciplines for open digital resources requires the involvement of additional programs for video recording, creating interactive tasks, posters, tables, tests and the use of design and modelling programs.

4. Results and discussion

Upon completion of the development of the presented technology, an experimental study was conducted, which included the identification of the appropriate level of application of the technology of creating educational content for open digital resources in general technical disciplines. The obtained experimental results before and after the experiment were verified using Pearson criterion and are presented in tables 1, 2.

There are considered the levels of use educational content for open digital resources in general technical disciplines.

Table 1. The results of the study of the level of use educational content for open digital resources in general technical disciplines before the experiment.

Level	EG,%	EG, n_i	CG, %	CG, n_{i_1}	$(n_1 - n_{i_1})^2$	$(n_1 - n_{i_1})^2/n_{i_1}$
High (A)	1.79	2	2.61	3	1	0.333333
Sufficient (BC)	27.68	31	32.17	37	36	0.972973
Initial(CD)	70.53	79	65.22	75	16	0.213333
Total	100	112	100	115		1.52

Table 2. The results of the study of the level of use educational content for open digital resources in general technical disciplines after the experiment.

Level	EG,%	EG, n_i	CG, %	CG, n_{i_1}	$(n_1 - n_{i_1})^2$	$(n_1 - n_{i_1})^2/n_{i_1}$
High (A)	18.76	21	12.17	14	49	4,725
Sufficient (BC)	71.44	80	50.44	58	484	11,26552
Initial(CD)	9.8	11	37.39	43	1024	32,14884
Total	100	112	100	115		18,27783

The initial level (DE) of use of educational content for open digital resources in general technical disciplines is characterized by the acquisition with the theoretical material with video or interactive lectures. The sufficient level (BC) is considered the calculating the practical tasks with video instructions and interactive posters and performing interactive tests. The high level (A) takes into account the ability to prepare laboratory works and engineering and technical projects with creation of 3D models and performance of practical works with the use of modelling and design programs.

It is calculated the degree of freedom ν by the formula $\nu = k - 1$, k – number of levels. Therefore, $\nu = 2$. It is defined a critical value for the degree of freedom χ^2_{crit} (5.991; 9.210) for levels of statistical significance $\rho \leq 0.05$ and $\rho \leq 0.01$. The levels of statistical significance allow to define zones of significance and insignificance for the received values.

Before the experiment χ^2_{emp}=1.52, $\chi^2_{emp} \leq \chi^2_{crit}$, which means that the deviations between distributions are insignificant. Therefore, it is accepted hypothesis H0 – there are no significant differences in the level of use educational content for open digital resources in general technical disciplines in the experimental and control groups.

After the experiment χ^2_{emp}=18.2, $\chi^2_{emp} \geq \chi^2_{crit}$, which means that the deviations between distributions are significant. Therefore, it is accepted hypothesis H1 – there are significant differences in the level of use educational content for open digital resources in general technical disciplines in the experimental and control groups.

In the context of the discussion of the developed technology of creating educational content for open digital resources in general technical disciplines and its implementation to the educational process it is necessary to note that the educational horizon has changed with the arrival of open educational resources [28]. Empirical studies of using open digital resources noticed the numerous effects on a number of topics such as increased engineering knowledge, STEM skills etc [29]. Using open digital resources, in particular in studying general technical disciplines, contributes to generating and sharing educational knowledge. It can be adapted and combined to create new resources that better meet the specific needs of different kinds of users and scenarios [30].

The technology of creating educational content for open digital resources in general technical disciplines includes the construction of the video, graphic and interactive content. Various studies have demonstrated that video education can be helpful tool for studying technical disciplines, particularly for hard-to-visualize processes. Videos allow students to view content at their own pace and revisit materials on demand. Also well-designed videos can be repurposed by tutors, eventually reducing time needed to make high-quality educational content [31]. It is important to adopt the cloud technologies to the needs of educational institutions [32]. In general, it is necessary to develop skills in the use of technology for significant increase in student practice scores. However, the guidance of the tutors in the conditions of open digital resources plays crucial role [33]. Open digital resources are developed for a specific purpose and aligned with the specialized subject content, and the resource must be precise and peer reviewed for quality measures [34]. The proposed technology was developed for the general technical disciplines and it takes into account the specific of those disciplines. Video, graphic and interactive content as well as using special engineering services for this content makes it possible to demonstrate natural objects and phenomena, study the principles of operation of machines and equipment, present step-by-step the method of calculation of engineering objects and to consider and design technical objects in the dimension.

It is important to rise the lecturers' awareness and knowledge to utilising the free online digital tools available [35]. In the conditions of studying technical disciplines, it is necessary to understand and gain skills in the digital environment at a practical level and learn how to work in it, to give an understanding of the digital tools of the future specialist and their effectiveness [36]. The paper highlights practical aspects and experience of the functional approach applying to the development of contemporary digital learning aids in the progress of project-driven activity [37].

In the context of organizing the individual work of students it is principal to apply new approaches in the educational process with the using of the modern information technologies [38]. In studying general technical disciplines, particularly Engineering and Computer Graphic, there is a need to use modelling and design programs and 3D geometric environment [39]. Graphical content provides a more visual representation of the product, the absence of the need for an additional physical model, process automation, the possibility of using 3D models in various programs and devices. There is also the possibility of automated calculation of various properties of the product, such as the calculation of heat distribution, mass-inertial characteristics, which is important for interdisciplinary connections when studying general technical disciplines.

The experience of developing and implementing visualized cases using a combination of Google services and digital computer measurement system in the process of teaching STEM disciplines shows positive results [40]. It is important to take into account the specific of engineering disciplines [41]. Interactive laboratory tools and engineering calculators can be useful in order to avoid routine calculations in order to concentrate on the immediate topic of the lesson. Interactive infographics in the context of interactive lectures is a more attractive version of such a tool, as it more broadly reveals concepts and concepts. Interactive posters for practical work allow you to maintain the sequence and logic of the work and provide hints and useful tips during the execution. The use of interactive content in digital educational resources when studying general technical disciplines helps to carry out operations with their elements, interact with images, tests, surveys, videos, physical and technical models.

As a result of using proposed technology, higher education applicants execute tasks, obtain points and achieve competencies in general technical disciplines. The using of the technology of creating educational content for open digital resources in general technical disciplines is effective that was confirmed experimentally.

5. Conclusion

The processes of informatization of education, which have recently become more widespread, are aimed at the digitization of educational resources. The formation of the educational content for open digital resources in general technical disciplines has certain features due to the large number of graphic objects, calculations and natural and mathematical concepts. It is presented the technology of creating educational content for open digital resources in general technical disciplines. The proposed technology consist of the following stages: development, design, posting, final. The development stage outlines the methodical peculiarities of creating video, interactive, graphic content for different forms of classes: lectures, practical and laboratory classes and independent work. Video content includes video lectures, video instructions for practical and laboratory work, video recording of the speech of higher education applicants. Interactive content consists of the lectures and labs with interactive elements, interactive posters and tests. Graphic content includes creation of lectures with graphical models, 3D models for laboratory works, performance of practical works with the use of modelling and design programs and creation of engineering and technical projects. There are outlined services for achievement of the educational purposes for creating each type of content at the design stage of the proposed technology. At the posting stage the tutor download the relevant task (lecture, explanation for the practical or laboratory task, test) in an open digital resource. Final stage takes into account the execution of tasks by higher education applicants, obtaining points, acquisition of competencies. The result of using proposed technology is achieving competencies in general technical disciplines in the conditions of open digital resources. The reliability of the results was checked using the Pearson criterion. It is determined that the technology of using educational content for open digital resources in general technical disciplines is effective.

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References
[1] Saikkonen L and Kaarakainen M T 2021 *Computers & Education* **168** 104206 URL `https://doi.org/10.1016/j.compedu.2021.104206`
[2] Wang J, Tigelaar D and Admiraal W 2020 *Computers & Education* **2021** 104055 URL `https://doi.org/10.1016/j.compedu.2020.104055`
[3] Deyneka O, Kasperskiy A and Kuchmenko O 2019 *Physical and Mathematical Education* **20** 29–34 URL `https://doi.org/10.31110/2413-1571-2019-020-2-005`
[4] Yashchuk S, Shapran O, Martirosian L, Petukhova T, Artemieva I and Kolisnyk-Humenyuk Y 2021 *Brain. Broad research in artificial intelligence and neuroscience* **12** 278–299 URL `https://doi.org/10.18662/brain/12.1/183`
[5] Ivanov M, Parnikova T, Gulyaev V and Petrov N 2020 *Revista Amazonia Investiga* **9** 205–210 URL `https://doi.org/10.34069/AI/2020.26.02.23`
[6] Fong B Y F, Yee H H L, Ng T K C and Law T C V 2022 *International Review of Education* **68** 389–407 URL `https://doi.org/10.1007/s11159-022-09957-7`
[7] Aldahdouh A 2021 *The Internet and Higher Education* **50** URL `https://doi.org/10.1016/j.iheduc.2021.100808`
[8] Abramovich S and McBride M 2018 *The Internet and Higher Education* **39** URL `https://doi.org/10.1016/j.iheduc.2018.06.002`
[9] Xie K, Tosto G, Chen S B and Vongkulluksn V 2018 *Computers & Education* **127** 90–106 URL `https://doi.org/10.1016/j.compedu.2018.08.011`
[10] Reisoglu I and Çebi A 2020 *Computers & Education* **156** 103940 URL `https://doi.org/10.1016/j.compedu.2020.103940`
[11] Rahimi S, Shute V, Kuba R, Dai C P, Yang X, Smith G and Alonso-Fernandez C 2021 *Computers & Education* **165** 104135 URL `https://doi.org/10.1016/j.compedu.2021.104135`
[12] Kaiper-Marquez A, Wolfe E, Clymer C, Lee J, McLean E G, Prins E and Stickel T 2020 *International Review of Education* **66** 691–713 ISSN 1573-0638 URL `https://doi.org/10.1007/s11159-020-09861-y`
[13] Post L, Guo P, Saab N and Admiraal W 2019 *Computers & Education* **140** 103596 URL `https://doi.org/10.1016/j.compedu.2019.103596`
[14] Tosheva E 2020 3D Modeling Solutions in the Cloud *International Conference on Information Technology and Development of Education – ITRO 2020. October, 2020. Zrenjanin, Republic of Serbia* URL `https://www.researchgate.net/publication/348806388`
[15] Velychko V Y, Fedorenko E G, Soloviev V N and Dolins'ka L V 2022 *CTE Workshop Proceedings* **9** 278–289 URL `https://doi.org/10.55056/cte.120`

[16] Li T, Min X, Zhu W, Xu Y and Zhang W 2021 *Displays* **69** 102030 URL https://doi.org/10.1016/j.displa.2021.102030
[17] Hevko I, Potapchuk O, Lutsyk I, Yashchyk O and Makarenko L 2022 *Informational Technologies and Learning Tools* **87** 95–110 URL https://doi.org/10.33407/itlt.v87i1.4710
[18] Grammens M, Voet M, Vanderlinde R, Declercq L and De Wever B 2022 *Educational Research Review* **37** 100461 URL https://doi.org/10.1016/j.edurev.2022.100461
[19] Cooper V A, Forino G, Kanjanabootra S and Von Meding J 2020 *The Internet and Higher Education* **47** 100757 URL https://doi.org/10.1016/j.iheduc.2020.100757
[20] Mavrikios D, Alexopoulos K, Georgoulias K, Makris S, Michalos G and Chryssolouris G 2019 *Procedia Manufacturing* **31** 404–410 URL https://doi.org/10.1016/j.promfg.2019.03.063
[21] Tkachuk V, Yechkalo Y, Semerikov S, Kislova M and Hladyr Y 2021 Using Mobile ICT for Online Learning During COVID-19 Lockdown *Information and Communication Technologies in Education, Research, and Industrial Applications* ed Bollin A, Ermolayev V, Mayr H C, Nikitchenko M, Spivakovsky A, Tkachuk M, Yakovyna V and Zholtkevych G (Cham: Springer International Publishing) pp 46–67 ISBN 978-3-030-77592-6 URL https://doi.org/10.1007/978-3-030-77592-6_3
[22] Husár J and Knapčíkova L 2019 Exploitation of augmented reality in the industry 4.0 concept for the student educational process *INTED2019 Proceedings* 13th International Technology, Education and Development Conference (IATED) pp 4797–4805 ISBN 978-84-09-08619-1 ISSN 2340-1079 URL https://doi.org/10.21125/inted.2019.1195
[23] Bernarduzzi L, Bernardi E and Ferrari A 2021 *Science & Education* **30** 755–733 URL https://doi.org/10.1007/s11191-021-00197-z
[24] Uchitel A D, Batsurovska I V, Dotsenko N A, Gorbenko O A and Kim N I 2021 *CTE Workshop Proceedings* **8** 233–246 URL https://doi.org/10.55056/cte.235
[25] Dotsenko N 2021 *Journal of Physics: Conference Series* **1946** 012014 URL https://doi.org/10.1088/1742-6596/1946/1/012014
[26] Batsurovska I 2021 *Journal of Physics: Conference Series* **1946** 012015 URL https://doi.org/10.1088/1742-6596/1946/1/012015
[27] Pearson K 1900 *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science* **50** 157–175 URL https://doi.org/10.1007/978-1-4612-4380-9_2
[28] Mishra M, Dash M, Sudarsan D, Santos C, Mishra S, Kar D, Bhat I, Panda B, Sethy M and da Silva R 2022 *The Journal of Academic Librarianship* **48** 102520 URL https://doi.org/10.1016/j.acalib.2022.102520
[29] Hrynevych L, Morze N, Vember V and Boiko M 2021 *Educational Technology Quarterly* **2021** 118–139 URL https://doi.org/10.55056/etq.24
[30] Santos R, Santos M and Ciferri R 2023 *Heliyon* **9** e13311 URL https://doi.org/10.1016/j.heliyon.2023.e13311
[31] Krumm I, Miles M, Clay A, Carlos W and Adamson R 2021 *Chest* **161** URL https://doi.org/10.1016/j.chest.2021.09.015
[32] Naved M, Sanchez D, Dela Cruz A, Peconcillo L, Peteros E and Tenerife J J 2021 *Materials Today: Proceedings* **51** URL https://doi.org/10.1016/j.matpr.2021.11.414
[33] Onggirawan C, Kho J, Kartiwa A, Anderies A and Gunawan A 2023 *Procedia Computer Science* **216** 274–283 URL https://doi.org/10.1016/j.procs.2022.12.137
[34] Mncube S and Mthethwa L 2022 *Heliyon* **8** e09623 URL https://doi.org/10.1016/j.heliyon.2022.e09623
[35] Alordiah C, Osagiede M, Omumu F, Emiko-Agbajor H, Chenube O and Oji J 2023 *Heliyon* **9** e12669 URL https://doi.org/10.1016/j.heliyon.2022.e12669
[36] Abuseridze G, Mohylevska O, Kompanets N and Iushchenko L 2022 *Transportation Research Procedia* **63** 2759–2766 URL https://doi.org/10.1016/j.trpro.2022.06.319
[37] Bilousova L, Gryzun L and Zhytienova N 2021 *Educational Technology Quarterly* **2021** 415–428 URL https://doi.org/10.55056/etq.34
[38] Kuzmina N, Samusenko P and Kuzmin A 2022 *Journal of Physics: Conference Series* **2288** 012009 URL https://doi.org/10.1088/1742-6596/2288/1/012009
[39] Kuz'mich V, Kuzmich L, Savchenko A and Valko K 2022 *Journal of Physics: Conference Series* **2288** 012024 URL https://doi.org/10.1088/1742-6596/2288/1/012024
[40] Golovko N, Goncharenko T and Korobova I 2022 *Journal of Physics: Conference Series* **2288** 012026 URL https://doi.org/10.1088/1742-6596/2288/1/012026
[41] Lu X, Casal J E, Liu Y, Kisselev O and Yoon J 2021 *Journal of English for Academic Purposes* **52** 101006 URL https://doi.org/10.1016/j.jeap.2021.101006

Journal of Physics: Conference Series

Understanding and attitude toward upcycling according to the survey of students of various specialities

To cite this article: T M Derkach *et al* 2023 *J. Phys.: Conf. Ser.* **2611** 012020

Understanding and attitude toward upcycling according to the survey of students of various specialities

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Abstract. The attitude to upcycling technologies of undergraduate students of five specialities (design, clothing industry technology, vocational education and training, industrial pharmacy and psychology) and their teachers was investigated using the questionnaire method. Students' preferences practically do not depend on specialities. For all students, subgroups of upcycling enthusiasts and sceptics are observed which regularly resort to upcycling or almost do not use it. An almost complete misunderstanding and imperception of the benefits and importance of upcycling is a key and common problem. Social factors have a minimal influence on the opinion of respondents, which may indicate a lack of understanding in society of the role and importance of waste management. All the shortcomings and problems in understanding upcycling are common to students and teachers. In general, the positive attitude towards upcycling and the intention to use upcycling in life in the answers most likely has an unconscious and artificial character (like a fashion trend) because the attitude towards other formative factors does not support it. The identified problems are related to the shortcomings of secondary school and undergraduate curricula, which hinder the formation of the necessary competencies for sustainable development. Methods of their solution are proposed and discussed.

1. Introduction

More than 300 universities in Ukraine educate students in more than 210 specialities (according to 2021 data) [1]. The wide variety of educational programs is due to the dynamics of economic development, which requires specialists with a high level of specialisation in various fields. At the same time, the modern world is developing towards globalisation in its various manifestations – economic, political, and cultural. An increase in the load on the environment and nature as a whole accompanies the development of industrial technologies and the constant growth of production volumes. Destruction of forests [2, 3], pollution of water [4, 5], soil and plants [6, 7] for some time was considered as an undesirable but inevitable price for rapid economic growth.

Forming a responsible attitude towards the environment has become one of the priorities in global challenges. If environmental problems were a priority only for professional ecologists a few decades ago, there has been a change in value orientations in recent years.

The concept of sustainable development was gradually developed, and the goals of sustainable development were defined at the UN level [8]. Thus, the list of spheres of human activity on which the planet's ability to support life depended significantly expanded. It, in turn, strengthened the importance of environmental literacy of the population. Ukraine supported the announced goals and adopted them, considering national interests. At the state level, it is recommended to view them in determining the directions of scientific research until 2030 [9].

A tool for achieving sustainable development goals is education for sustainable development and lifelong learning, which is focused on the formation of values and motivation to act for sustainable development [10, 11]. Such transformations concern both personal life and societal actions on a global scale. The consequence of education for sustainable development should be to increase knowledge about the problems of sustainable development, educate people who can think critically and systematically [12], implement innovations and propose solutions for more sustainable models of life.

Since educational activity is very broad, forming an attitude towards sustainable development should begin from childhood, initially focusing on constructing basic concepts. For many years, this issue was not given enough attention in Ukraine. Only in 2020, a new standard [13] was adopted, which provides for the necessary elements in the secondary school curriculum, including the formation of environmental competence as one of the key ones [14]. However, the consequences of its implementation will be analysed no earlier than five years when the first graduates will appear.

Continuing education for sustainable development should take place in higher education. Depending on the field of study, immediate attention should be paid to those sustainable development goals that are a priority for that field. Two previous works were devoted to the problems of engineering education for sustainable development [15–17], and this work further develops the obtained results. Sustainable technologies and materials are a priority for engineering education. Accordingly, the focus should be on the economical production and consumption of resources and energy, waste management, and sustainable consumption and production models.

Attention has been paid to the problem of waste management for a long time. But, with the development of the concept of sustainable development, the focus of research has shifted towards better and more efficient consumption of waste. The standard term recycling, i. e. waste processing, has been divided into two or even three terms, recycling, downcycling and upcycling [18]. At the same time, the term recycling continues to be used in a general sense to define the processing of products without specifying the technology used.

In general, downcycling means reducing quality and cost, recycling in a narrow sense corresponds to keeping them at the same level, and upcycling means increasing quality. In the first case, the price of processed waste is lower than the original cost of the processed material. In the latter case, on the contrary, the cost of recycled materials may be higher than the original cost. The last type of processing has a significant advantage over the first but simultaneously requires using more complex technologies and developing the latest technological processes.

For example, the processing of plastic waste has long followed downcycling technologies, which include, for example, grinding the waste into pellets and its subsequent use as backfill and other simpler applications. In the case of upcycling, the use of biotechnology in combination with chemical technologies makes it possible to increase the value of the used product during the recycling process, for example, to obtain valuable chemical compounds from plastic waste [19,20].

Waste recycling is critical for the textile and clothing industry [21]. The textile industry ranks fourth in terms of environmental impact after the housing, transport and food sectors [22]. Among the industrial sectors, the textile sector ranks second in the world in terms of global carbon emissions (10%) and volume of wastewater (20%) [23]. Global fibre production has recently doubled, from 58 million tons in 2000 to 109 million tons in 2020 [24]. Approximately 63% of world consumption is synthetic fibres, 25% cotton, 7% and 5% wood, and other natural fibres [23].

Two types of textile waste are usually distinguished: those generated during production (pre-consumer waste) and those generated after consumer use (post-consumer waste). Pre-consumer waste is believed to be easier to recycle because its nature and form of existence, fibre, yarn or fabric scraps are known precisely.

Post-consumer waste is usually more complicated due to textile waste's heterogeneity and complex nature. Different substances (natural, synthetic, organic and inorganic fibres) make processing economically tricky. Therefore, there are several ways to recycle [23]. In some cases, it is possible to use facilities for processing waste before consumption. The second approach is mechanical processing, which includes grinding without considering the type of fibres that make up the fabric. The third is chemical treatment aimed at depolymerisation and obtaining oligomers and monomers for further use as raw materials. Finally, energy recovery is one way of recycling, and it seeks to restore the energy content of fibre by burning or fermenting some types of textile waste.

New technologies open up new prospects for waste disposal, as they allow one to obtain more valuable products, that is, to implement the ideology of upcycling. This problem is still among the primary issues and awaits its solution by involving various chemical and biochemical processes, such as pyrolysis [25]. For example, biotechnology and advanced chemical technologies, including green chemistry technologies, transform cotton textile materials into glucose and further into biobased building blocks [26]. Textile fibrous waste is transformed into a harmless secondary raw material for potential environmentally friendly applications in building materials, and geotechnical engineering [23].

However, only a tiny percentage of textile industry waste is reused or recycled worldwide [24]. For example, in the United States of America, only 15% of fibre waste is reused; in China and Japan, it is about 10% and 13%, respectively. In Europe, the situation is better; Germany recycles almost 66% of used textile fibre.

Clothing industry waste (primarily post-consumer waste) feels additional pressure from this market's supply and demand balance. Supply and demand are constantly balanced at an increasingly high level, and demand is continuously increasing due to population growth and living standards improvement. In addition, the demand is accelerated due to the annual market entry of cheap textile products (artificial fibres and materials already account for two-thirds) and the fashion industry's influence, when fashion trends change faster and faster. As a result, over-consumption becomes increasingly apparent, with some textile items ending up in landfills before at least one use [27]. Excessive consumption contrasts with the goals of sustainable development. However, it takes a long time to solve this problem.

In turn, growing demand accelerates supply. However, waste management in the ways described above takes some clothing products out of circulation, diverting recycled materials to other industries. Therefore, designer upcycling is promising, so to speak, when a used thing does not go out of circulation but continues to serve its original purpose without additional energy and material costs [28]. To implement such an approach, when opportunities for further upcycling are laid at the design stage, it is necessary to develop the appropriate competencies of future specialists at the training stage.

As mentioned above, the problems of engineering education for sustainable development, namely the perception of upcycling by students of various specialities in the clothing industry, were considered in previous works [16, 17]. The current research is expanded the started topic for students of other specialities not related to the study of textiles, as well as for teachers. The work aimed to identify the problems junior students face in understanding the benefits and prospects of upcycling, research teachers' attitudes to waste management and formulate ways to overcome identified problems.

2. Materials and methods

2.1. Sample of respondents

In previous studies [16, 17], the focus was on studying the change of attitude towards the waste management problem with years of study for students specialising in vocational education and training (VET) for the clothing industry. In contrast, this study covers more majors but only concerns junior students who have not yet had special classes to develop an understanding of the importance of waste management.

One hundred thirty-two teachers and students of Kyiv National University of Technologies and Design (KNUTD) took part in the survey (table 1). The students belonged to junior undergraduate courses (mostly 1 and 2 years of study) and did not listen to special lectures related to waste management. In terms of study fields, the interviewed students belonged to five specialities. Three (design, technology and VET) belonged to education in various aspects of the clothing industry. The other two specialities were not related to the textile and clothing industry.

In addition to students, 17 teachers (professors and associate professors) who teach mainly at the Faculty of Arts and Fashion were also interviewed.

Table 1. Respondents by specialities and years of study.

Speciality	1st year	2nd year	3rd year	Subtotal
Design	21	0	0	21
Technology	35	0	0	35
VET	1	8	5	14
Pharmacy	0	35	0	35
Psychology	10	0	0	10
Teachers	–	–	–	17
Total	67	43	5	132

2.2. Survey methodology

The questionnaire used in the survey was developed in [29] according to the principles of the Theory of Interpersonal Behavior [30] and the Theory of Planned Behavior [31]. According to these models, a person's attitude to waste processing is determined by the complex action of 9 influencing factors. To assess the effect of individual elements, respondents answered 62 questions. Factors of influence and the corresponding number of questions for their determination are illustrated in table 2. A 7-point Likert scale was used to quantify the responses. A 7-point Likert scale ranges from one extreme to another, from "strongly disagree" (1 point) through neutral "neither agree nor disagree" (4 points) to "strongly agree" (7 points).

The influencing factors form an interconnected scheme that illustrates the mutual dependence of the elements on each other and the order of their action. In more detail, the procedure and assessment of the influence of individual factors are described in [16, 17].

In addition to assessing the importance of factors, respondents directly answered questions about the frequency of their use of upcycling technologies in their lives, which determined the so-called frequency of upcycling or upcycling behaviour (UB) factor. Possible choices consisted of 8 options ranging from the most frequent use (less than once a week) to the option "never". Works [16, 17] show that answers 1-3 from "less than once a week" to "once a month" are characteristic of upcycling optimists. On the contrary, answers 5-8 from "never" to "once every six months" are typical of respondents who are sceptical about applying upcycling practices.

Table 2. Cronbach's Alpha to test the reliability of a scale.

Factors	Number of items	Cronbach's Alpha
Perceived benefits (PB)	15	0.944
Attitude (At)	5	0.892
Subjective norm (SN)	3	0.669
Personal norm (PN)	3	0.794
Role beliefs (RB)	4	0.851
Social factors (all 3 factors together)	10	0.861
Perceived behaviour control (BC)	4	0.867
Intention (In)	3	0.914
Perceived facilitating conditions (FC)	15	0.894
Perceived habits (PH)	10	0.811

2.3. Statistical processing of results
Statistical analysis of the results was performed using the software package IBM SPSS version 21 [32]. Descriptive statistics were applied for the results' general descriptions, calculating the mean and median values, standard deviations and standard errors (SE). The significance threshold in all tests was taken as $p < 0.05$. As a preliminary step, the survey questions' consistency and the survey results' reliability were investigated by Cronbach's alpha test (table 2). Cronbach's alpha measures internal consistency between elements in a group of questions describing an influencing factor. Cronbach's alpha is a coefficient of reliability (or consistency) that indicates how closely a set of elements is linked as a group. For the factor of subjective norms (SN), Cronbach's Alpha value is close to 0.67. For all other factors, Cronbach's alpha exceeds the value of 0.79. Acceptable internal consistency is suggested for the scale if Cronbach's Alpha varies between 0.6 and 0.79. A Cronbach's Alpha value above 0.8 indicates excellent reliability. High values of Cronbach's Alpha allow us to analyse not only the results of answers to individual questions but also to operate with average values of individual factors.

Correlation analysis methods analyse the presence or absence of correlations between individual factors. As virtually all indicators are rank variables and not all factors obey normal distribution, Spearman's rank correlation coefficients were calculated in the correlation analysis.

In the analysis, the total sample of respondents was divided into separate subgroups depending on the speciality. The Mann–Whitney U test (if two groups were compared) or the Kruskal–Wallis H test (if three or more groups were compared) was used to assess the presence or absence of a statistically significant difference between the rates of individual groups. The mentioned tests are non-parametric tests for two (or more) independent ordinal type variables that allow one to determine if the distributions of both populations are equal or not.

Fitting experimental curves using nonlinear curves with the fitting parameters, function expression, constraints and determination coefficients R^2 was performed using the software package OriginLab, version 8.

3. Results
3.1. Frequency of upcycling
The only direct source of information regarding the frequency of application of upcycling methods and technologies in real life is the respondents' answers regarding the UB factor (figure 1). Respondents were offered eight options for answering this question. These responses formed a bimodal curve with two peaks corresponding to the frequency of upcycling annually

and within 1 to 3 months. Similar results were obtained in [16, 17]. The positions, heights of the peaks, and ratios vary slightly and depend on the interviewed contingent.

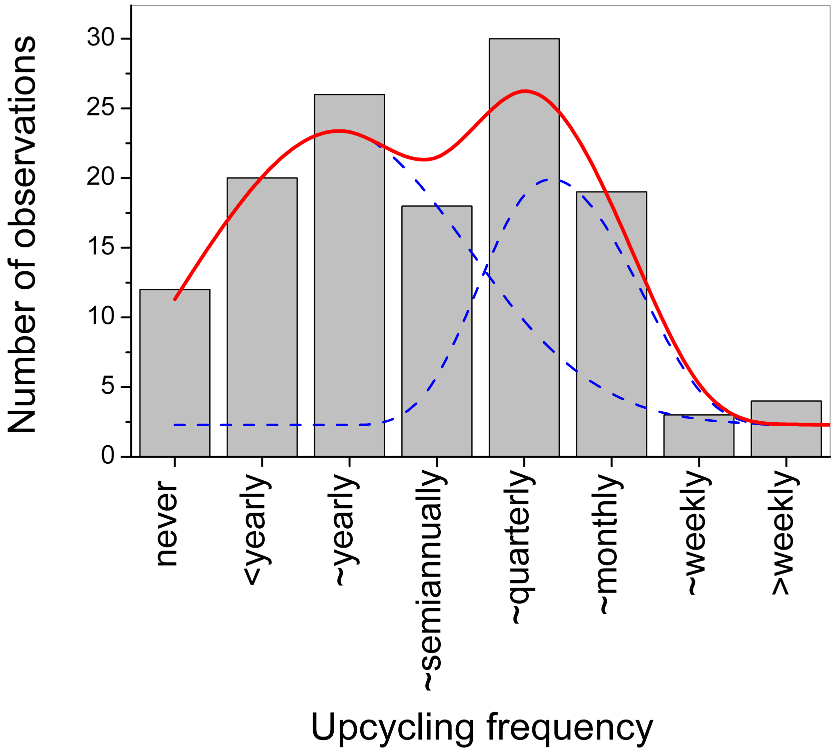

Figure 1. The number of observations vs the frequency of upcycling.

The determination coefficients of two Gaussian curves, approximating both extremes, have high values of R^2=0.98 for a left peak and R^2=0.68 for a right peak, which indicates a good agreement of the experimental data with fitting curves.

The most likely explanation for this observation is the existence of two subgroups of respondents. They are approximately equal in size in the studied cases and can be conventionally called upcycling enthusiasts and sceptics. Enthusiasts practice upcycling at least once every 1-2 months or more, and sceptics say to use it once a year or less. One can talk about some episodes, not constant meaningful use. Between these two groups, a small group of respondents claims to use upcycling once every six months. Most likely, these people have not yet fully decided on their attitude. Analysis of their behaviour may have additional complications due to the incomplete certainty of their position. The conclusion regarding the presence of different subgroups has great practical significance, as it indicates with whom educators will deal at the beginning of forming the necessary attitude to waste management. Significantly different initial beliefs of students require the use of different education methods.

The distribution of other factors according to the characteristics of respondents' answers does not show bimodality. The answers were distributed according to the strength of agreement or disagreement with the statements in the questions. So, the responses have no direct relation to the actual frequency of upcycling practices. Therefore, even if a respondent entirely agrees with the idea of starting to practice upcycling (Intension factor), this does not mean he will do it often. Thus, there is no direct agreement in the distribution of the UB factor and other factors among the individual responses. However, this does not mean that the applied model cannot correctly describe the frequency of upcycling practices. It is evidenced by the presence of

Table 3. Spearman rank correlation coefficients ρ and levels of statistical significance p (two-sided).

Factor	Value	UB	At	SN	PN	RB	BC	In	FC	PH	PB
UB	ρ	1.000	.241**	.323**	.195*	.168	.358**	.392**	-.276**	.118	.040
	p		.005	.000	.025	.054	.000	.000	.001	.178	.648
At	ρ	.241**	1.000	.339**	.285**	.461**	.460**	.467**	.132	.209*	.010
	p	.005		.000	.001	.000	.000	.000	.130	.016	.905
SN	ρ	.323**	.339**	1.000	.402**	.484**	.456**	.493**	.022	.273**	-.011
	p	.000	.000		.000	.000	.000	.000	.800	.002	.904
PN	ρ	.195*	.285**	.402**	1.000	.504**	.415**	.465**	-.029	.054	.037
	p	.025	.001	.000		.000	.000	.000	.742	.536	.677
RB	ρ	.168	.461**	.484**	.504**	1.000	.422**	.514**	-.017	.214*	-.083
	p	.054	.000	.000	.000		.000	.000	.847	.014	.343
BC	ρ	.358**	.460**	.456**	.415**	.422**	1.000	.681**	-.144	.161	.043
	p	.000	.000	.000	.000	.000		.000	.100	.065	.624
In	ρ	.392**	.467**	.493**	.465**	.514**	.681**	1.000	-.098	.180*	.110
	p	.000	.000	.000	.000	.000	.000		.265	.039	.208
FC	ρ	-.276**	.132	.022	-.029	-.017	-.144	-.098	1.000	.455**	-.043
	p	.001	.130	.800	.742	.847	.100	.265		.000	.628
PH	ρ	.118	.209*	.273**	.054	.214*	.161	.180*	.455**	1.000	-.135
	p	.178	.016	.002	.536	.014	.065	.039	.000		.123
PB	ρ	.040	.010	-.011	.037	-.083	.043	.110	-.043	-.135	1.000
	p	.648	.905	.904	.677	.343	.624	.208	.628	.123	

** The correlation is significant at $p < 0.01$.
* The correlation is significant at $p < 0.05$.

statistically significant correlations between various factors – the average values of 9 influencing factors and the upcycling behaviour of UB (table 3).

Altogether, the model predicts the presence or absence of pairwise correlations between 90 pairs of factors. Statistically significant correlations are present in 52 cases, while those are absent in the remaining 38 cases. It should be noted that the values of the correlation coefficients are usually not very high, which indicates the presence of relatively weak correlations. However, we note that the applied nine influence factors are calculated based on answers to 62 questions. Although the degree of consistency of the answers to the questions is relatively high (table 2), the correlation coefficients significantly improve when analysing the existing correlations between individual queries and not between the average values for the factors.

Some factors show a correlation with other elements in most cases. For example, the factors At, In, and SN are correlated with others for 7 of the available nine comparison pairs. Factors PN, RB, BC and UB – for 6 of the available 9 pairs. The PH factor shows the presence of correlations in 5 pairs out of 9. In contrast, the two factors show no correlations in most cases. The factor FC correlates with only two out of 9, and the factor PB shows no correlation with other elements in all cases.

As shown in [17], the factors with the most significant pairwise correlations with other factors make the main contribution to the model's predictive power. Conversely, factors with a lack of correlations can be considered as a field for analysing model weaknesses.

3.2. Individual influencing factors by specialities

This section is devoted to the central question of the article – how different aspects of attitudes towards upcycling are sensitive to the speciality studied by the respondents. The average scores of respondents grouped into subgroups by speciality were calculated for all ten factors based on the questionnaire results to clarify this issue. A general illustration of the results is provided in figure 2 – figure 5. A neutral line of 4 points is also marked for clarity, corresponding to the respondents' neutral or uncertain attitude.

The previous section proved that different factors show a different degree of correlation between themselves and the frequency of upcycling. Therefore, nine influencing factors are grouped into three groups with a high, medium, and low number of correlation (figures 2–4). The results of UB, which in their meaning differ from the influence factors, are shown separately (figure 5).

The general form of the obtained dependencies does not allow us to determine in which cases the differences between the average factors are statistically significant. The Kruskal–Wallis H test was performed to answer this question, and its results are shown in tables 4–7. The null hypothesis of the H test was that the average value for a factor has the same distribution among students of all subgroups under comparison. On the contrary, factors depend on the study's speciality if the null hypothesis is rejected (at significance $p < 0.05$).

The average values of the so-called social factors and the Kruskal–Wallis H test results are shown in figure 2 and table 4, respectively. The statements in the questionnaire are formulated in a positive tone. Therefore, respondents' agreement with the opinion developed in the question (corresponding to 5-7 points) indicates their positive attitude towards this or that aspect of upcycling. This answer hints at negativity if they do not agree (1-3 points). Thus, if the average score is above the neutral line of 4 points, we can talk about a positive perception of the effect of this factor (the higher scores, the stronger the perception). And vice versa if the average score is below the mark of 4 points.

Table 4. Testing the null hypothesis that the SN, PN and RB factors have identical distributions for the Speciality category using the Kruskal–Wallis H test.

Factor	Significance, p	Decision
SN	0.966	The null hypothesis accepted
PN	0.151	The null hypothesis accepted
RB	0.012	The null hypothesis accepted

Asymptotic significance levels are derived. The significance level is 0.05

No statistically significant difference was found between students of different specialities for all three factors. The SN values vary near the mark of 4 points, indicating an uncertainty regarding this factor's influence. Regarding the PN and RB factors, there is a slight optimism in the responses in most of the subgroups. In these cases, the respondents, to some extent, agree with the expressed opinion. The most sceptical are psychologists who take an uncertain position on all three social factors. Again, it should be remembered that the difference between

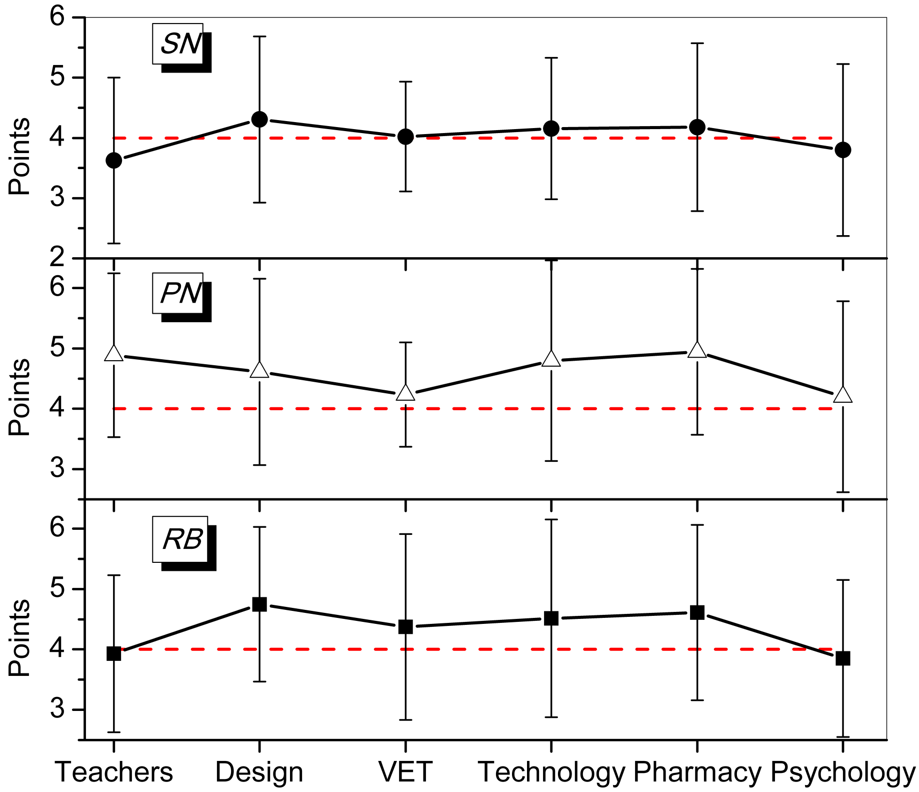

Figure 2. Average values of points for SN, PN and RB factors by specialities.

specialities is not statistically significant; therefore, the observed differences cannot be considered reliably established.

The average values of the factors PH, FC and PB, together with the Kruskal–Wallis H test results, are shown in figure 3 and table 5, respectively. These factors are characterised by the lowest correlations with other factors (table 3). For PH and FC factors, the advantage of a positive attitude is very insignificant (next to neutral). In most cases, the average score for the PB factor falls below the mark of 4 points. In addition, a statistically significant difference between the characteristics of individual specialities was found for this factor.

Table 5. Testing the null hypothesis that the PH, FC and PB factors have identical distributions for the Speciality category using the Kruskal–Wallis H test.

Factor	Significance, p	Decision
PH	0.966	The null hypothesis accepted
FC	0.151	The null hypothesis accepted
PB	0.012	The null hypothesis is rejected

Asymptotic significance levels are derived. The significance level is 0.05

The average values of factors In, At and BC and Kruskal–Wallis H test results are shown in figure 4 and table 6, respectively. These factors indicate the most significant correlations with others (table 3).

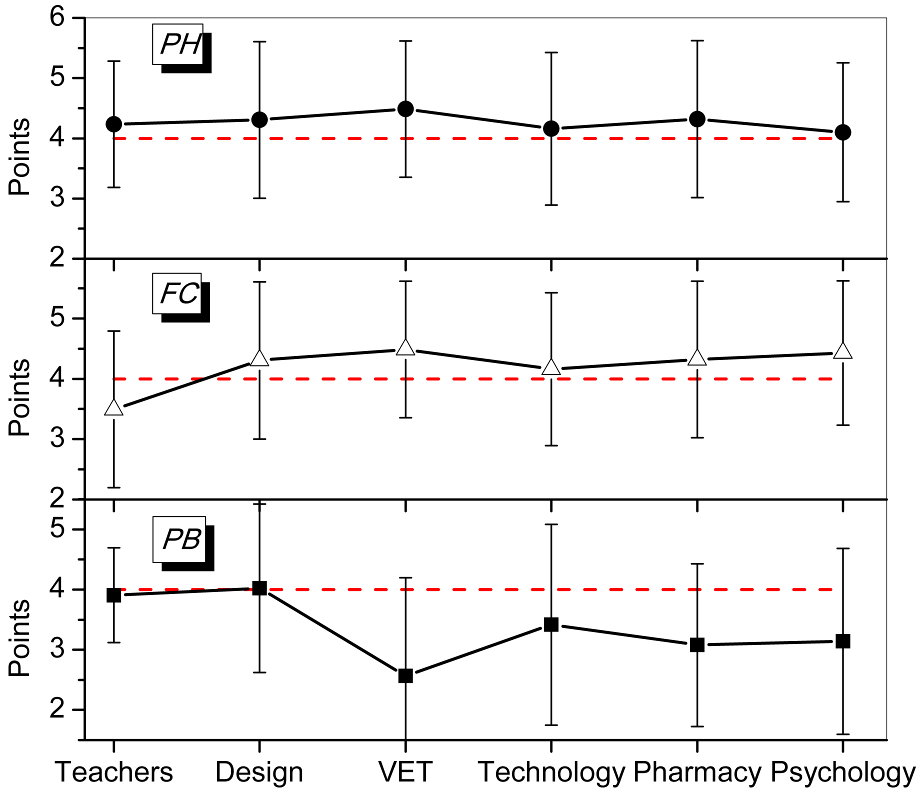

Figure 3. Average values of points for PH, FC and PB factors by specialities.

Table 6. Testing the null hypothesis that the In, At and BC factors have identical distributions for the Speciality category using the Kruskal–Wallis H test.

Factor	Significance, p	Decision
In	0.170	The null hypothesis accepted
At	0.001	The null hypothesis is rejected
BC	0.599	The null hypothesis accepted

Asymptotic significance levels are derived. The significance level is 0.05

All three elements are characterised by a considerable excess of the limit of 4 points. In other words, students of all specialities agree with the statements in questions, indicating a positive impression of these statements. In addition, for the At factor, a statistically significant difference was found between the values of individual specialities. Future designers demonstrate the highest values of At, while teachers have the lowest. In contrast, designers and teachers exhibit the highest values of In. Most sceptical matters concerning intentions, attitude and behaviour control among all subgroups show psychologists.

The UB factor is unique because, unlike the impact factors, it describes the actual frequency of application of upcycling methods in practice (figure 5 and table 7). In addition, 4 points are a neutral indicator for all impact factors in the Likert scale. In contrast, it is a conditional neutral level for UB resulting from the experimental data.

The results show that the frequency of upcycling, characterised by the UB values, does not

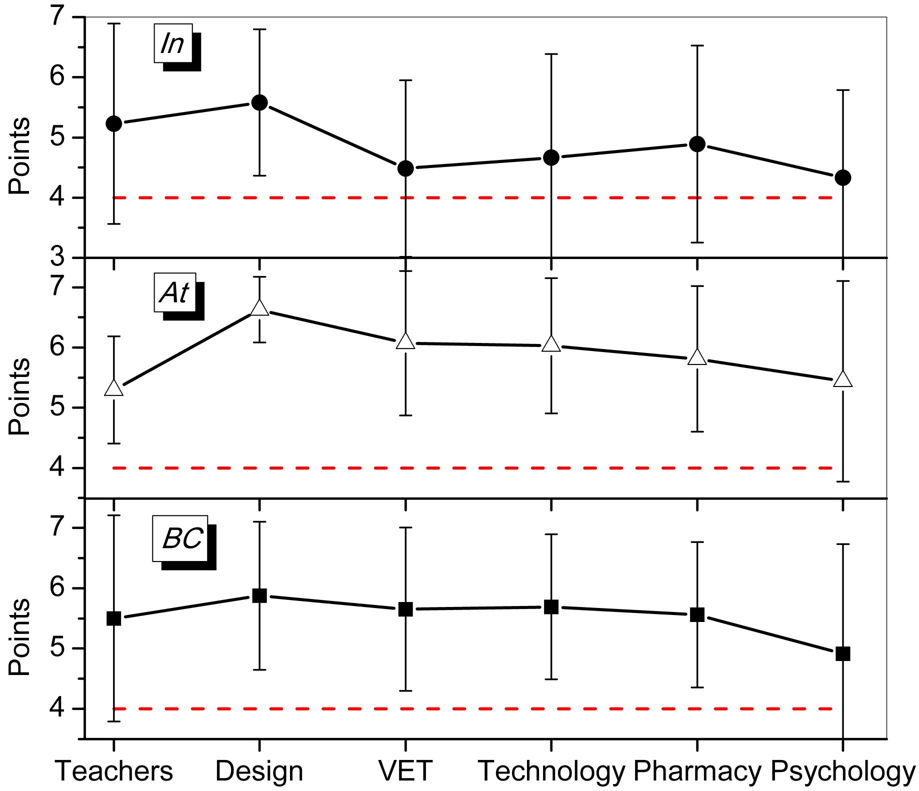

Figure 4. Average values of points for In, At and BC factors by specialities.

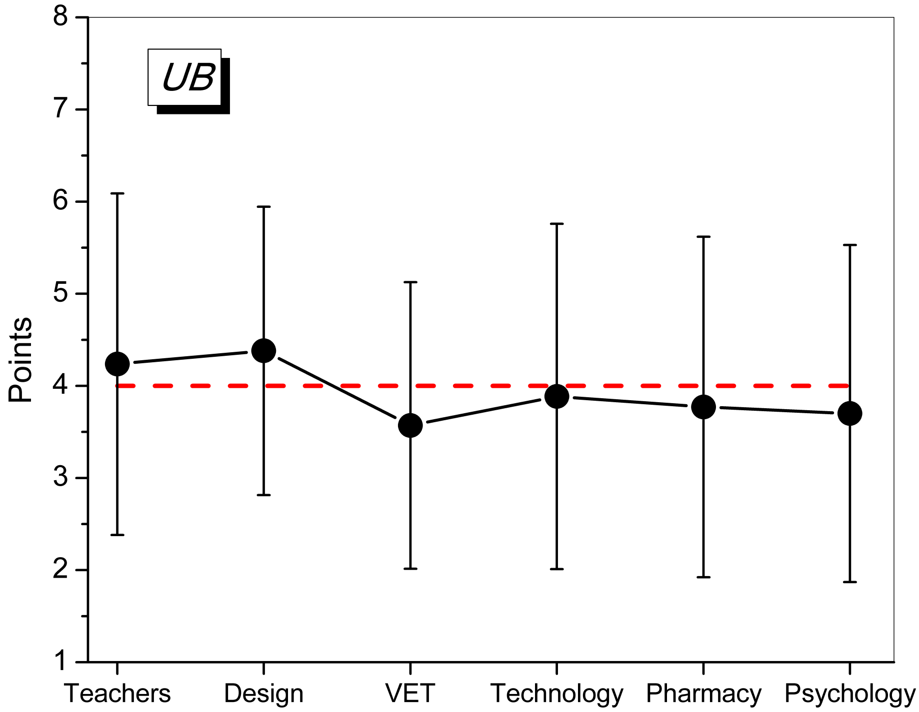

Figure 5. Average values of points for UB factor by specialities.

Table 7. Testing the null hypothesis that the UB factor has identical distributions for the Speciality category using the Kruskal–Wallis H test.

Factor	Significance, p	Decision
UB	0.755	The null hypothesis accepted

Asymptotic significance levels are derived. The significance level is 0.05

change significantly from subgroup to subgroup, and UB fluctuates close to the neutral line of 4 points. There is no significant difference between the values of UB among specialities. However, teachers and designers can be formally classified as weak upcycling optimists, while students of other specialities are sceptics.

4. Discussion

4.1. Identified problems in understanding and applying upcycling technologies

The survey results and analysis of the obtained results allow us to formulate several problems in mastering upcycling technologies that correspond to Ukraine's current level of education.

First, the presence of two subgroups among students, which can be conventionally called upcycling enthusiasts and sceptics, seems characteristic. The former actively use upcycling technologies in everyday life, while the latter hardly do it. Different practical experience, in turn, forms a different attitude to upcycling in different manifestations. From such conditions, developing various pedagogical approaches and training forms for the groups' representatives is necessary.

Secondly, the existing preferences in various aspects of the relation to upcycling remain practically the same for students of different specialities. It should be noted that the interviewees were students who might have a professional interest in upcycling (designers, technologists) and VET students who will educate future professionals in the field. Thus, they also have something to do with promoting or rejecting the idea of upcycling. Along with this, future psychologists are not directly related to the application of waste management methods. Industrial pharmacy students face waste management challenges, albeit in a slightly different format than upcycling (for example, following the principles of green chemistry). Students with no professional interest in upcycling technologies may be interested in using the relevant technologies in life as a hobby. Thus, the problem of ensuring an understanding of the benefits and mastery of available upcycling technologies is not limited to the training of clothing industry specialists but has a more global nature.

Thirdly, the attitude towards upcycling of teachers is not very different from that of students. Thus, all the shortcomings and problems in understanding upcycling are inherent to teachers. Accordingly, without solving this problem, it is impossible to hope for an improvement in the perception of upcycling by students.

Fourthly, there is a complete lack of understanding of the benefits of using upcycling technologies (figure 3). The responses of only teachers and designers are close to the neutral mark, and other groups of students are sure that upcycling has no benefits. The results of the Kruskal–Wallis H test (table 5) indicate a significant difference between different specialities in terms of PB. Additionally, the Mann–Whitney U test demonstrates that a substantial difference is observed in 5 of the 15 available pairs, namely between the following groups:

- teachers > VET at p=0.017,
- teachers > pharmacy at p=0.006,

- design > VET at p=0.003,
- design > pharmacy at p=0.013,
- technology > VET at p=0.05.

A lack of understanding of the benefits involved seems to be a key and common problem in the uptake of upcycling. According to the model from [29], perceived benefits directly form an attitude to upcycling $PB \to At$. The lack of perceived benefits deforms the perception of upcycling and does not allow one to take a conscious, positive attitude.

Fifth, according to the respondents, social factors have a minimal influence (figure 2). If the SN factor shows even a tiny level of perception, then the other two factors, PN and RB, vary practically at the zero level. At the same time, social factors, according to the [29] scheme, are among the main factors that shape human intentions. It can be assumed that the mentioned situation indicates a lack of understanding in society (respondents show similar behaviour from entirely different spheres of activity) of the role and importance of waste management. We are talking about public opinion, which currently does not see the importance of using upcycling technologies.

In the sixth, factors At and In unexpectedly reached a rather high level of approval by respondents (figure 4). It is really unexpected because such a result is not supported by other related factors, such as PB and social factors. According to the behavioural scheme used, the following links should be held: $PB \to At$ and $SN, PN, RB \to In$. The respondents demonstrate a perception of factors At and In but do not indicate the basis for such perception. In this case, we probably should not talk about a conscious choice but only about following fashion trends. Such imitation is as easy to appear as it is to disappear.

Thus, "I'm good at upcycling and intend to use upcycling in the future" is groundless and unconscious. It is evidenced by the experimentally confirmed misunderstanding of the benefits that upcycling can provide and the generally indifferent attitude towards the introduction of upcycling both on the part of society and on the part of personal preferences.

It should be determined that the At factor shows a statistically significant difference when switching from one speciality to another (table 6). Additional Mann–Whitney U test indicates that a significant difference is observed in 7 out of 15 available pairs, namely between the following groups:

- design > teachers at p=0.001,
- VET > teachers at p=0.006,
- technology > teachers at p=0.003,
- pharmacy > teachers at p=0.027,
- design > technology at p=0.041,
- design > pharmacy at p=0.002,
- design > psychology at p=0.035.

As we can see, the desire of future designers to express a positive attitude to upcycling is significantly higher than that of all other subgroups except VET students. This fact makes the greatest contribution to forming a statistically significant difference concerning At among all subgroups.

4.2. Ways to solve the identified problems

The results of our research testify to a certain lack of awareness and unreasonableness of the position, sometimes a certain indifference regarding the implementation of upcycling. As a result, there is a need to rethink existing and develop new approaches to methods and training forms for different groups of respondents.

We single out several possible reasons for such low awareness among students of various specialities who participated in our survey. The first is insufficient attention to sustainable development in the State Standard of Basic and Comprehensive General Secondary Education issued in 2011 and, accordingly, in the curricula of various educational fields. The respondents who took part in the study studied under these programs. Optimistic is the built-in competence potential in a new edition of the State Standard [13]. It has been operative since 2020 and pays attention to forming environmental competence in natural, social and health-preserving, technological educational fields. It also supports the construction of basic knowledge, skills and values regarding sustainable development.

We consider the second reason to be a lack of awareness of some teachers. They influence their consciousness in working with students, so they should explain to students during classes and involve them in other forms of work.

The third reason can be considered low attention from society, particularly parents, friends, peers and the community in general. In part, this can be justified by social conditions – the COVID-19 pandemic and Russian military invasion in 2022 brought the issue of preserving one's life and health to the fore, and the rest of the problems are of secondary importance [33].

Regarding ways to solve this problem, we fully agree with [34] about the possibilities of implementing the concept of sustainable development in separate courses and integration into various disciplines, as well as in the process of non-formal education [35].

According to the results of our research, it was found that the most sceptical about the introduction of upcycling is a group of psychologists who take an uncertain position regarding three social factors. In its specialisation and future profession, this student group is not related to the production of products or teaching activities. Therefore, we consider it reasonable to use informal education opportunities, particularly participation in project activities and training [36].

One of the ways is the participation of students in group activities. At the Department of Professional Education in Technologies and Design of KNUTD, a student scientific society, "Education for Sustainable Development", has been operating since September 2022. It focuses on spreading educational activities regarding sustainable development and the formation of awareness of ecological and ethical norms, values, lifestyle, household and production, which are required to ensure sustainable development. Future teachers of VET and practical psychologists participate and work in the following scientific areas:

(i) Reorientation of goals, content and methods of the educational process of training specialists in the field of technology and design in the context of the concept of sustainable development.
(ii) Ecological trends and possibilities of their use in the field of technology and design.

The society uses various forms and methods of work [37] and covers the following topics:

- seminar "Reduce-Reuse-Recycle concept (consume less – reuse – recycle)",
- discussion "Ways and possibilities of using the ideas of education for sustainable development in professional activity" (Interactive exercise "Mat of ideas", solving situational problems),
- round table "How to get rid of unnecessary clothes without harming the environment? Ecological trends: recycling, upcycling and freecycling", and
- training "Ideas of recycling".

The influence of societal activities on the awareness of upcycling usage can be checked by conducting a repeat survey.

A meaningful way to overcome the identified problems is the study and application of the best European practices in the organisation of sustainable education. We consider it a priority to introduce appropriate changes in the training of future VET teachers because the graduates will go to vocational training institutions and teach skilled workers in addition to being industrial technologists.

Some work has been done in this direction. Several changes have been made to the educational programs of the VET speciality at KNUTD, which contribute to the formation of competencies of critical importance for the training of a future specialist in sustainable education. Program learning outcomes have been developed for such competencies, which are strictly measurable, and new educational modules have been developed for three disciplines. Teaching is based on pedagogical approaches that optimise forms, methods and means of learning following the characteristics of the profiles of educational preferences of student groups [38, 39]. Such approaches ensure the achievement of the stated competencies of sustainability:

1. Project/problem-based learning (in an organisation/community),
2. Integrative learning (inter- and transdisciplinary),
3. Project/problem-based learning (in class),
4. Active learning (in class),
5. Research-based learning,
6. Critical text/information analysis/interpretation,
7. Reflexive learning, and
8. Collaborative learning.

The applied approach gives positive results and provides an opportunity to form the necessary knowledge in graduates of KNUTD, as well as in students of vocational schools due to interaction with university students during the latter's pedagogical practice [40]. The new task of the interns is to prepare and conduct two lectures for vocational training students on sustainable clothing production. Such measures contribute to the involvement of a wide range of future workers in the textile industry in European practices. It improves their professional prospects in terms of employment and organisation of the competitive business.

We believe that implementing a new bachelor's program, Sustainability Education for Clothing Manufacturing and Design, and incorporating it into Ukrainian professional education [41] would allow for more comprehensive and practical training of professional education specialists. Three new compulsory and one optional discipline with all the necessary educational resources based on the best practices of EU universities [42] are being developed for the implementation of such a program.

It is planned to introduce a short course of lectures for teacher training courses to solve the problem of inadequate training of university teachers. It is intended to use the format of organising and holding annual one-day workshops for better interaction and involvement of educators and industry producers. The platform for their organisation will be the International Scientific Conference "KyivTex&Fashion", which has been held annually at KNUTD for many years.

5. Conclusions

1. The problems faced by junior year students of various specialities of KNUTD in understanding the advantages and prospects of upcycling have been studied. It is shown that the existing educational programs do not motivate and do not develop among students a thrifty attitude to resources and a careful attitude to reducing the environmental burden on the environment. Such a situation does not give reason to expect specialists capable of working effectively in accordance with sustainable development goals.

2. Several problems in mastering upcycling technologies are formulated, which are appropriate to Ukraine's current level of education. It is shown that the issue of ensuring an understanding of the advantages and mastery of available upcycling technologies is not limited to the training of clothing industry specialists but has a global character. The general preferences in various aspects of the relationship to upcycling remain practically the same for students of different specialities. Teachers show indifference and ignorance in understanding upcycling. Most respondents do not understand the benefits of using upcycling technologies, although some express a desire to use recycling technologies. According to respondents, social factors have minimal influence. It is evidenced by the experimentally confirmed misunderstanding of the benefits that upcycling can provide and the generally indifferent attitude towards the introduction of upcycling both on the part of society and on the part of personal preferences.
3. Possible ways to overcome the formulated problems in the training of future engineering specialists have been determined by: implementing the concept of sustainable development both in the form of developed new educational programs and programs of individual courses; integration of new modules in various disciplines; in the process of informal education using the example of group activities; appropriate professional development of teachers.

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References

[1] 2021 Education of Ukraine URL https://osvita.ua
[2] Kvitko M O, Savosko V M, Lykholat Y V, Holubiev M I, Hrygoruk I P, Lykholat O A, Kofan I M, Chuvasova N O, Yevtushenko E O, Lykholat T Y, Marenkov O M and Ovchinnikova Y Y 2022 *IOP Conference Series: Earth and Environmental Science* **1049**(1) 012046 ISSN 17551307 URL https://doi.org/10.1088/1755-1315/1049/1/012046
[3] Scheidel A and Gingrich S 2020 *One Earth* **3**(6) 680–690 ISSN 2590-3322 URL https://doi.org/10.1016/j.oneear.2020.11.005
[4] Stoliarenko V, Chernova M and Yakovchuk O 2020 *E3S Web of Conferences* **166** 01005 ISSN 25550403 URL https://doi.org/10.1051/e3sconf/202016601005
[5] Shah N W, Baillie B R, Bishop K, Ferraz S, Högbom L and Nettles J 2022 *Forest Ecology and Management* **522** 120397 ISSN 0378-1127 URL https://doi.org/10.1016/j.foreco.2022.120397
[6] Savosko V, Podolyak A, Komarova I and Karpenko A 2020 *E3S Web of Conferences* **166** 01007 ISSN 25550403 URL https://doi.org/10.1051/e3sconf/202016601007
[7] Derkach T M and Starikova O O 2019 *Journal of Chemistry and Technologies* **27**(1) 479–92 URL https://doi.org/10.15421/091909
[8] United Nations 2023 The 17 goals — sustainable development URL https://sdgs.un.org/goals
[9] President of Ukraine 2019 About the sustainable development goals of Ukraine for the period until 2030 URL https://zakon.rada.gov.ua/laws/show/722/2019#Text
[10] Australian Education for Sustainability Alliance 2022 What is Education for Sustainability? URL https://sustainabilityinschools.edu.au/what-is-efs
[11] Lavrentieva O, Pererva V, Krupskyi O, Britchenko I and Shabanov S 2020 *E3S Web of Conferences* **166** 10031 ISSN 25550403 URL https://doi.org/10.1051/e3sconf/202016610031
[12] Shekhavtsova S, Koknova T and Shekhavtsov M 2021 *Educational Technology Quarterly* **2021**(2) 310–330 URL https://doi.org/10.55056/etq.28
[13] Cabinet of Ministers of Ukraine 2020 State standard for basic secondary education URL https://zakon.rada.gov.ua/laws/show/898-2020-%D0%BF#n16
[14] Morkun V S, Semerikov S O, Morkun N V, Hryshchenko S M and Kiv A E 2018 Defining the Structure of Environmental Competence of Future Mining Engineers: ICT Approach *Proceedings of the 1st International Workshop on Augmented Reality in Education, Kryvyi Rih, Ukraine, October 2, 2018*

(*CEUR Workshop Proceedings* vol 2257) ed Kiv A E and Soloviev V N (CEUR-WS.org) pp 198–203 URL https://ceur-ws.org/Vol-2257/paper19.pdf

[15] Kolchanova M, Derkach T and Starova T 2020 *E3S Web of Conferences* **166** 10028 ISSN 25550403 URL https://doi.org/10.1051/e3sconf/202016610028

[16] Shuhailo Y V, Derkach T M, Shpetna A V and Ustenko T 2022 *Journal of Physics: Conference Series* **2288**(1) 012041 URL https://doi.org/10.1088/1742-6596/2288/1/012041

[17] Derkach T M and Shuhailo Y V 2022 *IOP Conference Series: Earth and Environmental Science* **1049**(1) 012021 URL https://doi.org/10.1088/1755-1315/1049/1/012021

[18] Singha K, Pandit P, Maity S, Srivasatava R and Kumar J 2020 Sustainable Strategies from Waste for Fashion and Textile *Recycling from Waste in Fashion and Textiles* (John Wiley & Sons, Ltd) chap 9, pp 199–214 ISBN 9781119620532 URL https://doi.org/10.1002/9781119620532.ch9

[19] Lee S, Lee Y R, Kim S J, Lee J S and Min K 2023 *Chemical Engineering Journal* **454** 140470 ISSN 1385-8947 URL https://doi.org/10.1016/j.cej.2022.140470

[20] Skolia E, Mountanea O G and Kokotos C G 2022 *Trends in Chemistry* ISSN 2589-5974 URL https://doi.org/10.1016/j.trechm.2022.10.003

[21] Sandin G and Peters G M 2018 *Journal of Cleaner Production* **184** 353–365 ISSN 0959-6526 URL https://doi.org/10.1016/j.jclepro.2018.02.266

[22] Sohn J, Nielsen K S, Birkved M, Joanes T and Gwozdz W 2021 *Sustainable Production and Consumption* **27** 2153–2164 ISSN 2352-5509 URL https://doi.org/10.1016/j.spc.2021.05.013

[23] Rahman S S, Siddiqua S and Cherian C 2022 *Cleaner Engineering and Technology* **6** 100420 ISSN 2666-7908 URL https://doi.org/10.1016/j.clet.2022.100420

[24] Kahoush M and Kadi N 2022 *Sustainable Materials and Technologies* **34** e00513 ISSN 2214-9937 URL https://doi.org/10.1016/j.susmat.2022.e00513

[25] Lee H S, Jung S, Lin K Y A, Kwon E E and Lee J 2023 *Science of The Total Environment* **859** 160393 ISSN 0048-9697 URL https://doi.org/10.1016/j.scitotenv.2022.160393

[26] Clark J H 2022 *Current Opinion in Green and Sustainable Chemistry* **38** 100685 ISSN 2452-2236 URL https://doi.org/10.1016/j.cogsc.2022.100685

[27] Vesterinen E and Syrjálá H 2022 *Cleaner and Responsible Consumption* **5** 100061 ISSN 2666-7843 URL https://doi.org/10.1016/j.clrc.2022.100061

[28] Marques A D, Moreira B, Cunha J and Moreira S 2019 *Procedia CIRP* **84** 1063–1068 ISSN 2212-8271 29th CIRP Design Conference 2019, 08-10 May 2019, Póvoa de Varzim, Portgal URL https://doi.org/10.1016/j.procir.2019.04.217

[29] Sung K 2017 *Sustainable production and consumption by upcycling: Understanding and scaling-up niche environmentally significant behaviour* Ph.D. thesis Nottingham Trent University

[30] Triandis H C 1977 *Interpersonal Behavior* The Strategyzer Series (Monterey, CA: Brooks/Cole Publishing Company)

[31] Ajzen I 2011 *Psychology & Health* **26**(9) 1113–1127 URL https://doi.org/10.1080/08870446.2011.613995

[32] Landau S and Everitt S B 2004 *A Handbook of Statistical Analysis Using SPSS* (Boca Raton: Chapman & Hall/CRC)

[33] Kovalchuk V I, Maslich S V and Movchan L H 2023 *Educational Technology Quarterly* **2023**(1) 1–17 URL https://doi.org/10.55056/etq.49

[34] Sammalisto K, Sundström A and Holm T 2015 *Journal of Cleaner Production* **106** 45–54 ISSN 0959-6526 URL https://doi.org/10.1016/j.jclepro.2014.10.015

[35] Tare M 2020 *Technology & Innovation* **21**(4) 1–3 ISSN 1949-8241 URL https://doi.org/10.21300/21.4.2020.2

[36] Lozano R, Merrill M Y, Sammalisto K, Ceulemans K and Lozano F J 2017 *Sustainability* **9**(10) 1889 ISSN 2071-1050 URL https://doi.org/10.3390/su9101889

[37] Wamsler C 2020 *International Journal of Sustainability in Higher Education* **21**(1) 112–130 URL https://doi.org/10.1108/IJSHE-04-2019-0152

[38] Gryshchenko I M, Jin L, Derkach T M and Tang S 2021 *Journal of Physics: Conference Series* **1946**(1) 012008 URL https://doi.org/10.1088/1742-6596/1946/1/012008

[39] Derkach T M 2019 *Orbital: Electron Journal of Chemistry* **11**(3) 219–227 URL https://doi.org/10.17807/orbital.v11i3.1395

[40] Hoque F, Yasin R M and Sopian K 2022 *Sustainability* **14**(14) 8296 ISSN 2071-1050 URL https://doi.org/10.3390/su14148296

[41] Lozano F J and Lozano R 2014 *Journal of Cleaner Production* **64** 136–146 ISSN 0959-6526 URL https://doi.org/10.1016/j.jclepro.2013.08.022

[42] Ceschin F and Gaziulusoy I 2016 *Design Studies* **47** 118–163 ISSN 0142-694X URL https://doi.org/10.1016/j.destud.2016.09.002

Journal of Physics: Conference Series

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Analysis of the state of the art of modern e-learning in higher education in Germany

Analysis of the state of the art of modern e-learning in higher education in Germany

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Abstract. E-learning as a part of blended learning and a means for implementing distance learning, as well as an independent phenomenon of the modern information society, has been introduced and studied by researchers for several decades. In various countries, the relevance of e-learning and the use of e-learning tools in higher education have increased during the coronavirus pandemic. Different countries have their own approach and experience in using e-learning tools. Therefore, it is advisable to study it both for each country separately and in comparison. In the course of the research, the analysis of scientific publications on the topic of e-learning in higher education in Germany over the last 10 years has been made, which has shown certain changes in the interest in this issue of German scientists. The survey of students and teachers of the University of Konstanz (Germany) has been conducted regarding the use of e-learning tools and their attitude to e-learning. Despite the fact that the results of the analysis of the scientific works of German scientists show a drop in interest in e-learning problems in Germany and a slight rise during the coronavirus pandemic, the results of the survey indicate an unequivocal interest in e-learning tools of teachers. In general, it is possible to state the positive attitude on the part of teachers and uncertainty on the part of students.

1. Introduction

Digital technologies have revolutionized all spheres of human activities, including higher education. Large volumes of knowledge today are difficult to convey at clearly allocated lecture time, so e-learning tools are often used to deepen learning and provide more information to those students who need it. The advent of e-learning tools has allowed universities to attract more students who cannot attend face-to-face classes for religious, political or financial reasons to learning.

Studies conducted by scientists show the growing demand for e-learning services in the USA [1], China [2], Ukraine [3–6], etc. and the use of e-learning tools in traditional education, that is, blended learning [7–9]. In general, interest in e-learning has been growing in the EU countries for the last few years. In 2021, 27% of people aged 16 to 74 in the EU reported that they did an online course or used online learning material in the last three months prior to the survey, there was a 4 percentage points (pp) increase compared with 23% in 2020. Compared with 2019 before the pandemic, the share of people doing online courses or using online learning material increased in all Member States, except for Romania where it decreased (-4pp) to 10%. Among the sharpest increases were the Netherlands (+21pp), followed by Luxembourg and Slovenia (both +19pp), and Greece (+18pp) [10] (figure 1).

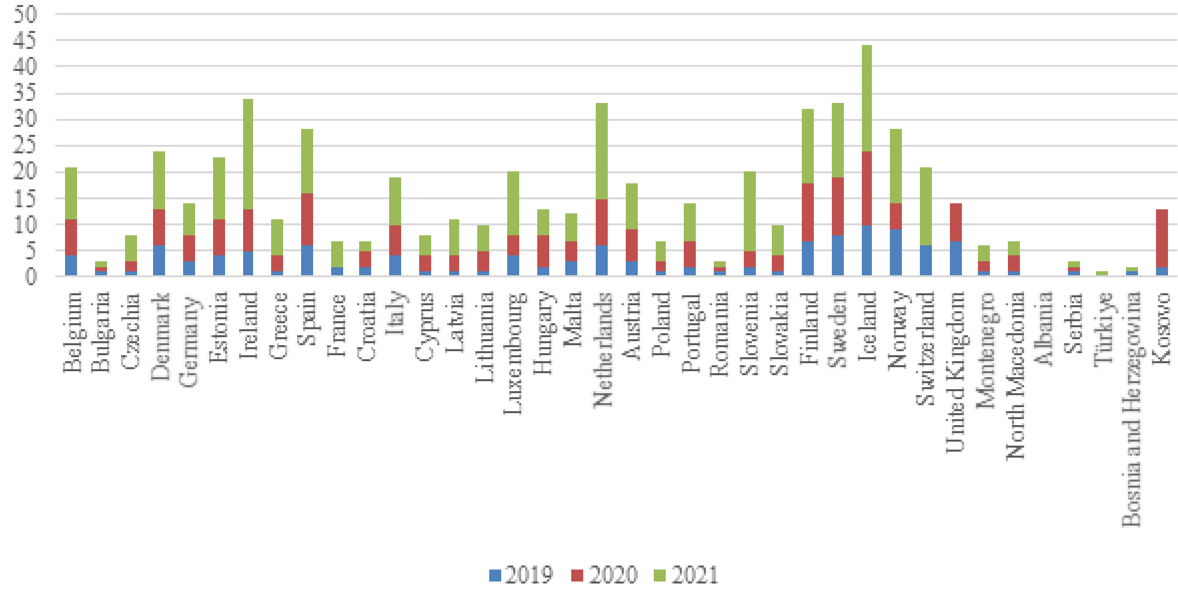


Figure 1. People doing an online course or using online learning material in the EU in the 3 months prior to the survey (percentage of people 16 to 74 years old) [10].

At the same time, the study of e-learning and its tools in EU countries, namely Germany, requires additional research, in relation with the changes caused by the coronavirus pandemic. Also, according to the research data illustrated in figure 1, in Germany the percentage of those interested in online courses is increasing, but not much (2019 – 3%, 2020 – 5%, 2021 – 6%). Therefore, the question arises: what is the reason for such a small increase in interest in e-learning in Germany?

Therefore, we have set the purpose to analyze the state of the art of e-learning and the tools used for e-learning in higher education in Germany. For this, we consider it expedient to perform the following research tasks:

- to analyze scientific publications on the topic of e-learning in higher education in Germany for the last 10 years;
- to conduct a survey of students and teachers of the University of Konstanz regarding the use of e-learning tools and their attitude to e-learning;
- to analyze the results of the survey of students and teachers of the University of Konstanz and compare with the theoretical analysis of scientific publications.

2. Methods of the research

The following research methods have been used during the research:

- the quantitative analysis of papers on the research topic to select criteria for selecting papers for the analysis;

- in order to determine the priority directions of the research, the methods of analysis, systematization, classification, generalization of psychological-pedagogical, specialized and technical sources regarding e-learning in Germany for the last 10 years have been used;
- methods of concretization and systematization of theoretical knowledge and practical achievements of German scientists have been used to develop research tasks, as well as the anonymous survey, the analysis of its results and presentation using graphical methods of statistical data representation.

3. Results

3.1. Analysis of scientific publications for the last 10 years

In the course of the research, we have set the objective to find out how important the issue of e-learning in higher education is in the German scientific discourse. For this purpose, the search has been carried out in the Google Trends service to identify the appearance frequency of the term "e-learning" and "electronic learning" in relation to the total volume of search queries in Germany in the German and English languages for the last 10 years (figure 2).

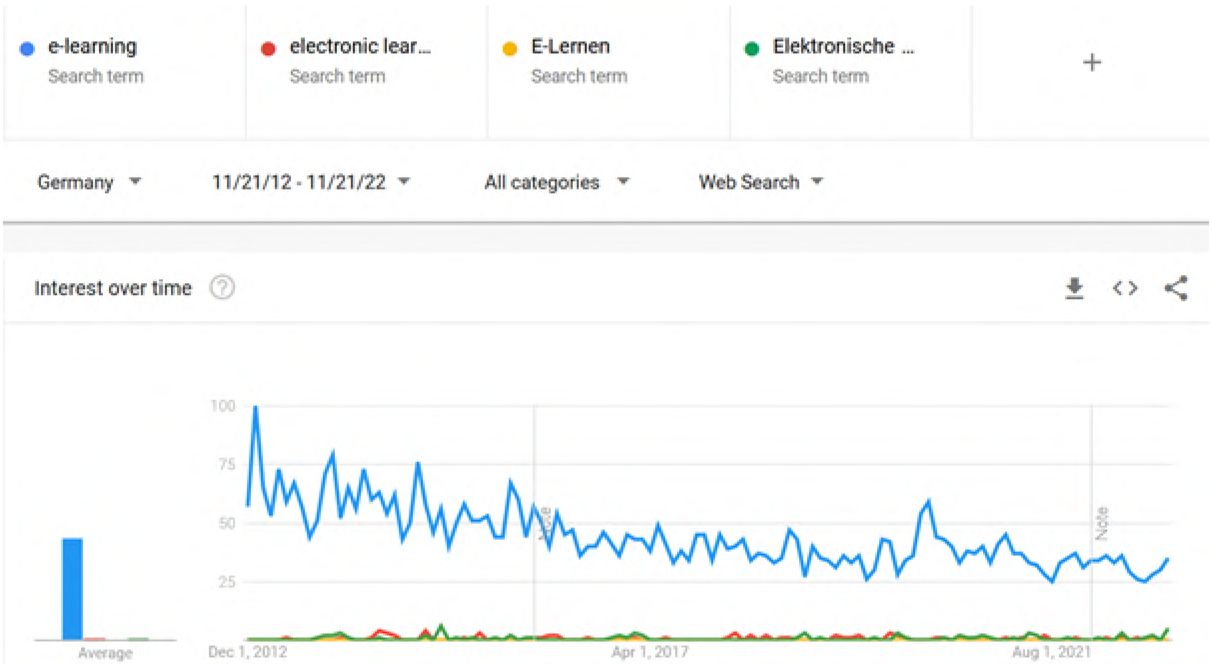


Figure 2. Search results in the Google Trends service for the term "e-learning" and "electronic learning" in the German and English languages for the last 10 years.

Analyzing the search results in Google Trends, it can be stated that e-learning became the most popular in 2012. The interest in e-learning subsequently declined until 2020, which can be explained by the demand for e-learning tools during the coronavirus pandemic. As we can see, the decrease in the intensity of the pandemic ultimately leads to a decrease in interest in the problem of e-learning.

As a result of the analysis of the data displayed in figure 3, the interesting fact is observed: in all 16 German states, the most popular term is "e-learning" (100 percent).

The search for the key phrases "e-learning" and "electronic learning" (German: "E-Lernen" and "Elektronisches Lernen") has been carried out using the search engine according to Google Scholar scientific publications. The search results have been divided into 2 periods for 5 years (table 1).

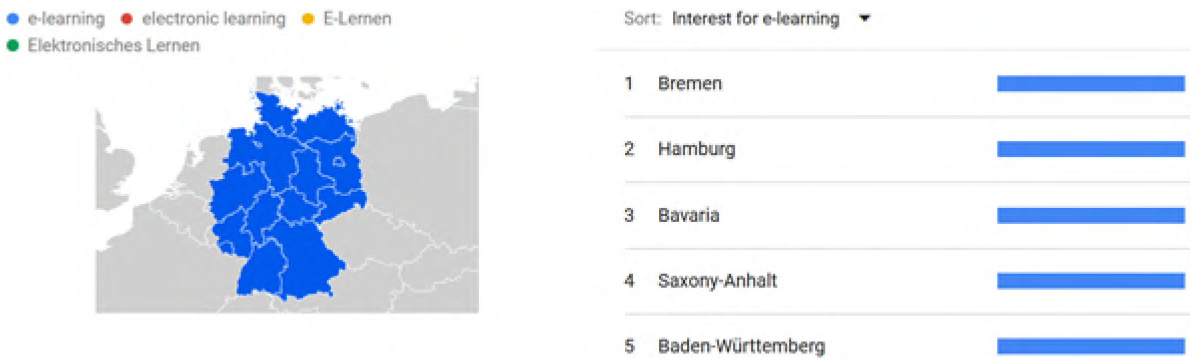


Figure 3. Comparison of the terms "e-learning" and "electronic learning" according to the frequency of their use in certain regions of Germany.

Table 1. Google Scholar search results for the term "e-learning" and "electronic learning" in Germany for the last 10 years.

Period	"e-learning" ("E-Lernen")	"electronic learning" ("Elektronisches Lernen")
2013-2017	131	16700
2018-2022	136	16200
Total	267	32900

Analysis of the search results by key phrases in Google Scholar confirms:

(i) the most used term in Germany is "electronic learning" ("Elektronisches Lernen");

(ii) the number of publications in which the term "e-learning" ("E-Lernen") is used has slightly increased;

(iii) the number of publications in which the term "electronic learning" ("Elektronisches Lernen") is used has not decreased significantly.

So, we can conclude that for 10 years there has been no significant surge of scientific articles on the topic of e-learning in Germany indexed in Google Scholar, if compared, for example, with the USA [11].

The search on the Web of Science platform for article titles using keywords in the German language ("E-Lernen", "Elektronisches Lernen") has yielded no results. Therefore, the search has been conducted using keywords in the English language ("e-learning", "electronic learning") with clarification by years (2012-2022) and the country (Germany) [12, 13] (figure 4).

As a result, 263 items have been obtained for the search term "e-learning" for the specified period (2013-2022), and 3 articles for the search term "electronic learning". Therefore, it can be concluded that the term "e-learning" is widely used among German scientists. This conclusion has been also confirmed by the results of a search in the Scopus database (table 2), which was carried out according to the following search queries:

1) "E-Lernen" – `TITLE-ABS-KEY ( e-lernen ) AND ( LIMIT-TO ( PUBYEAR , 2019 ) );`
2) "Elektronisches Lernen" – `TITLE-ABS-KEY ( elektronisches AND lernen ) ;`

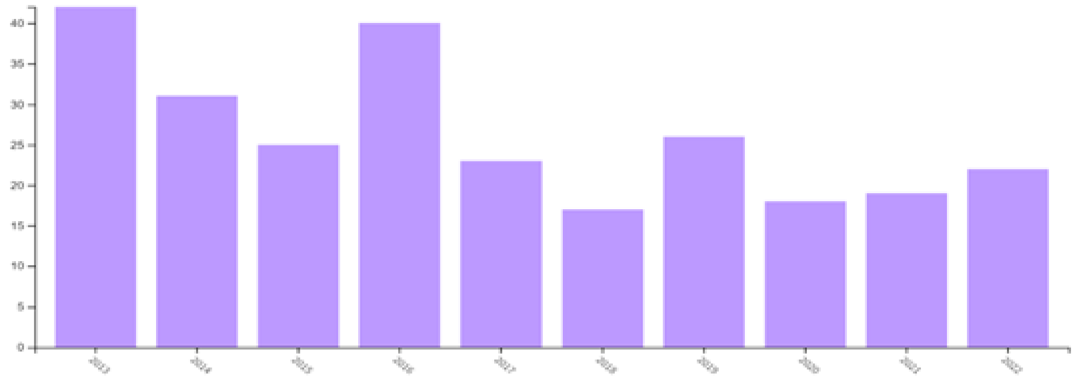


Figure 4. Search results for the term "e-learning" for the last 10 years in the WoS platform.

Table 2. Search results for the term "Digital transformation in education" for the last 10 years in the Scopus.

Year	"E-Lernen"	"Elektronisches Lernen"	"e-learning"	"electronic learning"
2013			490	
2014			542	
2015			445	
2016			394	
2017			342	2
2018			255	
2019	1		311	
2020			309	
2021		1	248	2
2022			212	
Total	1	1	3548	4

3) "e-learning" – `TITLE-ABS-KEY (e-learning) AND (LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2013)) AND (LIMIT-TO (AFFILCOUNTRY , "Germany")) ;`
4) "electronic learning" – `TITLE ("electronic learning") AND (LIMIT-TO (AFFILCOUNTRY , "Germany")) AND (LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2013)).`

From the analysis of the search results in the Scopus database, it can also be concluded that the interest of scientists in the problems of e-learning has decreased from 2013 to 2019, that is, before the start of the coronavirus pandemic. Next, we can observe the small increase in interest in 2019-2020 and a fading again in 2021-2022.

The next step in our research was a content analysis of the scientific articles found through search queries. It has been aimed at finding out what e-learning tools are used in higher education institutions in Germany and how teachers and students feel about e-learning. Therefore, for this purpose we have selected those articles in which these issues have been covered. In total, the number of analyzed articles has been 294. In this analysis, the following results regarding the use of e-learning tools in German universities have been obtained (table 3).

Table 3. E-learning tools in Germany.

E-learning tools	Web of Science	Scopus	Total reference number
Virtual reality		75	75
Massive Open Online Course (MOOC)		51	51
Mobile applications		33	33
Multimedia	2	27	29
Learning management system, e-learning-platform	1	28	29
Online course		18	18
Online laboratory, simulations		11	11
Automatic assessment management system, testing		8	8
Social media		6	6
Augmented reality		6	6
Cloud E-learning	1	5	5
Advising systems		3	3
Learning Analytics		3	3
Platform for video communications		3	3
Wiki systems		3	3
Conversational agents		2	2
3D-modeling		2	2
E-assessments		1	1
Hybrid campuses		1	1
Electronic Learning Diary	1		1
Podcasts		1	1
Educational chatbot		1	1
Learning glasses app		1	1
Total	5	289	294

As a result of the content analysis of scientific publications for the last 10 years, the following conclusions have been made:

(i) the vast majority of scientific works on the topic of e-learning relate to the study and implementation of virtual technologies, massive open online course (MOOC), mobile applications, multimedia technologies, learning management systems and platforms, online courses, online (virtual) laboratories and simulations;

(ii) among the analyzed scientific works, the vast majority of papers deal with medical education and the use of virtual technologies in it;

(iii) the vast majority of scientific publications are indexed in the Scopus database.

We have also paid attention to the research of German scientists regarding the positive and negative results of the implementation of e-learning tools. However, we should immediately note that there are more positive results of research on the impact on the quality or improvement of the level of education than negative ones. In particular, Peine et al. [14] have conducted their research in order to compare extant traditional teaching methods with new instruction forms (such as e-learning and curriculum-guided self-study) in terms of learning effect and student satisfaction. The study shows that students in modern study curricula learn better through modern self-instructed methods than through conventional methods. These methods should be used more intensively, as they also show good levels of student acceptance and higher scores in personal self-assessment of knowledge.

Skulmowski and Rey [15] describe the positive experience of implementing the strategy of hybrid campuses. They highlight the need for multimodal learning, that is, learning settings that use multiple sensory modalities. This approach describes how the social distancing measures currently in effect can be used to re-think higher education based on a reasonable use of technology. This research shows, that students in modern study curricula learn better through modern self-instructed methods than through conventional methods. So, researchers state that these methods should be used more, as they also show good levels of student acceptance and higher scores in personal self-assessment of knowledge.

In the research [16] the results indicate that learning approach goals of faculty are positively associated with perceiving the shift to online teaching as a positive challenge and as useful for their own competence development.

Considering the benefits of ILIAS in e-learning van Bonn et al. [17] make the following conclusions:

- e-learning cannot completely replace the conventional training in medicine, but it offers a good alternative in case of restrictions due to diseases or pandemics;
- e-learning is highly valued by students as an additional offer for practice;
- the results indicate a high degree of acceptance of e-learning among students, as well as its use regardless of place and time;
- e-learning is not a competitor, but a complement to face-to-face learning.

The last conclusion of the previous study has been confirmed in the article [18] which, based on the results of the survey, shows that medical students demonstrate broad acceptance of the online course during COVID-19 pandemic and indicates that digital learning options can partially replace conventional face-to-face teaching. For the content taught by lecture, online teaching might be an alternative or a complement to traditional education.

Händel et al. [19] has investigated how higher education students were ready for emergency remote teaching due to the COVID-19 pandemic and how this influenced their socio-emotional perceptions. Results indicate that higher education students seem to be ready for digital learning. A k-means cluster analysis revealed two groups of students that significantly differed with respect to their readiness for digital learning (in terms of technology equipment availability, prior experiences with e-learning, and skills for digital learning). Students' socio-emotional perceptions, that is, stress-related emotions (worries, tension, joy, and overload) as well as social and emotional loneliness significantly differed due to cluster membership. Hence, the study points the need for support of higher education students in successfully coping with the challenges of emergency remote studying.

So, in general, German scientists indicate a positive attitude towards the implementation of various e-learning tools, while noting that their implementation should not be an end in itself. It should be appropriate and justified, as well as be based on the experience of using information and communication technologies by teachers and students.

3.2. Research on the use of e-learning tools

In addition to the theoretical analysis of the experience of using e-learning tools in higher education in Germany, the aim of the research is to conduct a survey of students and teachers regarding the use of e-learning tools and their attitude to e-learning. The survey has been conducted at the University of Konstanz. It has been anonymous and consisted of two parts. In the first part, questions about the use of distance learning systems and e-learning tools have been asked in order to find out which e-learning tools were used by teachers and students in the educational process. In the second part, with the help of questions, we have been aimed to study how teachers and students perceive e-learning.

For the survey, a university mailing has been made with an offer to take the survey. 26 students and 8 teachers of the University of Konstanz have taken part in the survey. In total, 10 966 students studied at the university during the winter semester when the survey was conducted [20]. By 2022, 219 professors and 7 teachers and assistants had worked at the university [21]. The results of the survey are given below.

Almost all teachers (90.9%) and students (96.2%) have admitted that their educational institution (University of Konstanz) has opportunities for introducing e-learning (figure 5).

RQ1. Is there an opportunity to provide e-learning at your educational institution? *(for teachers)*

RQ1. Does your institution have the opportunity to provide e-learning? *(for students)*

a b

Figure 5. Teacher (a) and student (b) opinions on accessibility of e-learning at their educational institution.

The majority of teachers (72.7%) have noted that they used e-learning tools in the educational process, and 18.2% partially used them. Instead, 48 percent of students have indicated that teachers partially used e-learning tools, and 44% of students indicated that teachers mostly used e-learning tools (figure 6).

Both the vast majority of teachers (90% respondents) and students (88.5% respondents) prefer blended learning to traditional or electronic learning (figure 7).

Based on the answers to the question RQ4 (figure 8), 81.8% of teachers and 61.5% of students used more than 50% of their time for e-learning. So, we can conclude that many teachers need a lot of time to work with electronic learning tools.

The vast majority of teachers (72.7%) and all students (100%) note that ILIAS is most often used as a distance learning platform (table 4).

ILIAS is the main educational platform of the University of Konstanz. Electronic educational documents from all departments and other institutions of the university are available here. The access to certain courses is free, and it is possible to have the access for members of the University of Konstanz after logging in. The hosting and support of ILIAS are provided

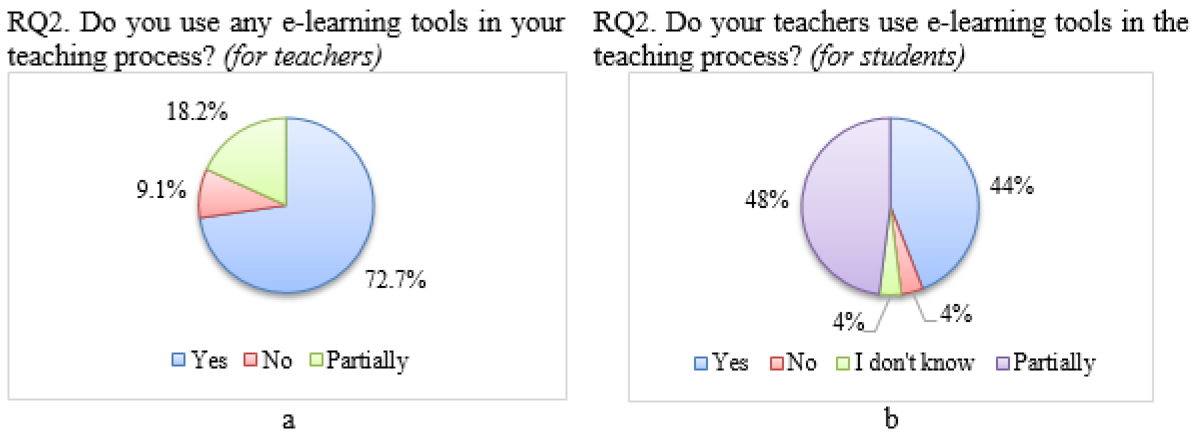


Figure 6. Application of e-learning tools by teachers in the teaching process: teacher (a) and student (b) opinions.

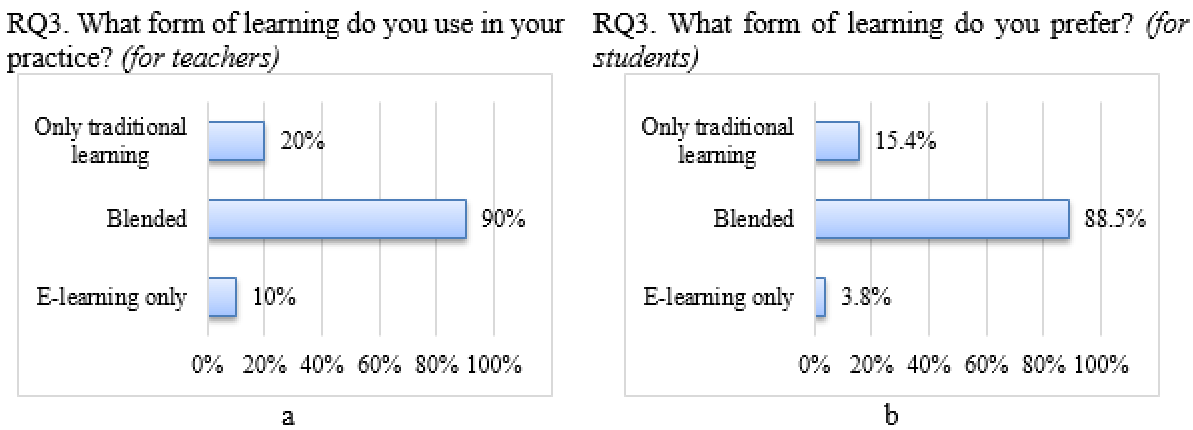


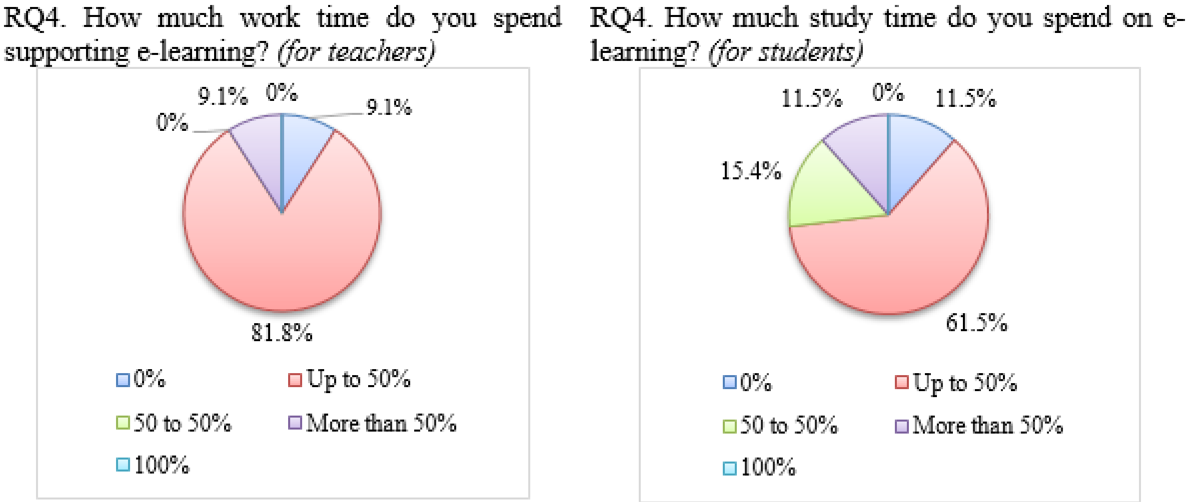
Figure 7. Information about the most used (a) / preferable (b) form of training.

Table 4. The most used e-learning platforms.

Questions	Answers
RQ5. Which e-learning platforms do you prefer? (for teachers)	ILIAS (72.7%), Moodle (9.1%), Mahara (9.1%), Twitch and Discord (9.1%), None (9.1%)
RQ5. Which e-learning platforms are used at your educational institution? (for students)	ILIAS (100%), Moodle (7.7%), D2L (3.8%), Articulate 360° (3.8%), Kahoot (3.8%), I do not know (3.8%)

by the Communication, Information, Media Centre. In addition, this centre offers a separate environment for ILIAS exams. This means that two different types of online written exams or a combination of both (home exam and online exam) are available.

In the ILIAS exercise module, students can take exams at home using the Download-Work-Upload model, where they download the exam task file, then they work offline and finally re-upload the answer sheet. This type of exam is particularly suitable if students have to write



a b

Figure 8. Time spent on e-learning by teachers (a) and students (b).

longer texts. Its advantage is that this type of exam places lower demands on students' technical equipment (such as the Internet connection), since they do not need to be online during the entire exam. The disadvantage is that autocorrection of single or multiple choice questions is not possible.

Online exams can be taken in the ILIAS test module, in which students must be online in ILIAS during the exam and enter their answers directly into ILIAS (e.g. single-choice, multiple-choice, assignment questions, open-ended questions). This type of test is particularly suitable for automatic testing. It is not suitable for longer texts (essays, numerous open-ended questions, etc.). It is not possible to comment on texts or upload corrections for further examination reviews with this type of exam. The disadvantage of this type of exam is that this form of the exam places high demands on the technical equipment of the students (for example, the Internet connection), since they must be online during the entire exam. The advantage is the possible automatic correction of questions with one or more answer options.

Answering the question "Which e-learning tools do teachers prefer?", 36% of respondents answered None, 27% of respondents have difficulties with the answer, 27% of respondents use Articulate 360, 9% of respondents use Mentimeter, Learningapps, Oncoo (figure 9).

The vast majority of teachers (83.3%) note that they use other e-learning tools in their professional activities. Almost the same percentage of students indicate that teachers do not use (46.2%) or use (42.3%) other e-learning tools (figure 10), except for those indicated above in table 4.

The results of the answers of teachers and students regarding which e-learning tools are used in the educational process in addition to the mentioned above are presented in table **??**. From their analysis, it becomes clear that teachers and students agree that they most often use electronic correspondence and teamwork services.

Figure 11 presents the results of the survey of teachers about what has helped them master e-learning tools. All the teachers (100%) claim that they independently have mastered e-learning tools, 82% have mastered e-learning tools with the advice of colleagues, 46% have mastered e-learning on special courses at the educational institution where they work, 19% have learned it during participation in conferences and seminars, 9% – during university studies, 9% – during courses and trainings of the pedagogical society.

The vast majority of interviewed teachers (72.7%) have a positive attitude towards e-learning,

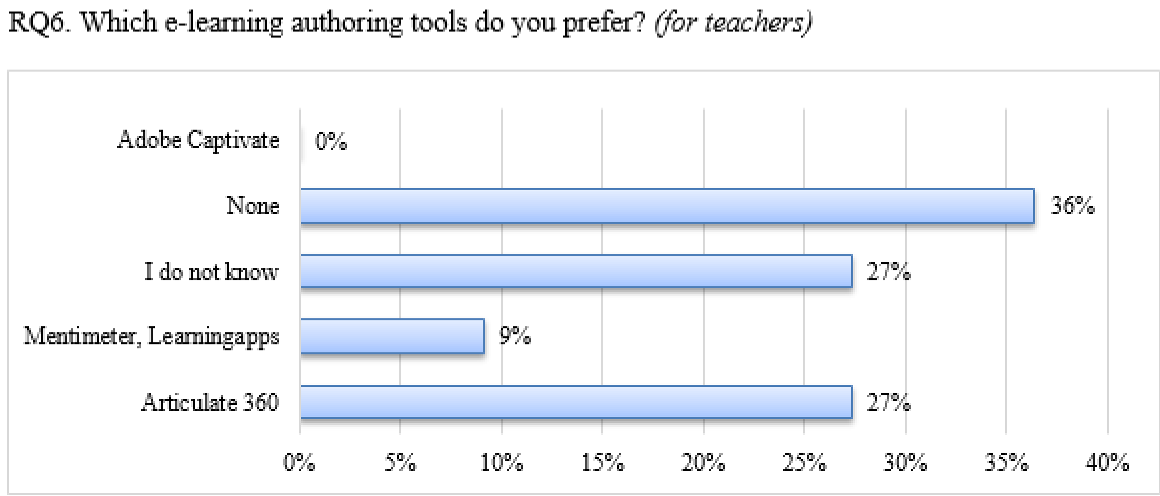


Figure 9. Additional e-learning tools which teachers prefer.

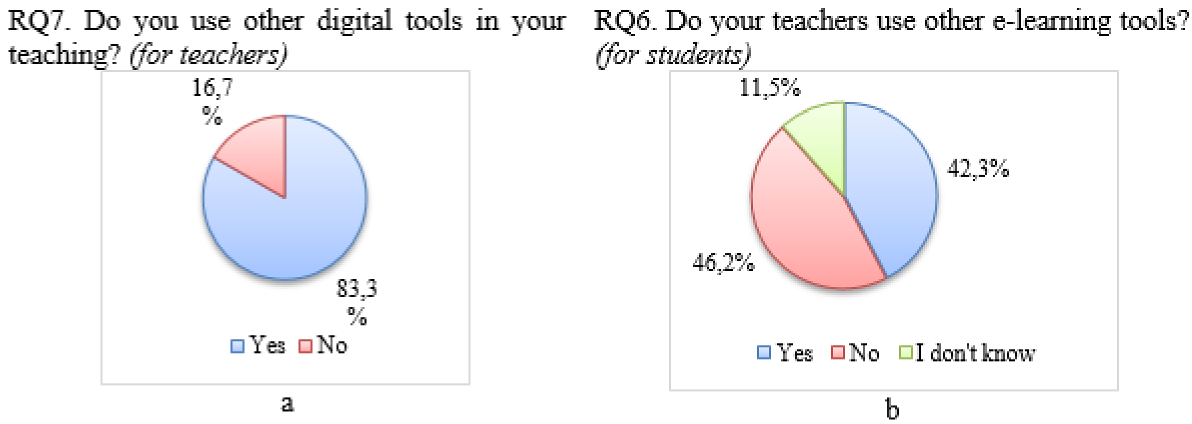


Figure 10. Details of other digital tools used by teachers (a) and students (b) in e-learning.

Table 5. The most used e-learning platforms.

Questions	Answers
RQ8. Which of the following do you use in e-learning? (for teachers)	Email (72.7%), Teamwork services (online boards, online documents) (54.5%), Video Hosting (YouTube) (45.5%), Learning websites (36.4%), Virtual reality (9.1%), Social networks (Facebook, Instagram, TikTok) (9.1%), Messengers (WhatsApp, Skype) (9.1%), Forum (9.1%), ILIAS Forum (9.1%), VEO (9.1%)
RQ7. Which of the following do your teachers most often use in e-learning? (for students)	Email (64%), Teamwork services (online boards, online documents) (44%), Video Hosting (YouTube) (40%), Learning websites (32%), Microblogging (Twitter, Tumblr, Tencent Weibo) (4%), Messengers (WhatsApp, Skype) (4%), Discord (4%), I do not know (4%), None (4%)

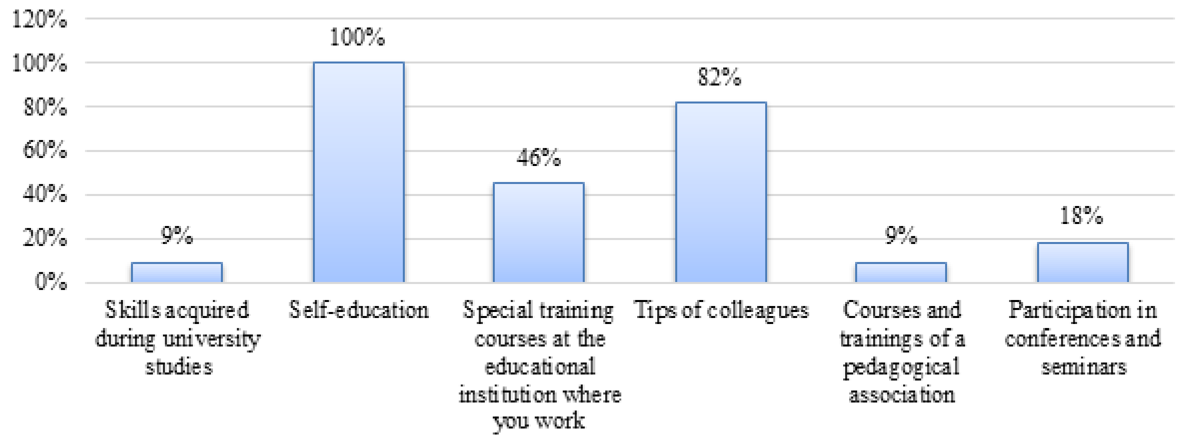


Figure 11. Ways of mastering e-learning tools by teachers Both teachers and students were asked a clear question about their attitude to e-learning.

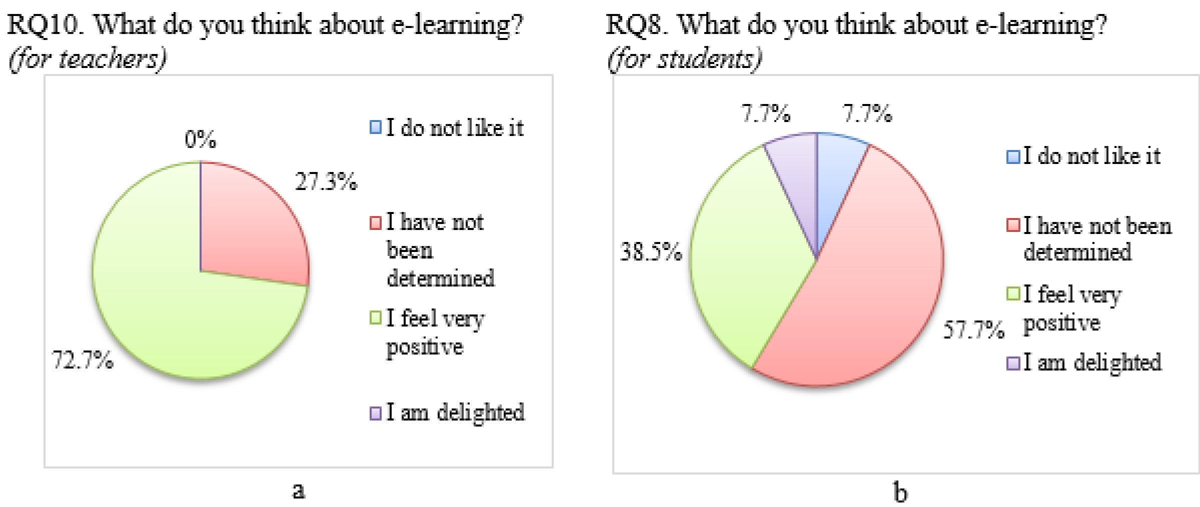


Figure 12. Teacher (a) and student (b) opinions on e-learning.

and a significant percentage of them (27.3%) have not yet decided on their attitude regarding e-learning. Among the surveyed students, slightly more than half (57.7%) have been undecided about their attitude to e-learning, while 38.5% of students have a very positive attitude towards it. Therefore, e-learning is not as successful for students as for teachers (figure 12).

Thus, with the help of the survey and the study of electronic resources at the University of Konstanz, we have studied the practical aspects of the use of various electronic learning tools used by teachers and offered to students during their studies. Based on the analysis of the scientific papers of German scientists, we understand the importance of the attitude and motivation of the subjects of the educational process (teachers and students) to e-learning for the implementation of a successful educational process. Therefore, with the help of the survey we have also analyzed how teachers and students of the German higher education institution perceive e-learning. In general, it is possible to state the positive attitude on the part of teachers and uncertainty on the part of students.

4. Conclusions

As the result of the analysis of scientific publications on the subject of e-learning in higher education in Germany for the last 10 years, it has been concluded that the relevance of the problem of the introduction of e-learning tools decreased from 2013 to 2019, but we observe the small increase in interest in 2019-2020 and fading again in 2021-2022. The content analysis of the scientific articles found by the search queries has been aimed at finding out which e-learning tools are used at higher institutions in Germany. Virtual technologies, massive open online courses (MOOCs), mobile applications, multimedia technologies, learning management systems and platforms, online courses, online (virtual) laboratories and simulations have turned out to be the most used e-learning tools. It has been also concluded that German scientists indicate the positive attitude towards the implementation of various e-learning tools, while noting that their implementation should be appropriate and justified, as well as based on the experience of using information and communication technologies by teachers and students, take into account students' motivation and access to information technologies.

In addition to the theoretical and content analysis of the experience of using e-learning tools in higher education in Germany, the survey of students and teachers of the University of Konstanz has been conducted regarding the use of e-learning tools in the educational process and their attitude to e-learning. Despite the fact that the results of the analysis of the scientific works of German scientists show a drop in interest in the problems of e-learning in Germany and a slight rise during the coronavirus pandemic, the results of the survey indicate an unequivocal interest in the means of e-learning of teachers and the uncertainty of students on this issue. Also, the analysis of resources and the information and technical support system of the University of Konstanz testifies the availability of modern technical equipment, information services and structures to support e-learning at the university.

The conducted research has some limitations: 1) as a result of the search in scientific databases by the selected keywords, some important scientific studies might have been missed; 2) the survey conducted at the University of Konstanz was voluntary and did not cover a sufficient number of respondents, being limited to teachers and students of one university. Therefore, in further studies, it is advisable to expand the geography of research.

Acknowledgments

Funded by the Federal Ministry of Education and Research (BMBF) and the Baden-Württemberg Ministry of Science as part of the Excellence Strategy of the German Federal and State Governments.

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References

[1] Edelson P J and Pittman V V 2001 *Indian Journal of Open Learning* **10**(2) 123–134 URL `https://www.learntechlib.org/p/93608/`

[2] Osadcha K P, Osadchyi V V and Spirin O M 2021 *Information Technologies and Learning Tools* **85**(5) 208–227 URL `https://doi.org/10.33407/itlt.v85i5.4399`

[3] Matviichuk L, Ferilli S and Hnedko N 2022 *Future Internet* **14**(10) 295 URL `https://doi.org/10.3390/fi14100295`

[4] Falfushynska H I, Buyak B B, Tereshchuk H V, Torbin G M and Kasianchuk M M 2021 *CTE Workshop Proceedings* **8** 261–273 URL `https://doi.org/10.55056/cte.237`

[5] Voloshinov S, Kruglyk V, Osadchyi V, Osadcha K and Symonenko S 2020 *Ukrainian Journal of Educational Studies and Information Technology* **8** 1–16 URL https://doi.org/10.32919/uesit.2020.01.01
[6] Vlasenko K, Chumak O, Achkan V, Lovianova I and Kondratyeva O 2020 *Universal Journal of Educational Research* **8**(8) 3527–3535 ISSN 23323205 URL https://doi.org/10.13189/ujer.2020.080828
[7] Bilousova L, Gryzun L and Zhytienova N 2021 *Educational Technology Quarterly* **2021**(3) 415–428 URL https://doi.org/10.55056/etq.34
[8] Osadcha K, Osadchyi V, Kruglyk V and Spirin O 2021 *Educational Dimension* **5** 109–125 URL https://doi.org/10.31812/educdim.4721
[9] Mintii I S 2023 *Educational Dimension* URL https://doi.org/10.31812/ed.539
[10] 2022 Interest in online education grows in the EU URL https://ec.europa.eu/eurostat/web/products-eurostat-news/-/edn-20220124-1
[11] Chernev B 2023 29 Astonishing E-learning Statistics for 2023 URL https://techjury.net/blog/elearning-statistics/#gref
[12] 2023 Results from Web of Science Core Collection for: e-learning URL https://www.webofscience.com/wos/woscc/summary/84975c64-a732-4706-936d-051d692fb822-602744e2/relevance/1
[13] 2023 Results from Web of Science Core Collection for: "electronic learning" URL https://www.webofscience.com/wos/woscc/summary/e269bef7-46da-4fc8-bb1c-832247910866-602bdfcc/relevance/1
[14] Peine A, Kabino K and Spreckelsen C 2016 *BMC Medical Education* **16** 158 URL https://doi.org/10.1186/s12909-016-0679-0
[15] Skulmowski A and Rey G D 2020 *Human Behavior and Emerging Technologies* **2**(3) 212–216 URL https://doi.org/10.1002/hbe2.201
[16] Daumiller M, Rinas R, Hein J, Janke S, Dickhäuser O and Dresel M 2021 *Computers in Human Behavior* **118** 106677 ISSN 0747-5632 URL https://doi.org/10.1016/j.chb.2020.106677
[17] van Bonn S M, Grajek J S, Großmann W, Bernd H E, Rettschlag S, Mlynski R and Weiss N M 2021 *HNO* **69**(8) 642–649 ISSN 1433-0458 URL https://doi.org/10.1007/s00106-021-01008-1
[18] Olmes G L, Zimmermann J S M, Stotz L, Takacs F Z, Hamza A, Radosa M P, Findeklee S, Solomayer E F and Radosa J C 2021 *Archives of Gynecology and Obstetrics* **304**(4) 957–963 URL https://doi.org/10.1007%2Fs00404-021-06131-6
[19] Händel M, Stephan M, Gläser-Zikuda M, Kopp B, Bedenlier S and Ziegler A 2022 *Journal of Research on Technology in Education* **54**(2) 267–280 URL https://doi.org/10.1080/15391523.2020.1846147
[20] Universität Konstanz 2023 The University of Konstanz in numbers URL https://www.uni-konstanz.de/en/division-of-finance-and-controlling/controlling/facts-and-figures
[21] Universität Konstanz 2023 Staff URL https://www.uni-konstanz.de/en/division-of-finance-and-controlling/controlling/facts-and-figures/staff

Journal of Physics: Conference Series

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Selection of pedagogical conditions for training STEM teachers to use augmented reality technologies in their work

Selection of pedagogical conditions for training STEM teachers to use augmented reality technologies in their work

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Abstract. The focus of the study is on choosing the pedagogical conditions that will best prepare STEM teachers to utilize augmented reality tools in their classrooms. 20 conditions were initially proposed during a brainstorming session and were then sorted into five groups: (1) conditions relating to the material support of the educational process, (2) methods and forms of training, (3) best practices for utilizing augmented reality in education, (4) unique circumstances made in order to achieve the goal of training STEM teachers; and (5) conditions relating to the psychological and pedagogical support of students. A survey was conducted with 94 participants to determine the importance of these conditions. The processing of the survey data allowed for the selection of the following conditions: (a) accessibility of immersive digital educational resources for STEM teachers and mobile hardware for augmented reality (laptops, tablets, smartphones, augmented reality glasses, etc.), (b) inclusion of augmented reality-related topics in STEM teachers' curricula, (c) use of research methodologies and interactive technologies in the STEM classroom, (d) having hands-on experience with the use of augmented reality technologies in STEM instruction.

1. Introduction

The operational plan for the "Strategy for the Development of Higher Education in Ukraine for 2022-2032" [1] implementation in 2022-2024 to achieve strategic goal 3 "Ensuring quality educational and research activities, competitive higher education, which is accessible to different segments of the population" defines operational goal 5 "Taking into account scientific research and innovations when determining the educational programs' content and development", the implementation of which in 2022-2023 provides for the popularization of natural sciences and mathematics for students. To achieve strategic goal 3 and the corresponding operational objectives, a number of tasks are provided, including:

- providing special support to residents of the temporarily occupied territories;

- supporting modern basic educational laboratories and advanced research laboratories of higher education institutions with equipment for information technologies (digital infrastructure);
- promoting the use of innovative technologies and the latest teaching aids in the educational process, research infrastructures development: "innovation should be realized through the application of new and improved methods and practices (including digital technologies) for teaching, learning and assessment, which should be carried out in close connection with research" [1].

In [1] it is stated that "in general, the higher education system of Ukraine has demonstrated great adaptive potential during the forced transition to distance innovative learning technologies during the quarantine period. At the same time, the limited capabilities of the IT infrastructure of many higher education institutions and the unsatisfactory digital competence level of scientific, scientific-pedagogical and pedagogical workers [2] did not allow to ensure the educational process in distance learning at a sufficient level [3]. Distance innovative learning technologies have become especially important with the Russian Federation armed aggression in 2014 [4] and, in particular, the act of armed aggression against Ukraine on February 24, 2022 [5], which resulted in a large number of temporarily displaced persons, higher education institutions and an increase in number of temporarily occupied territories' residents that have a need in quality educational services [6].

In order to achieve strategic goal 5 "Attractiveness of higher education institutions for study and academic career", it is envisaged to introduce a state program of research and teaching staff continuous professional development, ensuring their digital competencies development [1]. Thus, in 2020, the European Commission approved the "Digital Education Action Plan for 2021-2027", which provides for the following priority areas [7]:

(i) Accelerating the development of effective digital educational ecosystems, which requires:
  - availability of infrastructure, connectivity and digital equipment;
  - effective planning and development of digital potential;
  - trained teachers with digital competencies;
  - high quality educational content, tools and secure platforms that meet privacy and ethical standards and are user-friendly.

(ii) Digital skills and competences development for digital transformation, in particular:
  - basic digital skills and competencies starting from preschool age;
  - digital literacy, including countering misinformation;
  - information education;
  - good data processing technologies, such as artificial intelligence knowledge and understanding;
  - advanced digital skills, more professionals trained in this field;
  - ensuring gender balance.

The scientific and mathematical education (STEM education) development concept [8] determines that in order to ensure its proper quality it is necessary to:

- raising the level of professional teachers' competence;
- updating the content of natural, mathematical and technological educational fields (in particular, teaching aids and electronic educational resources on artificial intelligence, computer modeling, 3D modeling, basics of video technologies, digital art);
- implementation of digital technologies into the educational process.

In detailing the priority areas of the "Digital Education Action Plan for 2021-2027", the European Commission pays special attention to digital education ecosystems based on artificial intelligence technologies, data processing, virtual reality, augmented reality, etc. for which high-speed Internet access is critical [9].

"There is evidence that existing forms of professional development for teachers do not always meet their needs. In particular, there is a need to move from acquiring skills in certain tools or technological competencies to finding ways to adapt technologies to specific subjects, goals and activities. The emergence of new technologies such as artificial intelligence, virtual or augmented reality and social robotics requires teachers to play a more active role in the design and implementation of these tools to ensure their effective, desirable and inclusive use" [10].

Thus, there is a socially defined need to develop the digital competence of STEM teachers [11–13] in the digital educational resources using artificial intelligence [14] and augmented reality technologies design and implementation [15–17].

2. Literature review

In Ukraine, the application of STEM technologies in education was considered in the research works of O. Y. Shagova (pedagogical conditions were determined and a model for the future officers of the Armed Forces of Ukraine readiness formation to use STEM technologies in professional activities was developed [18]), O. S. Kuzmenko (developed the concept of STEM education of a technical higher education institution to ensure the integration of physics and professionally oriented disciplines [19]), L. I. Melnychenko (developed pedagogical conditions for the formation of research skills of future primary school teachers by means of STEM technologies [20]), V. V. Pikalova (determined pedagogical conditions for the use of package GeoGebra as a tool for concept of STEM education implementation in the process of future mathematics teachers training [21]), V. V. Boychenko (the specifics of professional and pedagogical training of STEM teachers of high school in the USA are determined and the corresponding programs at the first (bachelor's) and second (master's) levels of higher education are characterized [22]). N. Valko's dissertation developed the concept of training future teachers of natural and mathematical disciplines for the use of STEM technologies (primarily robotic STEM projects) in professional activities [23]; the author's latest works are devoted to educational applications of artificial intelligence technologies [24].

Since 2000, there have been studies devoted to the electronic educational resources design with the help of virtual and augmented reality [25]: V. G. Li (developed a technology for synthesizing the virtual reality environment [26]), S. M. Danilov (built a virtual reality tools continuum system model as an environment for testing innovative technologies in architecture [27]), O. M. Makoveichuk (developed a technology for the construction and use of visual information structures of augmented reality by constructing and using mosaic stochastic markers [28]), N. M. Gnedko (developed a technology for the future teachers readiness formation to use virtual visualization tools in professional activities [29]).

Among the foreign studies on the use of virtual and augmented reality in STEM education and teacher training, we distinguish the thesis of Wen Huang (it is shown that the effect of novelty in the virtual reality use does not necessarily increase learning success: the key to improving learning achievements is the match between the content and teaching methods [30]), Carolyn F. Pollack (the expediency of using augmented reality for the formation of spatial concepts of students in teaching Earth sciences is shown [31]), K. K. Arcand (the joint usage expediency of programming tools, 3D modeling, 3D printing and virtual reality for the development of spatial concepts in teaching astrophysics and students' professional orientation to the STEM industry [32]), A. M. Villanueva (developed tools that enable teachers and developers to create digital educational resources with augmented reality for collaborative work and distance learning, in particular – for mastering robotics [33]), K. Doty (application of augmented reality simulators to prepare future teachers to work with students in physics lessons [34]).

At the same time, in the studies known to us, there is no holistic methodology for the digital competence of future STEM teachers formation and development in the digital educational resources with augmented reality design and application. Therefore, the task of the study is to select pedagogical conditions for training future STEM teachers to use augmented reality technologies in professional activities.

3. Methodology

Pedagogical conditions are significant circumstances in the educational process (material conditions, methods, forms and real situations, etc.) that have objectively been developed or subjectively created for achieving a specific purpose.

Pedagogical conditions for for training STEM teachers to use augmented reality technologies in their work are material conditions, methods, forms, real situations, etc., of the augmented reality technologies application, which were objectively developed during the training process or subjectively created to achieve the goal.

To identify the pedagogical conditions for training STEM teachers to use augmented reality technologies in their work, a brainstorming session was conducted, during which 20 conditions were proposed and divided into 5 groups:

- Conditions connected to material support of the educational process (the future STEM teachers training, using augmented reality technologies).
  1. Availability of equipped classrooms in higher education institutions (immersive labs, lecture halls with virtual and augmented reality).
  2. Availability of mobile (handheld, portable, partially energy-dependent) augmented reality devices: laptops, tablets, smartphones, augmented reality glasses etc.
  3. Availability of subject-specific (computer science, physics, mathematics, chemistry, biology, technology, etc.) digital educational resources with augmented reality, specially designed for future STEM teachers.
  4. Availability of interdisciplinary (transdisciplinary) digital educational resources with augmented reality, specially developed for future STEM teachers.
  5. Availability of digital educational resources with augmented reality for the future STEM teachers' psychological and pedagogical training.
- The training methods and forms of future STEM teachers to use augmented reality technologies.
  6. Application of interactive technologies in the training of future STEM teachers.
  7. The use of research and project methods in the training.
  8. Engaging students in adaptation, development, testing and implementation of digital educational resources with augmented reality.
  9. Organization of pedagogical practice using augmented reality technologies.
  10. Organization of independent work using augmented reality technologies.
  11. Organization of distance learning using augmented reality technologies.
  12. Application of learning management systems.
- Real situations regarding the best practices of using augmented reality technologies in training.
  13. Selection, adjustment, adaptation, etc. of digital educational resources with augmented reality for educational activities in STEM disciplines.
  14. Acquisition practical experience in the application of augmented reality technologies in teaching STEM disciplines.
- Specifically created to achieve the purpose of preparing future STEM disciplines teachers for using augmented reality technologies in professional activity.

15. Imposition to the content of the training of future STEM teachers, issues related to the use of augmented reality in teaching STEM disciplines.
16. Imposition to the content of the training of future STEM teachers of the special course on the development of digital educational resources with augmented reality.
17. Creation of a cloud-based educational and methodological complex for the digital educational resources development with the augmented reality for future STEM teachers.
18. Engaging students in the contests on the development of digital educational resources with augmented reality.

- Conditions related to participants in the educational process psychological and pedagogical support.

19. Positive motivation to use augmented reality technologies in teaching STEM disciplines.
20. Maintaining an educational website, blog, channel for STEM teachers on immersive learning technologies, holding "unconferences", seminars, pedagogical workshops, etc.

Taking into account the pedagogical conditions are the most significant circumstances of the educational process, a survey was organized in order to estimate the importance of the proposed conditions (Appendix A).

The questionnaire was developed in Google Forms, and the corresponding link (`https://forms.gle/zNWwY43eRF7pCJcC9`) was distributed through several Facebook and Google groups (in particular, cc_seminar). For answers, the questionnaire was opened for 10 days in the period from 07.22.2022 to 08.05.2022.

4. Results

94 participants replied to the questionnaire, among them there were 69.1% – university teachers, 20.2% – teachers, 16% – researchers and 3.2% – students (figure 1).

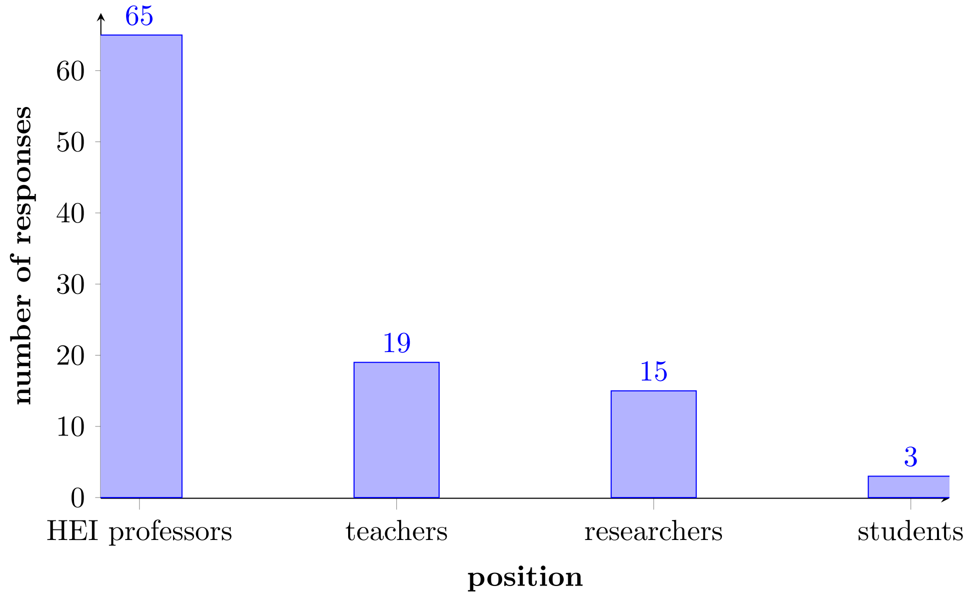

Figure 1. Distribution of answers by positions.

51.1% of respondents are teachers of STEM disciplines (figure 2) – this category of survey participants in the context of the survey topic has the highest level of significance $L_{STEM} = 1$;

for those survey participants who are not STEM disciplines teachers, we will set the level of significance in $L_{STEM} = 0.5$.

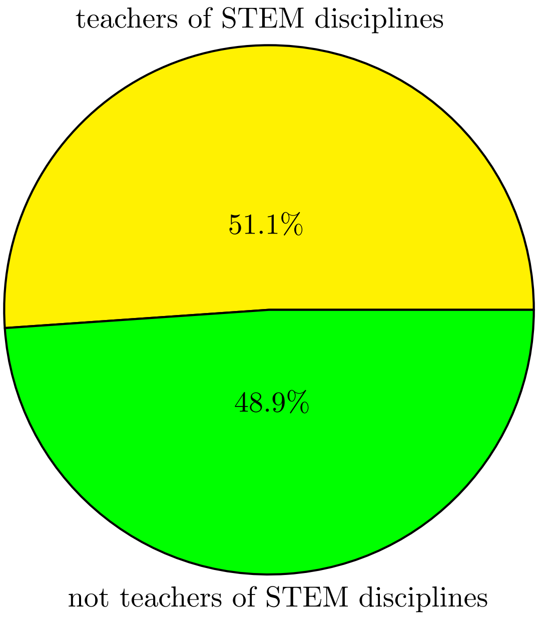

Figure 2. Distribution of answers to the question "Are you a teacher of STEM disciplines?".

In figure 3 shows the distribution of survey participants by the length of service: 10.6% of respondents have experience from 5 to 10 years, 12.8% of respondents have experience from 11 to 15 years, 20.2% of respondents have experience from 16 to 20 years, 31.9% of respondents have experience from 21 to 30 years, that is, more than (75.5%) of the respondents have work experience from 5 to 30 years, which corresponds to a high professional activity level.

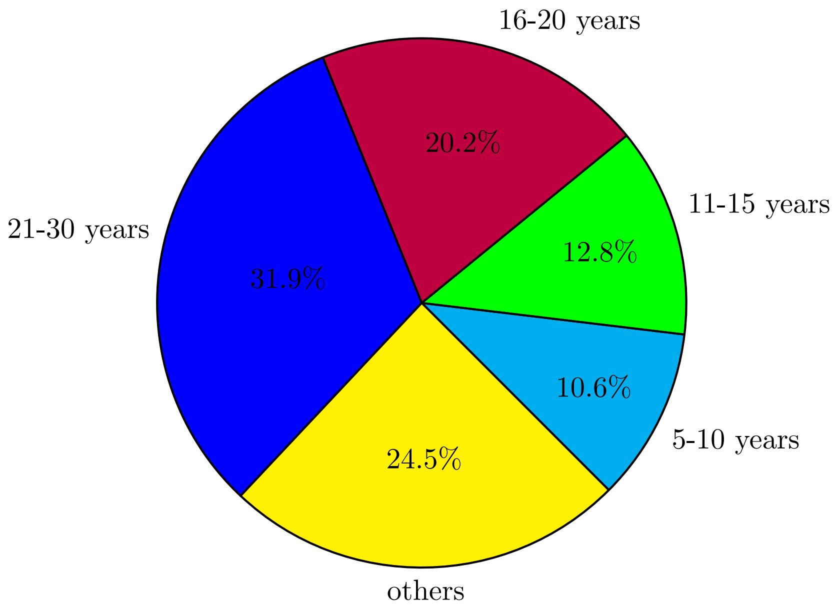

Figure 3. Distribution of answers to the question "Indicate your work experience?".

In the context of the survey, the second significant factor is the augmented reality application level in their professional activity (figure 4): 10.6% of the respondents can develop their means of augmented reality, therefore, the significance level of $L_{AR} = 1$ was set for their answers; 61.7% of respondents use ready-made tools of augmented reality, therefore, the significance level of $L_{AR} = 0.75$ was set for their answers; 27.7% of respondents do not use augmented reality tools in their professional activities but are familiar with them, therefore, the significance level of $L_{AR} = 0.5$ was set for their answers.

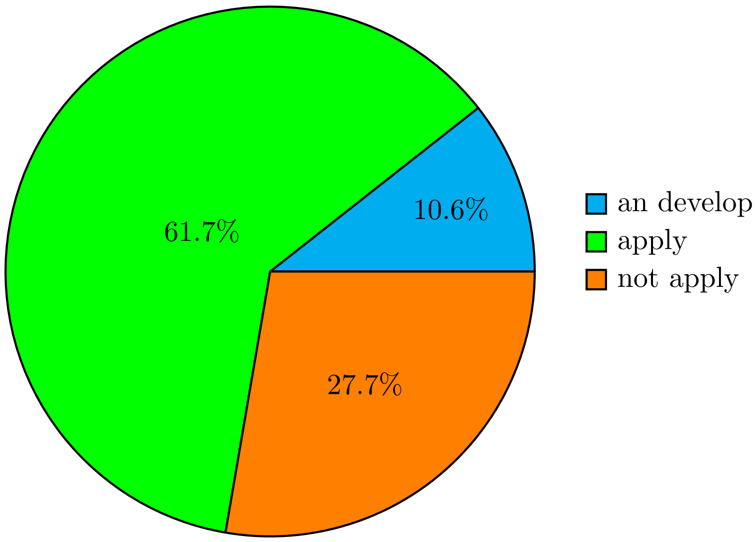

Figure 4. Distribution of survey participants by the level of use of augmented reality in their professional activities.

Proceeding from the questions "Are you a STEM disciplines teacher?" and "Can you rate your level of using augmented reality during your professional activity?" the weight (i) of this answer was established in such a way:

$$W^{(i)} = L^{(i)}_{STEM} \cdot L^{(i)}_{AR} \tag{1}$$

The significance of each of the 20 conditions was proposed to be assessed on a 5-point Likert-type scale: 1 – "very insignificant", 2 – "insignificant", 3 – "moderate", 4 – "significant", 5 – "very significant". Considering that the third level corresponded to an uncertain (neutral) answer, the first and second to insignificance, and the fourth and fifth to the significance of the condition, for the convenience of processing the evaluation results, the scale [1, 2, 3, 4, 5] was shifted to the left and transformed on the scale [-2, -1, 0, 1, 2]. Therefore, a negative score indicated the insignificance of the condition, a positive score indicated significance, and a zero score indicated uncertainty.

Let us consider the results of the conditions assessment, related to the educational process material support. Figure 5 shows significance assessment distribution for condition 1 (Availability of equipped classrooms in higher education institutions). 9.5% of the polled consider the availability of equipped classrooms in HEI to be insignificant, 6.4% have not decided on the answer, and 84.1%of the polled consider the availability of equipped classrooms in HEI significant.

Figure 6 shows distribution of significance assessment for condition 2 (Availability of mobile augmented reality devices) 5.3% of respondents consider the mobile tools for augmented reality availability to be insignificant, 4.3% have not decided on the answer, and 90.4% of respondents consider the mobile tools for augmented reality availability to be significant.

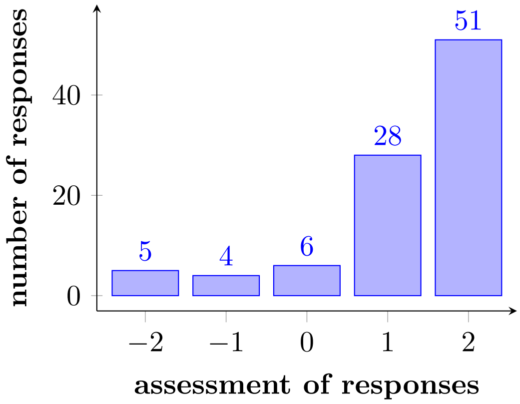

Figure 5. Distribution of significance assessment for condition 1 (Availability of equipped classrooms in higher education institutions).

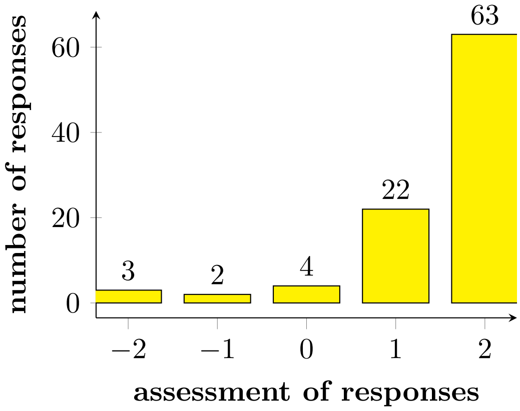

Figure 6. Distribution of significance assessment for condition 2 (Availability of mobile augmented reality devices).

Figure 7 shows the distribution of significance assessment for condition 3 (Availability of subject-specific digital educational resources with augmented reality, specially designed for future STEM teachers). 8.6% of respondents consider the availability of subject-specific digital educational resources with augmented reality specially developed for future STEM disciplines teachers to be insignificant, 7.4% have not decided on the answer, and 84.0% consider the availability of subject-specific digital educational resources with augmented reality specially developed for future STEM disciplines teachers to be significant.

Figure 8 shows the distribution of significance assessment for condition 4 (Availability of interdisciplinary (transdisciplinary) digital educational resources with augmented reality, specially developed for future STEM teachers). 7.5% of respondents consider the availability of cross-curricular digital educational resources with augmented reality specially designed for future STEM disciplines teachers to be insignificant, 5.3% have not decided on the answer, and 87.2% of respondents consider the availability of subject-specific digital educational resources with augmented reality specially designed for future STEM disciplines teachers of to be significant.

Figure 9 shows the distribution of significance assessment for condition 5 (Availability of digital educational resources with augmented reality for the future STEM teachers' psychological and pedagogical training). 14.9% of respondents consider the availability of digital educational resources with augmented reality for future STEM disciplines teachers psychological and pedagogical training to be insignificant, 12.8% have not decided on the answer, and 72.3% of respondents consider the availability of digital educational resources with augmented reality for future STEM disciplines teachers psychological and pedagogical training to be significant.

Figure 10 shows the distribution of significance assessment for condition 6 (Application of interactive technologies in the training of future STEM teachers). 5.3% of respondents consider the use of interactive technologies in the future STEM disciplines teachers training process to be insignificant, 10.6% have not decided on the answer, and 84.1% of respondents consider the use of interactive technologies in the future STEM disciplines teachers training process to be significant.

Figure 11 shows the distribution of significance assessment for condition 7 (The use of research and project methods in the training). 3.2% of respondents consider the application of research

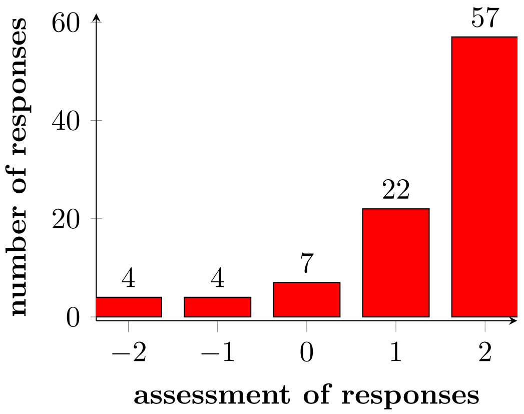

Figure 7. Distribution of significance assessment for condition 3 (Availability of subject-specific digital educational resources with augmented reality, specially designed for future STEM teachers).

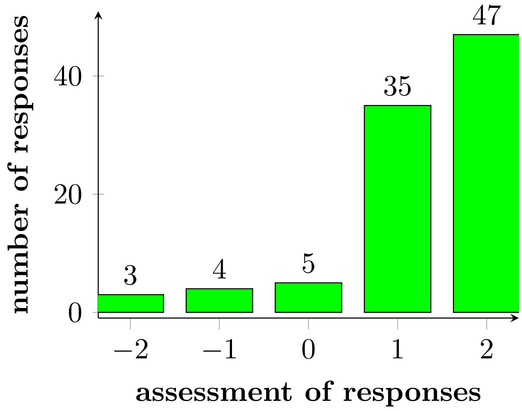

Figure 8. Distribution of significance assessment for condition 4 (Availability of interdisciplinary (transdisciplinary) digital educational resources with augmented reality, specially developed for future STEM teachers).

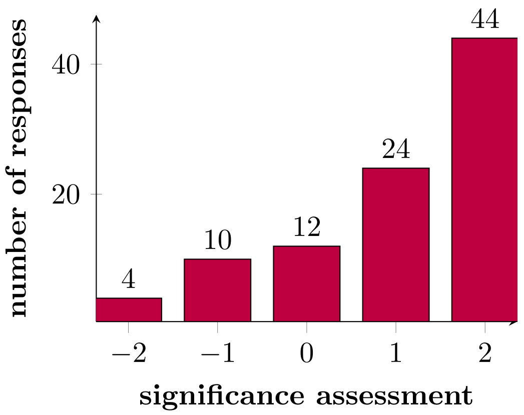

Figure 9. Distribution of significance assessment for condition 5 (Availability of digital educational resources with augmented reality for the future STEM teachers' psychological and pedagogical training).

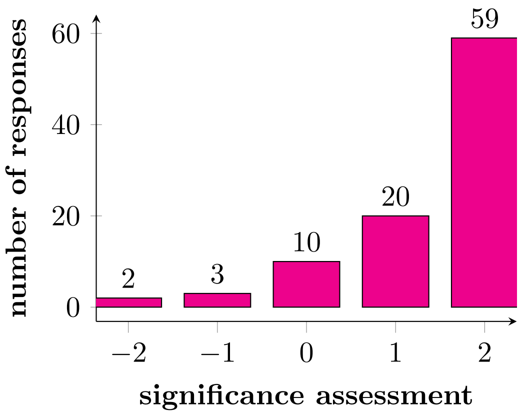

Figure 10. Distribution of significance assessment for condition 6 (Application of interactive technologies in the training of future STEM teachers).

and design methods in the training process to be insignificant, 9.6% have not decided on the answer, and 87.2% of respondents consider the research and design methods application in the training process to be significant.

Figure 12 shows the distribution of significance assessment for condition 8 (Engaging students in adaptation, development, testing and implementation of digital educational resources with augmented reality). 10.7% of respondents consider the digital educational resources with augmented reality involvement of students in the adaptation, development, testing and implementation to be insignificant, 8.5% have not decided on the answer, and 80.8% of respondents consider the involvement of students in the adaptation, development, testing and implementation of digital educational resources with augmented reality to be significant.

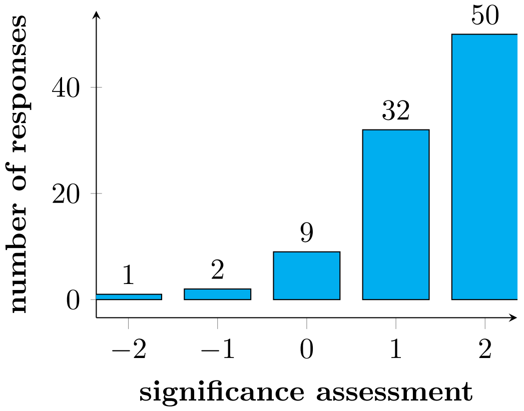

Figure 11. Distribution of significance assessment for condition 7 (The use of research and project methods in the training).

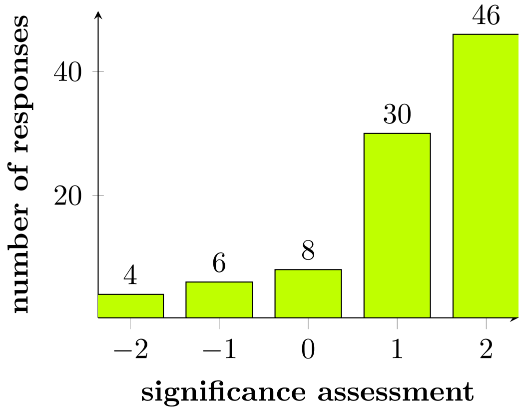

Figure 12. Distribution of significance assessment for condition 8 (Engaging students in adaptation, development, testing and implementation of digital educational resources with augmented reality).

Figure 13 shows the significance assessment for condition 9 distribution (Organization of pedagogical practice using augmented reality technologies). 9.6% of respondents consider the organization of pedagogical practice with the use of augmented reality technologies insignificant, 11.7% have not decided on the answer, and 78.7% of respondents consider the pedagogical practice with the use of augmented reality technologies organization significant.

Figure 14 shows the distribution of condition 10 significance assessment (Organization of independent work using augmented reality technologies). 8.6% of respondents consider the organization of independent work with the use of augmented reality technologies to be insignificant, 13.8% have not decided on the answer, and 77.7% of respondents consider the organization of independent work with the use of augmented reality technologies to be significant.

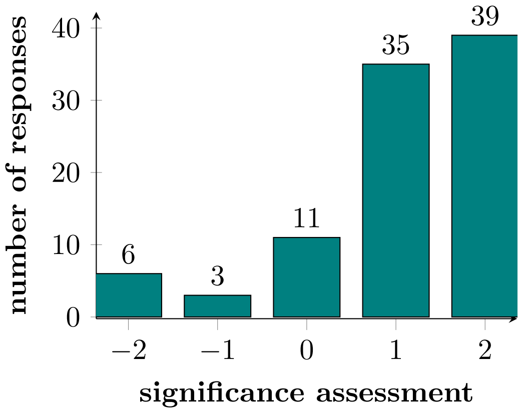

Figure 13. Distribution of significance assessment for condition 9 (Organization of pedagogical practice using augmented reality technologies).

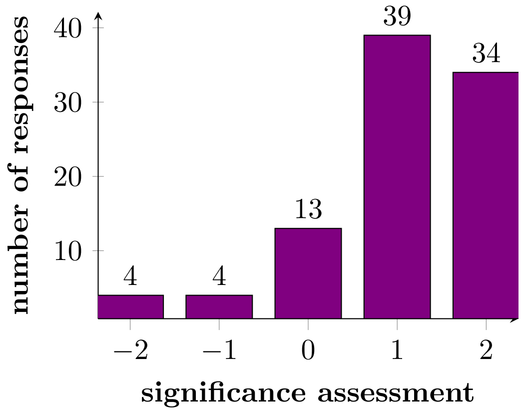

Figure 14. Distribution of significance assessment for condition 10 (Organization of independent work using augmented reality technologies).

Figure 15 shows the condition 11 significance assessment distribution (Organization of distance learning using augmented reality technologies). 10.6% of respondents consider the distance learning organization with the use of augmented reality technologies insignificant, 17% have not decided on the answer, and 72.3% of respondents consider the organization of distance learning with the use of augmented reality technologies significant.

Figure 16 shows the condition 12 significance assessment distribution (Application of learning management systems). 10.6% of respondents consider the use of learning support systems to be insignificant, 14.9% have not decided on the answer, and 74.4% of respondents consider the use of learning support systems to be significant.

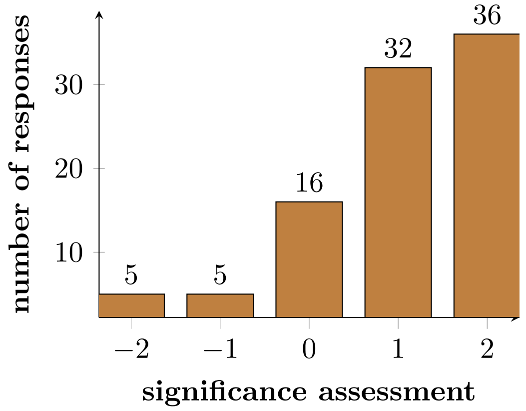

Figure 15. Distribution of significance assessment for condition 11 (Organization of distance learning using augmented reality technologies).

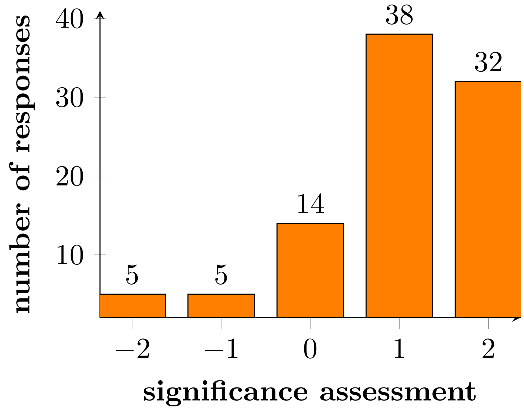

Figure 16. Distribution of significance assessment for condition 12 (Application of learning management systems).

Figure 17 shows the condition 13 significance assessment distribution (Selection, adjustment, adaptation, etc. of digital educational resources with augmented reality for educational activities in STEM disciplines). 6.4% of respondents believe that the selection, adaptation, etc. of digital resources with augmented reality for STEM disciplines is insignificant, 6.4% have not decided on the answer, and 87.3% of respondents believe that the selection, application, adaptation, etc. of digital resources with augmented reality for STEM is significant.

Figure 18 shows the condition 14 significance assessment distribution (Acquisition practical experience in the application of augmented reality technologies in teaching STEM disciplines). 7.4% of respondents believe that gaining practical experience in applying augmented reality technologies in teaching STEM disciplines is insignificant, 1.1% have not decided on the answer, and 91.5% of respondents believe that gaining practical experience in applying augmented reality technologies in teaching STEM disciplines is significant.

Figure 19 shows the distribution of significance assessment of condition 15 (Imposition to the content of the training of future STEM teachers, issues related to the use of augmented reality in teaching STEM disciplines). 5.3% of respondents consider the inclusion of issues related to the augmented reality in teaching STEM disciplines in the future STEM teachers training content to be insignificant, 9.6% have not decided on the answer, and 85.1% of respondents consider the introduction of issues related to the augmented reality in teaching STEM disciplines in the future STEM teachers training content to be significant.

Figure 20 shows the condition 16 significance assessment distribution (Imposition to the content of the training of future STEM teachers of the special course on the development

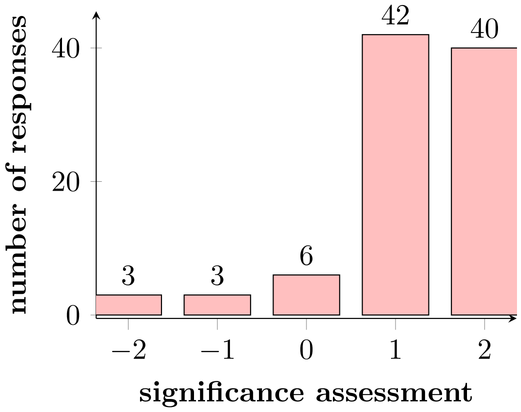

Figure 17. Distribution of significance assessment for condition 13 (Selection, adjustment, adaptation, etc. of digital educational resources with augmented reality for educational activities in STEM disciplines).

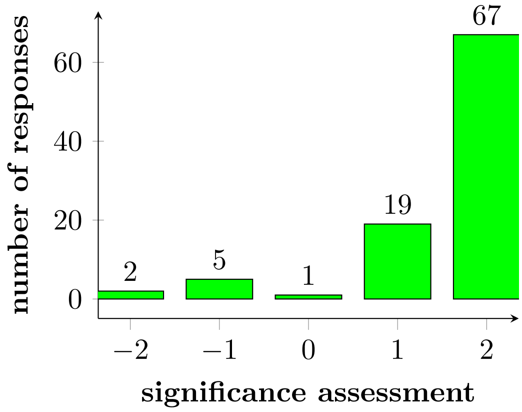

Figure 18. Distribution of significance assessment for condition 14 (Acquisition practical experience in the application of augmented reality technologies in teaching STEM disciplines).

of digital educational resources with augmented reality.). 5.3% of the respondents consider the introduction of a special course on the development of digital educational resources with augmented reality in the content of training of future STEM teachers to be insignificant, 9.6% have not decided on the answer, and 85.1% of respondents consider the inclusion of a special course on the development of digital educational resources with augmented reality in the content of training of future STEM teachers to be significant.

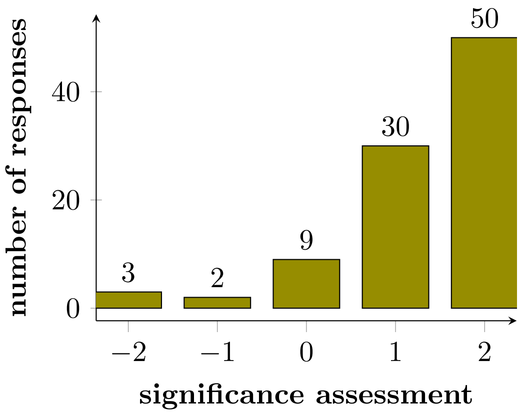

Figure 19. Distribution of significance assessment for condition 15 (Imposition to the content of the training of future STEM teachers, issues related to the use of augmented reality in teaching STEM disciplines).

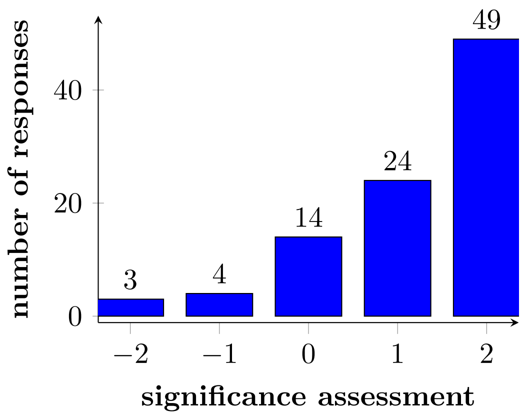

Figure 20. Distribution of significance assessment for condition 16 (Imposition to the content of the training of future STEM teachers of the special course on the development of digital educational resources with augmented reality).

Figure 21 shows the condition 17 significance assessment distribution (Creation of a cloud-based educational and methodological complex for the digital educational resources development with the augmented reality for future STEM teachers). 7.5% of the respondents consider the creation of a cloud-oriented educational and methodological complex for the development of digital educational resources with augmented reality for future STEM disciplines teachers insignificant, 13.8% have not decided on the answer, and 77.8% of respondents consider the creation of a cloud-oriented educational and methodological complex for the development of digital educational resources with augmented reality for future STEM disciplines teachers significant.

Figure 22 shows the condition 18 significance assessment distribution (Engaging students in the contests on the development of digital educational resources with augmented reality). 7.5% of respondents consider the involvement of students in competitions for the development of digital educational resources with augmented reality insignificant, 16% have not decided on the answer, and 76.6% of respondents consider the involvement of students in competitions for the development of digital educational resources with augmented reality significant.

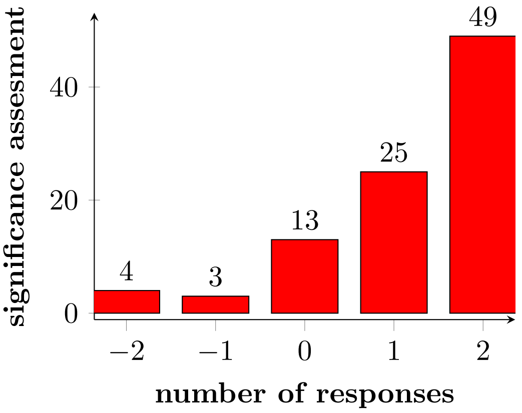

Figure 21. Distribution of significance assessment of condition 17 (Creation of a cloud-based educational and methodological complex for the digital educational resources development with the augmented reality for future STEM teachers).

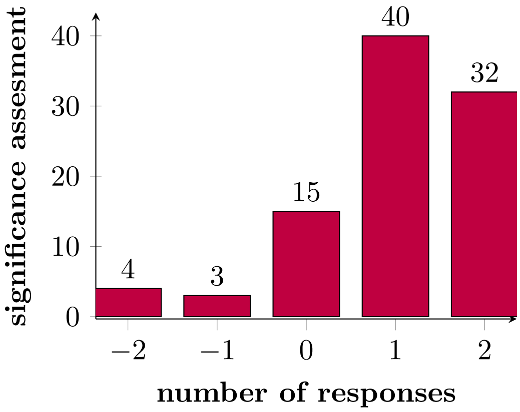

Figure 22. Distribution of significance assessment of condition 18 (Engaging students in the contests on the development of digital educational resources with augmented reality).

Figure 23 shows the condition 19 significance assessment distribution (Positive motivation to use augmented reality technologies in teaching STEM disciplines) 6.4% of respondents believe that the positive motivation to use augmented reality technologies in teaching STEM disciplines is insignificant, 10.6% have not decided on the answer, and 83.0% of respondents believe that positive motivation to use augmented reality technologies in teaching STEM disciplines is significant.

Figure 24 shows the condition 20 significance assessment distribution (Maintaining an educational website, blog, channel for STEM teachers on immersive learning technologies, holding "unconferences", seminars, pedagogical workshops, etc.) 10.6% of respondents consider maintaining an educational website, blog, channel for teachers of STEM disciplines on immersive learning technologies, holding "unconferences", seminars, pedagogical workshops, etc. to be insignificant, 21.3% have not decided on the answer, and 68.1% of respondents consider maintaining an educational website, blog, channel for teachers of STEM disciplines on immersive learning technologies, holding "unconferences", seminars, pedagogical workshops, etc. to be significant.

The following values were calculated for each condition in table 1:

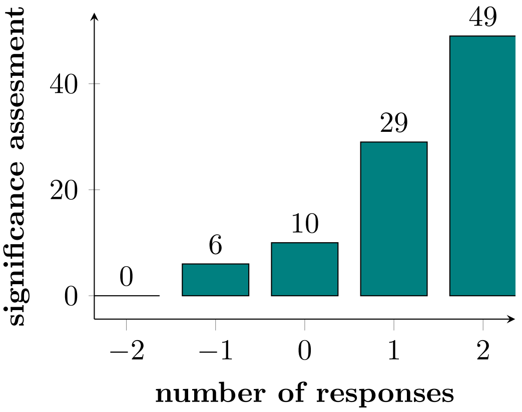

Figure 23. Distribution of significance assessment of condition 19 (Positive motivation to use augmented reality technologies in teaching STEM disciplines).

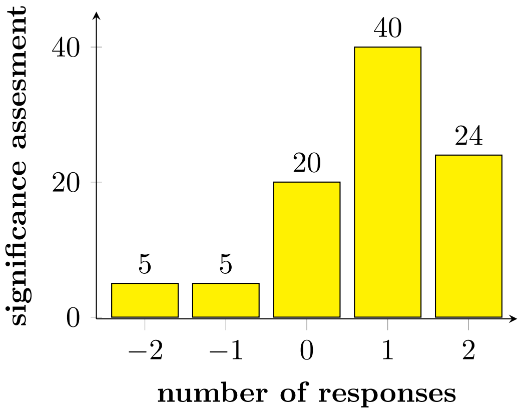

Figure 24. Distribution of significance assessment of condition 20 (Maintaining an educational website, blog, channel for STEM teachers on immersive learning technologies, holding "unconferences", seminars, pedagogical workshops, etc.)

- $AVG_k = \frac{1}{n}\sum_{i=1}^{n} S_k^i$ – average significance assessment of pedagogical condition without taking into account the weight of answers, where $k = \overline{1,20}$ – is the number of the evaluated pedagogical condition, $n = 94$ – number of respondents, $i = \overline{1,n}$ – number of the answer, S_k^i–is the significance assessment of the k-th condition by the i-th respondent;
- $WAVG_k = \frac{1}{n}\sum_{i=1}^{n} W^i S_k^i$ – average significance assessment of pedagogical condition with taking into account the weight of answers, where $k = \overline{1,20}$ is the number of the evaluated pedagogical condition, $n = 94$ – number of respondents, $i = \overline{1,n}$ – number of the answer, W^i – weight of the i-th answer (according to formula (1)), S_k^i – is the significance assessment of the k-th condition by the i-th respondent.

Table 1: Selection of pedagogical conditions.

Condition	AVG	WAVG	Experts pay more attention	Experts pay less attention	Selection by AVG	Selection by WAVG
Availability of equipped classrooms in higher education institutions (immersive labs, lecture halls with virtual and augmented reality)	1.234	1.198		*	0	0

Continued from Table 1

Condition	AVG	WAVG	Experts pay more attention	Experts pay less attention	Selection by AVG	Selection by WAVG
Availability of mobile (handheld, portable, partially energy-dependent) augmented reality devices: laptops, tablets, smartphones, augmented reality glasses etc.	1.489	1.498	+		**1**	**1**
Availability of subject-specific (computer science, physics, mathematics, chemistry, biology, technology, etc.) digital educational resources with augmented reality, specially designed for future STEM teachers	1.319	1.314		*	**1**	0
Availability of interdisciplinary (transdisciplinary) digital educational resources with augmented reality, specially developed for future STEM teachers	1.266	1.261		*	0	0
Availability of digital educational resources with augmented reality for the future STEM teachers' psychological and pedagogical training	1.000	0.998		*	0	0
Application of interactive technologies in the training of future STEM teachers	1.394	1.394	+		**1**	**1**
The use of research and project methods in the training	1.362	1.454	+		**1**	**1**
Engaging students in adaptation, development, testing and implementation of digital educational resources with augmented reality	1.149	1.179	+		0	0
Organization of pedagogical practice using augmented reality technologies	1.043	1.019		*	0	0
Organization of independent work using augmented reality technologies	1.011	1.012	+		0	0
Organization of distance learning using augmented reality technologies	0.947	0.940		*	0	0
Application of learning management systems	0.926	1.007	+		0	0
Selection, adjustment, adaptation, etc. of digital educational resources with augmented reality for educational activities in STEM disciplines	1.202	1.205	+		0	0
Acquisition practical experience in the application of augmented reality technologies in teaching STEM disciplines	1.532	1.551	+		**1**	**1**
Imposition to the content of the training of future STEM teachers, issues related to the use of augmented reality in teaching STEM disciplines	1.298	1.338	+		0	**1**

Continued from Table 1

Condition	AVG	WAVG	Experts pay more attention	Experts pay less attention	Selection by AVG	Selection by WAVG
Imposition to the content of the training of future STEM teachers of the special course on the development of digital educational resources with augmented reality	1.191	1.242	+		0	0
Creation of a cloud-based educational and methodological complex for the digital educational resources development with the augmented reality for future STEM teachers	1.191	1.200	+		0	0
Engaging students in the contests on the development of digital educational resources with augmented reality	0.989	1.048	+		0	0
Positive motivation to use augmented reality technologies in teaching STEM disciplines	1.287	1.309	+		0	0
Maintaining an educational website, blog, channel for STEM teachers on immersive learning technologies, holding "unconferences", seminars, pedagogical workshops, etc.	0.777	0.831	+		0	0
	1.180	1.200				
	1.298	1.320				

The weighted average value of $WAVG_k$, unlike AVG_k, reflects the opinion of the specialists to whom STEM discipline teachers who actively use augmented reality technologies in their professional activities are referred. Therefore, if the value of $WAVG_k > AVG_k$, for the k-th pedagogical condition, then the column "Specialists pay more attention" was entered as "+", otherwise the column "Specialists pay less attention" was entered as "*".

Further calculations were made $TAVG = \frac{1}{20}\sum_{k=1}^{20} AVG_k = 1.180$ – average value AVG for all conditions and $TWAVG = \frac{1}{20}\sum_{k=1}^{20} WAVG_k = 1.200$ – is the average $WAVG$ value for all conditions. The values obtained were the starting point for selecting pedagogical conditions by the conventional (AVG) and weighted ($WAVG$) mean significance values.

If take these values as thresholds (i.e. compare the each condition's significance level with them – if it is less than the threshold, the condition is discarded (0), otherwise the condition is accepted (1)), then there are 12 conditions selected for AVG (1, 2, 3, 4, 6, 7, 13, 14, 15, 16, 17, 19), and 11 for $WAVG$ (the same as for AVG, except 1). This number of conditions is excessive, so an empirically sampled multiplier (1.1) was introduced and applied to $TAVG$ and $TWAVG$, giving such limit values $1.1TAVG = 1.298$ and $1.1TWAVG = 1.320$ "Selection by AVG" and "Selection by WAVG" (1 – condition sampled, 0 – condition not sampled).

Conditions 2, 6, 7, and 14 are selected for AVG and $WAVG$ at the same time. Condition 15, selected only at $WAVG$, is of great significance for specialists, and condition 3, selected only at AVG, is of significance for the general public:

- 2, 3 – conditions related to the the educational process material support;
- 6, 7 – methods, forms of future STEM disciplines teachers training to apply augmented reality technologies;
- 14 – real situations concerning the best practices of augmented reality technology application in training;
- 15 – specifically created to achieve the goal of preparing future STEM disciplines teachers to apply augmented reality technologies in professional activities;
- conditions related to psychological and pedagogical support of educational process participants are not selected.

5. Conclusions

Thus, after combining, we obtain the following *pedagogical conditions for training STEM teachers to use augmented reality technologies in their work*:

(i) Availability of mobile augmented reality hardware (laptops, tablets, smartphones, augmented reality glasses, etc.) and immersive digital educational resources for future STEM disciplines teachers.

(ii) Supplementing the learning content with topics related to the use of augmented reality in teaching STEM disciplines.

(iii) Application of research approach and interactive technologies in training future STEM disciplines teachers.

(iv) Acquisition of augmented reality technology application practical experience in STEM disciplines training.

Acknowledgments

The work was carried out within the framework of the fundamental research "Theoretical and methodological bases of immersive cloud-oriented educational environment of the university design" (state registration number 0121U113711).

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Appendix A. Questionnaire "Conditions for training STEM teachers to use augmented reality technologies in their work"

Dear colleagues!

In order to select conditions for training STEM teachers to use augmented reality technologies in their work, we ask you to evaluate their importance on a 5–point scale (1 – "very insignificant", 2 – "insignificant", 3 – "moderate", 4 – "significant", 5 – "very significant") and provide your recommendations.

Availability of equipped classrooms in higher education institutions (immersive labs, lecture halls with virtual and augmented reality)

very insignificant ◯ 1 ◯ 2 ◯ 3 ◯ 4 ◯ 5 very significant

Availability of mobile (handheld, portable, partially energy-dependent) augmented reality devices: laptops, tablets, smartphones, augmented reality glasses etc.

very insignificant ◯ 1 ◯ 2 ◯ 3 ◯ 4 ◯ 5 very significant

Availability of subject-specific (computer science, physics, mathematics, chemistry, biology, technology, etc.) digital educational resources with augmented reality, specially designed for future STEM teachers.

very insignificant ◯ 1 ◯ 2 ◯ 3 ◯ 4 ◯ 5 very significant

Availability of interdisciplinary (transdisciplinary) digital educational resources with augmented reality, specially developed for future STEM teachers.

very insignificant ◯ 1 ◯ 2 ◯ 3 ◯ 4 ◯ 5 very significant

Availability of digital educational resources with augmented reality for the future STEM teachers' psychological and pedagogical training.

very insignificant ◯ 1 ◯ 2 ◯ 3 ◯ 4 ◯ 5 very significant

Application of interactive technologies in the training of future STEM teachers.

very insignificant ◯ 1 ◯ 2 ◯ 3 ◯ 4 ◯ 5 very significant

The use of research and project methods in the training.

very insignificant ◯ 1 ◯ 2 ◯ 3 ◯ 4 ◯ 5 very significant

Engaging students in adaptation, development, testing and implementation of digital educational resources with augmented reality.

	◯	◯	◯	◯	◯	
very insignificant	1	2	3	4	5	very significant

Organization of pedagogical practice using augmented reality technologies.

	◯	◯	◯	◯	◯	
very insignificant	1	2	3	4	5	very significant

Organization of independent work using augmented reality technologies.

	◯	◯	◯	◯	◯	
very insignificant	1	2	3	4	5	very significant

Organization of distance learning using augmented reality technologies.

	◯	◯	◯	◯	◯	
very insignificant	1	2	3	4	5	very significant

Application of learning management systems.

	◯	◯	◯	◯	◯	
very insignificant	1	2	3	4	5	very significant

Selection, adjustment, adaptation, etc. of digital educational resources with augmented reality for educational activities in STEM disciplines.

	◯	◯	◯	◯	◯	
very insignificant	1	2	3	4	5	very significant

Acquisition practical experience in the application of augmented reality technologies in teaching STEM disciplines.

	◯	◯	◯	◯	◯	
very insignificant	1	2	3	4	5	very significant

Imposition to the content of the training of future STEM teachers, issues related to the use of augmented reality in teaching STEM disciplines.

	◯	◯	◯	◯	◯	
very insignificant	1	2	3	4	5	very significant

Imposition to the content of the training of future STEM teachers of the special course on the development of digital educational resources with augmented reality.

	◯	◯	◯	◯	◯	
very insignificant	1	2	3	4	5	very significant

Creation of a cloud-based educational and methodological complex for the digital educational resources development with the augmented reality for future STEM teachers.

	◯	◯	◯	◯	◯	
very insignificant	1	2	3	4	5	very significant

Engaging students in the contests on the development of digital educational resources with augmented reality.

	◯	◯	◯	◯	◯	
very insignificant	1	2	3	4	5	very significant

Positive motivation to use augmented reality technologies in teaching STEM disciplines.

	◯	◯	◯	◯	◯	
very insignificant	1	2	3	4	5	very significant

Maintaining an educational website, blog, channel for STEM teachers on immersive learning technologies, holding "unconferences", seminars, pedagogical workshops, etc.

	◯	◯	◯	◯	◯	
very insignificant	1	2	3	4	5	very significant

What conditions for training STEM teachers to use augmented reality technologies in their work would you suggest?

[optional field for entering your own answer]

Your position

- student
- teacher
- research associate
- HEI Professors

Are you a STEM disciplines teacher?

- yes
- no

Specify your work experience

- up to 3 years
- up to 5 years
- 5-10 years
- 11-15 years
- 16-20 years
- 21-30 years
- 31-40 years
- 41-50 years
- more than 50 years

Evaluate augmented reality in your own professional activity level

- I don't apply
- I apply ready-made means of augmented reality
- I can elaborate my own means of augmented reality
- other – the possibility of entering your own answer

If you want to follow the development of this research, specify your e-mail address

[optional field for entering your own answer]

References

[1] Cabinet of Ministers of Ukraine 2022 Pro skhvalennia Stratehii rozvytku vyshchoi osvity v Ukraini na 2022—2032 roky [On approval of the Strategy of Higher Education Development in Ukraine for 2022-2032] URL https://zakon.rada.gov.ua/laws/show/286-2022-%D1%80#Text

[2] Morze N, Buinytska O, Varchenko-Trotsenko L, Vasylenko S, Nastas D, Tiutiunnyk A and Lytvynova S 2022 *Educational Technology Quarterly* **2022**(2) 152–168 URL https://doi.org/10.55056/etq.6

[3] Kukharenko V, Shunevych B and Kravtsov H 2022 *Educational Technology Quarterly* **2022**(1) 1–19 URL https://doi.org/10.55056/etq.4

[4] Verkhovna Rada of Ukraine 2015 Pro Zaiavu Verkhovnoi Rady Ukrainy "Pro vidsich zbroinii ahresii Rosiiskoi Federatsii ta podolannia yii naslidkiv" [On the Statement of the Verkhovna Rada of Ukraine "On repulsing the armed aggression of the Russian Federation and overcoming its consequences"] URL https://zakon.rada.gov.ua/laws/show/337-19#Text

[5] Verkhovna Rada of Ukraine 2022 Pro orhanizatsiiu roboty Verkhovnoi Rady Ukrainy u zviazku z aktom zbroinoi ahresii Rosiiskoi Federatsii proty Ukrainy 24 liutoho 2022 roku [On the organization of work of the Verkhovna Rada of Ukraine in connection with the act of armed aggression of the Russian Federation against Ukraine on February 24, 2022] URL https://zakon.rada.gov.ua/laws/show/2103-20#Text

[6] Semerikov S O, Vakaliuk T A, Mintii I S and Didkivska S O 2023 *Educational Technology Quarterly* URL https://doi.org/10.55056/etq.637

[7] European Commission 2020 Digital Education Action Plan (2021-2027) URL https://education.ec.europa.eu/focus-topics/digital-education/about/digital-education-action-plan

[8] Cabinet of Ministers of Ukraine 2020 Pro skhvalennia Kontseptsii rozvytku pryrodnycho-matematychnoi osvity (STEM-osvity) [On approval of the Concept for the development of science and mathematics education (STEM education)] URL https://zakon.rada.gov.ua/laws/show/960-2020-%D1%80#Text

[9] European Commission 2020 Digital education action plan 2021-2027 URL https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0624

[10] European Commission 2020 Digital education action plan 2021-2027 URL https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020SC0209&qid=1647943853396

[11] Hrynevych L, Morze N, Vember V and Boiko M 2021 *Educational Technology Quarterly* **2021**(1) 118–139 URL https://doi.org/10.55056/etq.24

[12] Martyniuk O O, Martyniuk O S, Pankevych S and Muzyka I 2021 *Educational Technology Quarterly* **2021**(3) 347–359 URL https://doi.org/10.55056/etq.39

[13] Shapovalov Y B, Bilyk Z I, Usenko S A, Shapovalov V B, Postova K H, Zhadan S O and Antonenko P D 2023 *Educational Technology Quarterly* **2023**(2) 210–232 URL https://doi.org/10.55056/etq.604

[14] Fadieieva L O 2023 *Educational Technology Quarterly* **2023**(3) 319–366 URL https://doi.org/10.55056/etq.613

[15] Kanivets O V, Kanivets I M and Gorda T M 2022 *Educational Technology Quarterly* **2022**(4) 347–365 URL https://doi.org/10.55056/etq.429

[16] Oleksiuk V P and Oleksiuk O R 2022 *Educational Technology Quarterly* **2022**(4) 307–327 URL https://doi.org/10.55056/etq.432

[17] Nechypurenko P P, Semerikov S O and Pokhliestova O Y 2023 *Educational Technology Quarterly* **2023**(1) 69–91 URL https://doi.org/10.55056/etq.44

[18] Shahova O Y 2020 *Formation of Readiness of the Future Officers of the Armed Forces of Ukraine for Using STEM-Technologies in Professional Activity* Thesis for obtaining a scientific degree of candidate of pedagogical sciences, speciality 13.00.04 "theory and methods of vocational training" Odesa Military Academy Odesa URL https://nrat.ukrintei.ua/searchdoc/0420U102110/

[19] Kuzmenko O S 2020 *Theoretical and methodical principles of teaching physics of students of technical institutions of higher education on the basis of STEM-education technologies* The thesis for the degree of doctor in pedagogical sciences, specialty 13.00.02 "theory and methods of teaching (physics)" Volodymyr Vynnychenko Central Ukrainian State Pedagogical University Kropyvnytskyi URL `https://nrat.ukrintei.ua/searchdoc/0520U100174/`

[20] Melnychenko L I 2022 *Formation of research skills of future primary school teachers by means of STEM-technologies* Ph.D. thesis Hryhorii Skovoroda University in Pereiaslav Pereiaslav URL `https://drive.google.com/file/d/1YTI6fvfXG--Y7S3F66ohLsCVwGSFx5hT/view?usp=sharing`

[21] Pikalova V V 2021 *Using GeoGebra as a tool for implementing the concept of STEM education in the process of pre-service mathematics teachers' training* The thesis for the degree of candidate of pedagogical science, in specialty 13.00.10 – information and communication technologies in education (01 – education/pedagogics) Kryvyi Rih State Pedagogical University URL `https://nrat.ukrintei.ua/searchdoc/0421U103003`

[22] Boichenko V V 2021 *Organizational and pedagogical foundations of STEM education in high school of the USA* Ph.D. thesis Sumy State Pedagogical University named after A. S. Makarenko Sumy URL `https://nrat.ukrintei.ua/searchdoc/0821U101809`

[23] Valko N V 2020 *The system of training future teachers of natural-mathematical disciplines for the application of STEM-technologies in professional activities* The dissertation for the degree of doctor of pedagogical sciences, specialty 13.00.04 – theory and methodology of professional education Kherson State University Kherson URL `https://nrat.ukrintei.ua/searchdoc/0520U101565/`

[24] Valko N V and Osadchyi V V 2022 *Journal of Physics: Conference Series* **2288** 012002 URL `https://doi.org/10.1088/1742-6596/2288/1/012002`

[25] Shevchenko A I, Ivanova S B, Gudaev O A, Zhebel L S, Piguz V N, Korotych N M, Nekrashevich S P, Boiko A V, Voronoi A S, Sidenko A V, Skliarenko I A and Fadeev F F 2010 Development of the intelligence system of monitoring school process of the distance education which uses coding of managing information by the markers of Augmented Reality Tech. Rep. 0211U000957 Institute of Artificial Intelligence Problems of the Ministry of Education and Science of Ukraine and the National Academy of Sciences of Ukraine Donetsk URL `https://nrat.ukrintei.ua/searchdoc/0211U000957`

[26] Lee V G 2000 *Geometrical Tools of Modelling of Virtual Reality Medium in Conformity With Simulators* The doctoral dissertation in the field of technical sciences on a specialty 05.01.01 – applied geometry, engineering graphics Kiev National University of Building and Architecture Kiev URL `https://nrat.ukrintei.ua/searchdoc/0500U000243`

[27] Danilov S M 2014 *The virtual reality as an environment for approbation of the innovation technologies in architecture* The dissertation on competition of a scientific degree of candidate of architecture in specialization 18.00.01 – theory of architecture, restoration of the architectural monuments Kharkov State Technical University of Civil Engineering and Architecture Kharkov URL `https://nrat.ukrintei.ua/searchdoc/0414U003479`

[28] Makoveichuk O M 2020 *Models, Methods and Information Technology of Designing and Use of Visual Information Structures of Augmented Reality* The thesis for the degree of doctor of engineering sciences in specialty 05.13.06 "information technologies" (05 – technical sciences) Kharkiv National University of Radio Electronics Kharkiv URL `https://nrat.ukrintei.ua/searchdoc/0521U100056`

[29] Gnedko N M 2015 *Forming of would-be teachers' preparedness for application of virtual aids in professional activity* Thesis for a scientific degree of a candidate of pedagogical sciences in the speciality 13.00.04 – theory and methodic of professional education Rivne State University of the Humanities Rivne URL `https://nrat.ukrintei.ua/searchdoc/0415U006712`

[30] Huang W 2020 *Investigating the Novelty Effect in Virtual Reality on STEM Learning by Wen Huang* Ph.D. thesis Arizona State University URL `http://repository.asu.edu/items/57391`

[31] Pollack C F 2019 *Investigating the Augmented Reality Sandbox: An Exploration of the Development and Implementation of a Reproducible STEM Resource in Secondary Education Geoscience* A Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science George Mason University Fairfax, Virginia URL `https://hdl.handle.net/1920/11682`

[32] Arcand K K 2020 *Putting the stars within reach: NASA 3D data-based models in 3D print and virtual reality applications, and their potential effects on improving spatial reasoning skills and STEM interest in underrepresented groups of young female learners* Ph.D. thesis University of Otago Dunedin, New Zealand URL `https://hdl.handle.net/10523/10250`

[33] Villanueva A M 2022 *New modalities and techniques of augmented reality in stem education* Ph.D. thesis Purdue University West Lafayette, Indiana URL `https://doi.org/10.25394/pgs.19653546.v1`

[34] Doty C 2021 *Optimizing mixed-reality simulation to support stem graduate teaching assistants in developing student-centered pedagogical skills* Ph.D. thesis University of Central Florida Orlando, Florida URL `https://stars.library.ucf.edu/etd2020/855`

Journal of Physics: Conference Series

Technologization of sudden cardiac death prevention based on the disciplinary-methodological matrix of health-preserving competence

Technologization of sudden cardiac death prevention based on the disciplinary-methodological matrix of health-preserving competence

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Abstract. The article presents the educational meta-technology of the disciplinary-methodological matrix of the health-preserving competence of the physical education teacher using the example of the prevention of sudden cardiac death during physical exertion. The disciplinary-methodical matrix is considered as a cognitive-value-educational and anthropoculturally oriented metatechnology developed by integrating various disciplines (and their systems) (mainly anthropologically and health-preserving oriented), systems of knowledge, discourses and narratives, ideas, values, meanings, methods and problematization and conceptualization strategies, etc. An actual aspect of this technology is the purposeful development of methodical disciplines in which attention is purposefully focused on a certain aspect of learning. The basis of the "Etiological method of prevention of sudden cardiac death" is the idea of an etiological (causal) approach actualized within the framework of the methodical discipline "Patopedagogy" formed on the basis of the transfer of knowledge from the medical science of pathology. As a result of an experimental study aimed at studying the dynamics of the formation of the cognitive and cognitive ability of physical education teachers for the prevention of sudden cardiac death, the positive dynamics of educational results is determined. This depends on the effectiveness of the application of the disciplinary-methodological matrix of health-preserving competence in physical education teacher. The necessary disciplinary and methodological matrices can be constructed for the formation of various competencies and goals and design of training.

1. Introduction

Through motor activity, which can be considered as a manifestation of the soul and spiritual essence of a person, human nature is revealed and its vitality is manifested. In turn, vitality, as well as motor activity itself, are connected with the heart. Vitality and motor activity are dependent on the functioning of the cardiovascular system, which is represented as the "cardiac basis" of life and movement. The specified "vital-cordocentric-motor" aspect of human nature is well-known and understandable for a physical education teacher. In the process of university training of a physical education teacher, this aspect is traditionally revealed from the positions of morphology and sports physiology, which are the basic disciplines in his training. At the same time, the humanitarian and medical, preventive dimensions of the phenomenon of the heart as a welcome and cultural phenomenon are not sufficiently revealed in the system of contents and meanings of the specified sciences, as well as the methods of physical culture and sports.

For example, it is typical for a physical education teacher to have an absolutely correct understanding that the heart is a hollow muscular organ that implements the pumping function that ensures the existence of a person [1]. At the same time, the specified physiologically oriented idea of the phenomenon of the heart is incomplete and insufficient for professional and anthropocultural understanding of human nature as a cardiac, motor, existential, spiritual being and one that can have systemic cardiological risks for its health and life. It is also important that the typical physiologically oriented understanding of the heart phenomenon indicated above does not fully reflect the medical and/or prophylactic understanding of the cardiovascular system as a special anthropobiological reality on which the biological existence of a person depends.

Currently, there is a pathological phenomenon that actualizes the problems of the heart in all its existential depth and vital and biological significance, multidimensionality, and systematicity. This is a well-known pathological phenomenon – *sudden cardiac death*, which can form and occur precisely in the process and as a result of motor activity or after it. Of course, there are other conditions and reasons for the formation of the indicated cardiac pathology.

From the point of view of education, it is significant that this problem is present in all countries of the world. Sudden cardiac death, as an acute cardiac pathology, is epidemiologically significant [2, 3]. Accordingly, the indicated problem is to some extent connected with physical culture [4, 5] and sports, including youth sports [6, 7].

In medical scientific literature, the problem of sudden cardiac death is presented quite widely. This problem in medicine is sufficiently analyzed, understood and revealed theoretically and, accordingly, developed in a practical and preventive direction (figure 1). In order to understand the significance of the problem and to implement the transfer of medical, hygienic and epidemiological knowledge into the health-preserving activities of the physical education teacher, we will consider the significant aspects of epidemiology, structure, causes (etiology) and pathogenesis of sudden cardiac death based on the data of scientific literature.

Gräsner et al. [2] points to the epidemiological significance of sudden cardiac death as a particularly life-threatening disease. The authors, analyzing data from the guidelines of the European Council on Resuscitation and using the European Register of Cardiac Arrest (EuReCa), notes that sudden cardiac death is the third leading cause of death in Europe and is between 67 and 170 per 100 000 inhabitants. The researchers emphasizes the need to take into account genetic factors and the organization of individual prevention as important directions for reducing mortality from the specified pathology.

Kelly et al. [3] presents epidemiological data that sudden cardiac death accounts for 15-20% of all deaths. The authors draws attention to the genetic factor as an important cause of this pathology.

Boden et al. [6] analyzes the epidemiology of nontraumatic deaths among high school and college football players from 1998 to 2018 in the United States. They indicates that the cause of death in 57.7% of cases was sudden cardiac death.

Peterson et al. [7] examines sudden cardiac death in US school and college athletes. They reports that the average age of the athletes is 16.7 (11-29) years; men dominate – 83.7%. According to their data, sudden cardiac death is in classes: basketball – 28.7%; American football – 25.4%.

Bagnall et al. [10] reveals the diagnostic and prophylactic significance of the rapid course of sudden cardiac death, its suddenness and unexpectedness, and often the absence of previous symptoms. Taking into account the specified features of the course of sudden cardiac death and, in many cases, its hereditary nature, it is necessary to apply it in prevention.

Teoh et al. [11] investigates the epidemiology of sudden cardiac death during the COVID-19 epidemic. They points out that the COVID-19 epidemic has significantly – by 35% increased

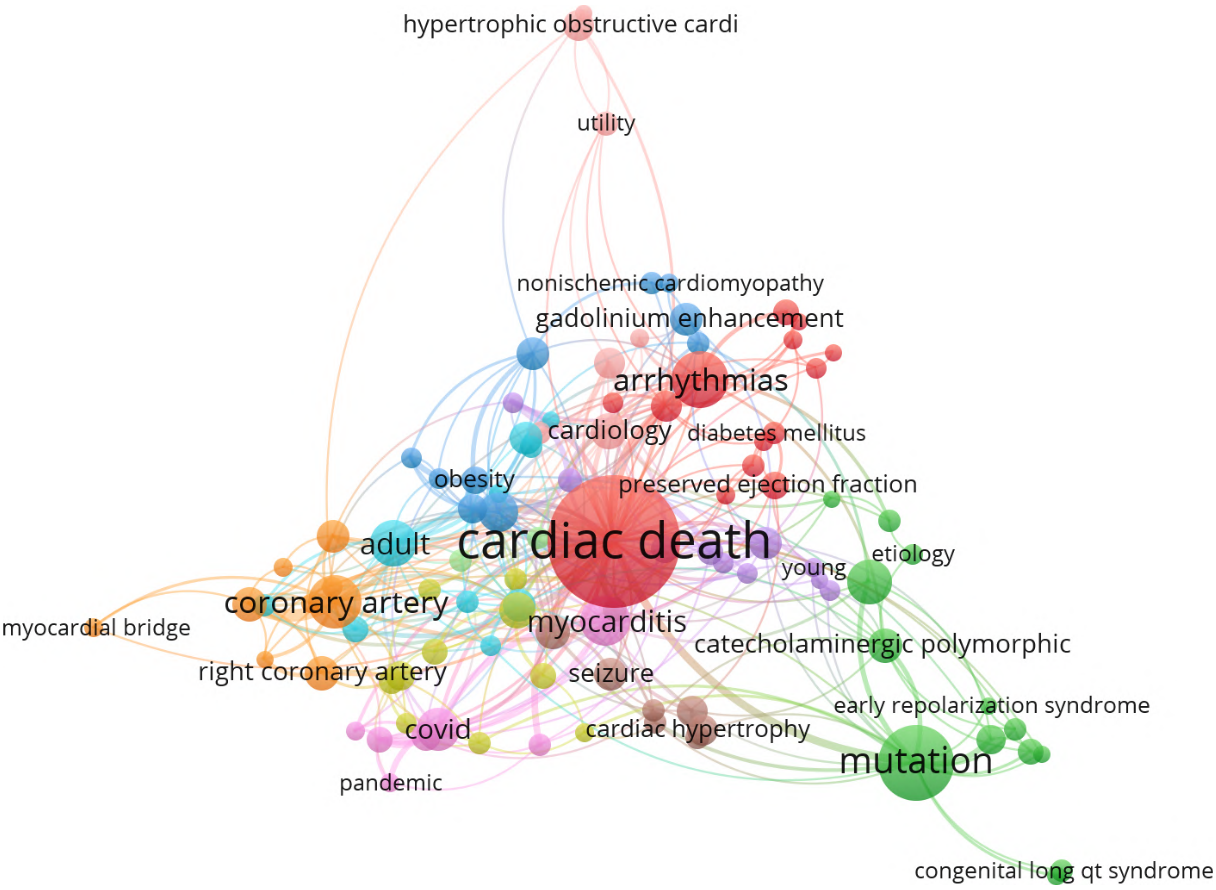


Figure 1. Connection map of thematic categories of research by scientists for five years (2018-2022) related to the topic "cardiac death" [8, 9].

the incidence of sudden cardiac death, which more often ends with negative consequences.

Studies by Dorian et al. [12] and McKinney et al. [13] examine the relationship between myocarditis, which may be caused by COVID-19, and sudden cardiac death in athletes.

Kaye et al. [14] considers sympathetic activation (general and cardiac) as a trigger for ventricular arrhythmias that can lead to sudden cardiac death.

Manolis et al. [15], like the previous researcher, emphasizes the importance of the arrhythmogenic effects of sympathetic activation in the development of cardiac pathology.

Depes et al. [16] on the basis of morphological studies are indicate the impoverishment of sympathetic innervation in the mouth of the superior vena cava. This can be considered as a morphological prerequisite for sudden cardiac death.

Tse et al. [17] on the basis of morphological studies of the Stellate ganglion, a preliminary conclusion was made about the connection of inflammation in the specified sympathetic structures with sudden cardiac death.

Chang Liu et al. [18] are investigating sudden cardiac death in persons who do not have cardiac disorders. They points to the significant role of stress as an etiological factor of this pathology.

Maturana et al. [19] draw attention to the role of sympathetic activation, which is formed in stressful and extreme situations such as earthquakes, wars, terrorism, in the development of sudden cardiac death. A similar pathogenetic mechanism of the development of this pathology can be present in fans of various sports – football, baseball, rugby.

Esler [20] on the basis of his own research says that psychological stress can be a trigger for heart arrhythmias, which are a prerequisite and a component of sudden cardiac death.

Boudoulas et al. [21] is investigating sudden cardiac death in patients with floppy mitral valve (FMV)/mitral valve prolapse (MVP) without significant mitral regurgitation. This pathology is more common in young people. The authors presents the importance of sympathetic activation in the development of sudden cardiac death in individuals with floppy mitral valve (FMV)/mitral valve prolapse (MVP) without significant mitral regurgitation.

Čulić et al. [22] based on the analysis of the scientific literature, considers the risk factors of sudden cardiac death. They single out the following as significant factors of this pathology: alcohol use – 15.5%; physical activity – 9.4; cocaine use – 6.9; occasional coffee consumption – 6%; psychoemotional stress – 3%; use of amphetamines – 0.9%; influenza – 0.3%.

Javalkar et al. [23] investigate fainting (syncopal) states, which they considers as a diagnostically significant harbinger of sudden cardiac death.

Corrado and Zorzi [24] investigate physical activity as an important factor in maintaining health. At the same time, they draw attention to the fact that intense physical activity increases the risk of sudden cardiac death, which can become fatal.

Monda et al. [25] in their study analyze the causes of sudden death of children. They note that the main factors are hereditary heart diseases. Researchers draw attention to the significant role of hypertrophic cardiomyopathy and arrhythmogenic cardiomyopathy in the development of sudden cardiac death.

Yevtuch et al. [5], based on the analysis of data from the scientific literature, actualize heterochronic (uneven) formation of nerve plexuses of the heart and generally uneven development of the cardiovascular system in ontogeny as an essential ontogenetic and morphofunctional prerequisite for sudden cardiac death in children and adolescents. Pedagogical strategies based on taking into account the heterochronic development of nerve plexuses of the heart for the prevention of sudden cardiac death are presented.

Klochko et al. [4] using data from the scientific literature in the preventive aspect, present ways of taking into account hemodynamics during exercise for the prevention of sudden cardiac death.

D'Ascenzi et al. [26] are analyze the results of the Sudden Cardiac Death Study from 1990 to 2020. Researchers determine that the main causes of this pathology in athletes are a non-ischemic scar of the left ventricle and hypertrophic and dilated cardiomyopathy. In non-athletes, the main cause of sudden cardiac death is ischemic heart disease, arrhythmogenic cardiomyopathies and channelopathies. According to the author, the etiology of sudden cardiac death in the USA and Europe is quite different.

Lee et al. [27] investigate the pathology of Commotio Cordis, which is often the cause of sudden cardiac death. The researchers note that a significant proportion of Commotio Cordis occurs outside of sports in a group dominated by young men.

Ha et al. [28] indicate a significant role of diabetes and obesity in the development of sudden cardiac death. Researchers draw attention to the important role of electrocardiography and machine learning in predicting the risks of sudden cardiac death and its prevention.

After analyzing the data of the above presented studies of sudden cardiac death, generalizations can be made. Epidemiologically, sudden cardiac death is a significant pathology in both childhood and adulthood. Athletes and student-athletes are a special risk group. Sports in which this pathology often occurs include long-distance running, football, American football, basketball, baseball, and others. Sudden cardiac death is associated with hereditary heart diseases, including heart defects. Among the significant pathologies that act as causes of sudden cardiac death are cardiomyopathies (first of all, hypertrophic and dilated cardiomyopathy), non-ischemic scar of the left ventricle, coronary heart disease, channelopathies, post-influenza myocarditis caused by both ordinary influenza and COVID-19, Commotio Cordis, herpetic infection, floppy mitral valve (FMV)/mitral valve prolapse (MVP) without significant mitral regurgitation, diabetes, obesity. Important triggers of malignant cardiac arrhythmias that lead to sudden cardiac death are physical exertion (first of all, intense), stress and use of: anabolic steroids, alcohol, cocaine, amphetamines, coffee. Among the pathogenetic mechanisms, we can single out the disturbance of sympathetic innervation as important, which includes depletion of sympathetic innervation and, above all, sympathetic activation. Heterochronic (uneven) formation in the ontogenesis of the nerve plexuses of the heart in children and adolescents is presented as an ontogenetic prerequisite for sudden cardiac death. Hemodynamic features of children and adolescents during physical exertion are significant in the development of sudden death. The considered aspects of the phenomenology of sudden cardiac death are cognitive and methodological-value guidelines for the development of prevention of this pathology in the conditions of the educational process during physical education classes.

The problem of prevention of sudden cardiac death, as well as the question of considering the heart as an anthropological and cultural phenomenon, in the professional discourse of a specialist in physical culture and sports is presented fragmentarily, not systematically and, in general, insufficiently. So far, the issue of prevention of sudden cardiac death in the conditions of physical exertion and after it in the context of improving the health-preserving competence of the physical education teacher in the conditions of postgraduate education has not been sufficiently updated and developed. Both theoretical issues and practically oriented aspects of the indicated problem are insufficiently developed, namely such a significant direction as the technologicalization of prevention of sudden death in the conditions of the educational process.

In the scientific pedagogical literature, the interdependent and interconnected problems of the heart as an anthropobiological and cultural phenomenon are also insufficiently disclosed in relation to the purely practical issues of prevention of sudden cardiac death and preservation and formation of cardiac health in the process of motor activity. From the standpoint of revealing the potential of a teacher's professional culture in relation to the professionalization of a specialist in physical culture and sports, the actualization of the indicated anthropoculturally oriented problems of the heart is necessary and significant for now. This is determined by the fact that the specified anthropocultural aspects of the heart phenomenon are aimed at the formation of intellectual and value-meaningful prerequisites and foundations of health-saving practices and technologies, including, first of all, the issue of technology for the prevention of sudden cardiac death.

The need to reveal the anthropocultural aspects of the heart in the professional activity of a physical education teacher is determined by many factors: ethical, based on traditional cultural ideas about the heart as a unique structure, which is a significant prerequisite for human morality, professional ethics; the cordocentric nature of many cultures, which represents a sensual, kind and compassionate heart and cordiality as a special world of humanity, as a central personal and cultural value; the modern trend of tolerance and humanism, which reflect the ideas of caring for people, humanity and kindness, which are interpreted as special manifestations of the human heart within the framework of cordocentric understandings; directions for preserving health in the conditions of the educational process based on the formation of a culture of health and professional culture, which reflect universal human culture, compassion, mercy; the importance of taking into account in the educational process issues of harmonizing a person with himself and with the surrounding natural, social and cultural environment, considering culturally acceptable "tools" of adaptation and harmonization; a professional request to reveal in a physical education teacher kindness, mercy, humanity, tolerance, care for children, trust as personal qualities and behavioral stereotypes connected with the heart, which are system-organizing personal and professional tools of both health-preserving and generally professional activity of a teacher; considering the heart qualities of humanity, kindness, tolerance as intentional and communicative prerequisites for the development of a safe and healthy educational environment, as well as professional personal and behavioral tools of intercultural communication and countering discrimination, manifestations of racism and non-tolerant attitudes towards students and others.

L. S. Mehta et al. [29] points out the importance of taking into account cultural factors in the training of medical workers. The researchers emphasize the culturally sensitive aspect of medical training as important for the preservation of women's cardiac health [29]. A. Huber and S. Chapa [30] on the basis of their research indicate the important role of taking into account the cultural factor in the formation of trust in medical workers, which is a prerequisite for providing effective medical care, including timely referral to a medical institution [30].

To clarify, we note that we believe that the necessary systemic prerequisite for technologization in the educational sphere is the actualization of cultural and anthropological potentials, both of the specialist and of the problem itself. Without cultural contexts, humanitarian, including educational technologies and methods, cannot be fully implemented and effective. That is, in humanitarian and physical culture and sports technologies and methods, including educational ones, health-preserving culture is presented as their "invisible component", context, condition and trigger. The specified cultural and anthropological prerequisites, first of all, which are humanitarian and integrative, contain knowledge, values, meanings of human culture. This largely concerns the introduction of technical technologies. For example, the organization of complex productions is possible provided there is an appropriate level of both general and professional culture. Accordingly, technological prevention of sudden cardiac death can be implemented and effective, provided that the technology is based on a developed professional culture, which includes a culturally and anthropologically oriented understanding, in this case, of both the phenomenon of the heart and human life.

Thus, on the basis of the problematization presented above, we define as an urgent problem the technologization of the prevention of sudden cardiac death, which is presented as a significant component of improving the health-preserving competence of a physical education teacher in the conditions of postgraduate education.

Purpose. Conceptualize the strategies of technologization of the prevention of sudden cardiac death based on the application of the disciplinary-methodological matrix of the health-preserving competence of the physical education teacher.

2. Selection of methods and diagnostics

Methods, approaches and concepts integrated into the methodological system were used in the study. The specified methodological system is anthropologically, culturally and technologically oriented. *The main approaches and methods used in the research* were: analysis of scientific literature; systemic, problematic; morphological, physiological; phenomenological; axiological [31]; anthropological [32]; cultural, competence.

Based on the transfer of knowledge, methodology, and values from the medical field, the following approaches were applied: patho-pedagogical [33]; etiological (in health pedagogy) [33]; propaedeutic (in health pedagogy) [33]. Preventive [4], transdisciplinary and case method were also used.

Ideas and concepts were used in the work: knowledge transfer [34, 35], anthropologising, humanizing, axiologising. Ancient Greek concepts were applied in their modern interpretation, available in the system of "Pedagogy-Paidei", formed by Foucault [36]. These are the concepts of care of oneself (epimelēsthai sautou) (interpreted by Foucault) [37] and human nature (ancient Greek $\phi\upsilon\sigma\iota\zeta\ \tau o\upsilon\ \alpha\nu\theta\rho\omega\pi o\upsilon$), agate (ancient Greek $\alpha\gamma\alpha\theta o\nu$ – inherently (intrinsically) good), arete (ancient Greek $\alpha\rho\epsilon\tau\eta$) – benevolence), healthy lifestyle.

Own methodical concepts the "Methodology for the development of health-preserving competence of the physical education teacher based on the knowledge of maintaining cardiac and mental health and prevention of cardiac diseases" developed by us was applied. Prevention of sudden cardiac death within the framework of this technique is one of its defining components ("methodology-subsystems"). This technique is formed on the basis of the application of our methodological concept – "disciplinary-methodological matrix of the health-preserving competence of the physical education teacher". In the system of the specified matrix, "integrative" disciplines, "methodological disciplines" are used, which are aimed at a systematic, multidimensional and practically oriented understanding of a person in conditions of health risks and in conditions of both health and pathology. These are such "integrative" methodically oriented disciplines as – "Pathopedagogy", "Propedeutics of health" and "Health therapy". The application of the "disciplinary-methodological matrix" is presented on the example of prevention of bronchitis [33], which included the use of the above methodological disciplines.

The practical-technological basis of this methodology is the application of systems of interrelated narratives and questions (dialogic-maeutic methods and practices), cases of pedagogical problems, analyzes and interpretations of situations related to cardiac health problems. Cognitive maps [38], illustrative material (including computer images and videos) are also used. Control of the level of formation of health care competence is carried out on the basis of the application of test tasks.

This method is central and systematically organized in our pedagogical system. It is aimed at the development of the physical education teacher's knowledge and skills of preservation and formation of both cardiac and mental health during physical exertion and in a state of relative rest. An important, special, systemic and defining aspect of this technique is its salutary orientation. Vitality in this pedagogical system is considered multidimensional. This includes special attention to ensuring the vital needs of the child (in food, physical activity, communication, etc.) and the implementation of life-creating ideas. But the main and defining thing is the preservation of life, first of all, in conditions of physical exertion. That is, this technique is, first of all, life-saving. Primarily, conceptually and thoroughly, this includes the prevention of life-threatening acute cardiac diseases and conditions that can develop during physical exertion.

"Methodology for the development of health-preserving competence of the physical education teacher based on the knowledge of maintaining cardiac and mental health and prevention of cardiac diseases" is a pedagogical system that is methodical and practical-technological. This technique is formed on the basis of the integration of several techniques. In the system of the specified methodology, two directions are disclosed and integrated: I – "Health-preserving preventive and health-preserving corrective" and II – "Health-forming and health-developmental". The specified two directions of this methodology and practice are generally used in this pedagogical system as foundations. The indicated directions consist of 4 methods: the first one consists of 3 methods, the second one consists of 1 method.

The first "Health-preserving preventive and health-preserving corrective" direction was formed on the basis of targeted transfer and further pedagogical integration of knowledge from various fields, namely: anthropobiological (physical anthropology, morphology, physiology, neurophysiology, etc.), medical and hygienic, cardiology, psychophysiological. Accordingly, the reception of practical-technological values, meanings, intentions, visions, interpretations, attitudes, cognitive schemes and significant aspects of experiences, practices and technologies, primarily medical and hygienic, relevant for the development of health-preserving competence is also applied. This direction includes 3 methods aimed at prevention: 1) sudden cardiac death; 2) acute cardiac pathology; 3) chronic cardiac diseases. Although the issue of sudden cardiac death is part of the problem of acute cardiac pathology. But in connection with the determining importance of the prevention of sudden cardiac death for the educational process (in particular, the development of a safe and healthy educational environment in the "New Ukrainian School" [39]) and for the preservation of children's lives, the specified violation is disclosed in detail by us as a particularly relevant life-saving strategy. The indicated attention to the specified problem is also due to its insufficient study and fragmentary and incomplete representation in educational practices and health preservation technologies. Therefore, for the optimal preventive solution to the problem of sudden cardiac death, we have developed a separate "Etiotropic technology of prevention of sudden cardiac death" (considered in the "Results and discussion" section).

The second "Health-forming and health-developmental" direction of maintaining cardiac and spiritual health is represented by one method – "The heart as a world of harmony, humanity and tolerance". This method is an anthropocultural basis for all other methods of maintaining cardiac health, as well as for this pedagogical system in general. This methodology is based on humanitarian insights and interpretations of the phenomenon of the heart as a special anthropological, cultural, existential, archetypal and spiritual reality. Accordingly, the phenomenon of the heart is represented multidimensionally and anthropologically and culturally oriented. Such defining humanitarian aspects of the phenomenon of the heart as: existential, philosophical, artistic, spiritual, ethical, aesthetic, cordocentric, temporal, mythological, ecological, psychological, religious, humanistic are updated. The humanistic ideas of paideya pedagogy and existential pedagogy are applied.

To determine the level of formation of the physical education teacher's intellectual ability to prevent sudden cardiac death, which includes, first of all, knowledge of the causes and mechanisms of the development of this disorder, the developed Fedorets test "Analysis of etiological risk factors for the development of sudden cardiac death during physical exertion" was used (below is a fragment of this test). Also applied were "Questionnaire of Fedorets-Klochko to assess the formation of critical thinking of a physical education teacher (trainer) based on the interpretation of hemodynamic knowledge" [4], Fedorets-Klochko questionnaire entitled "Determining heterochronically oriented interpretation of health preservation" [5]. In addition, the level of knowledge was determined with the help of an oral survey during the course.

The test is aimed at updating the physical education teacher's cognition and forming his intentionality and metacognitive strategies (goal setting, reflection) based on knowledge about the causes (etiological factors) of sudden cardiac death, which may be related to motor activity. Knowledge of these factors is also the basis of the teacher's health-preserving thinking and, accordingly, prevention strategies.

Fedorets test "Analysis of etiological risk factors for the development of sudden cardiac death during physical exertion":

1. In children and adolescents, heterochronic (uneven) development of the nervous system of the heart creates prerequisites for:
   1.1. imperfect regulation of the heart; 1.2. increase in blood pressure; 1.3. violation of blood supply to the heart; 1.4. development of rheumatism; 1.5. inflammation of the heart.

   Correct answer: 1.1.
2. How does a herpes infection affect a person, increasing the risk of developing sudden cardiac death, which can occur during physical exertion:
   2.1. affects the heart valves; 2.2. affects the nervous system of the heart; 2.3. affects capillaries; 2.4. affects the aorta; 2.5; affects the pulmonary trunk.

   Correct answer: 2.2.
3. How does lifting heavy objects affect the heart, increasing the risk of sudden cardiac death?
   3.1. violates the contractility of the heart; 3.2. leads to a sharp drop in blood pressure; 3.3. leads to a sharp increase in pressure in the inferior vena cava; 3.4. strengthens blood circulation (microcirculation) in the capillaries of the heart; 3.5. leads to a sharp increase in blood pressure.

   Correct answer: 3.3.

4. In a student (student) with a sufficient level of health and training against the background of complete well-being, the sharp (quick) appearance of pronounced general weakness during moderate physical exertion and which has a growing tendency may indicate the presence of:
   4.1. lack of oxygen in the blood; 4.2. danger of sudden cardiac death; 4.3. the dangers of rheumatism; 4.4. lack of vitamins in food; 4.5. lack of calcium and potassium in food;
   Correct answer: 4.2.
5. The risks of the formation of which disorder can be indicated by the general weakness that arose in a student during judo classes as a result of a light fall and that does not pass within 15 minutes?
   5.1. inflammation of the heart (myocarditis); 5.2. Commotio cordis; 5.3. acquired heart disease; 5.4. rheumatism; 5.5. circulatory disorders.
   Correct answer: 5.2.
6. What danger to the body that increases the risk of sudden cardiac death can be caused by holding your breath during exercise?
   6.1. a decrease in the concentration of oxygen in the blood; 6.2. desynchronization of respiratory and cardiovascular systems; 6.3. increase in the concentration of carbon dioxide in the blood; 6.4. sharp increase in blood pressure; 6.5. malfunction of the heart valves.
   Correct answer: 6.2.
7. What is the real health hazard of a blow to the heart or chest that can occur during boxing and martial arts?
   7.1. thrombus formation; 7.2. violation of blood circulation; 7.3. Commotio cordis and cardiac injury; 7.4. increase in blood pressure; 7.5. violation of lymphatic outflow.
   Correct answer: 7.3.

We used the non-parametric Wilcoxon test (the Wilcoxon signed-rank test) to perform pairwise comparisons of two dependent samples obtained as a result of the experimental study [40]. This choice was made because the non-parametric Wilcoxon test does not require the assumption of normality of the distributions and can be used in the presence of outliers. Also, the sizes of paired samples that were compared were not large – less than 30. We used the Shapiro-Wilk test to check the conformity of the samples to the normal distribution.

The null and alternative hypotheses of the Wilcoxon test were formulated:

X_0: the results of testing before conducting the study are equal to the results of testing after conducting the study;

X_1: the results of testing before conducting the study are not equal to the results of testing after conducting the study.

The R programming language was used to perform calculations according to the Wilcoxon signed-rank test. The calculations were performed in the Posit Cloud environment [41].

3. Method

Let's consider in detail the technique "Etiotropic technology of prevention of sudden cardiac death", which is aimed at technologization, objectification, optimization, axiologization, anthropologization, humanization of preservation of cardiac health and life of students. As indicated above, this method is the main and system-organizing component of "Methods for the development of health-preserving competence of the physical education teacher based on the knowledge of maintaining cardiac and spiritual health and prevention of cardiac diseases". "Etiotropic technology of prevention of sudden cardiac death" contains 6 blocks (or components). The specified components are simultaneously considered as successive stages of implementation of the methodology itself. Studying the methodology itself in postgraduate education has the same stages. These include the following stages:

I – Anthropological;
II – Pathopedagogical;
III – Propaedeutic;
IV – Therapeutic;
V – Practical and technological;
VI – Control-reflexive.

Let's consider successively the stages of this technique, which coincide with the stages of its training.

The first stage is anthropological. To implement this stage, the actualization of two epistemological directions is used: 1) anthropobiological knowledge that reveals the biological nature of a person and the normal cardiovascular system; 2) anthropocultural knowledge about the heart as an anthropological, cultural, psychological, philosophical phenomenon.

The first epistemological direction – the actualization of anthropobiological knowledge includes the application of such disciplines, which are mainly used in the training of a specialist in the specialty "Physical culture and sport" when receiving basic education. This is knowledge and ideas about a person and the cardiovascular system, which are formed by such disciplines as: human anatomy, histology, physiology, psychophysiology, neurophysiology, biochemistry, physical anthropology, sports anthropology, environmental anthropology. In the conditions of postgraduate education, it is recommended that students restore, update and expand a significant amount of the specified "classical" knowledge about the cardiovascular system and a person under normal conditions using flipped learning [42].

At this anthropological stage, we are expanding knowledge about certain morphofunctional and biochemical phenomena that are significant for understanding sudden cardiac death. Such a defining phenomenon, which is analyzed in detail at the specified stage, is heterochrony [5]. The biological and temporal essence of heterochrony consists in uneven growth, formation of both the organism itself and its structures and functions, in this case – the cardiovascular system. Accordingly, the ontogenetic (related to individual development) and morphophysiological prerequisites of possible cardiac disorders, which are represented as a manifestation of the phenomenon of heterochrony, are presented in the training process. In the phenomenon of heterochrony, the temporal essence of a person is revealed through the stages and unevenness of its formation. The following heterochronies are analyzed [5]:

1) the relative lag behind the growth of the heart from the formation of the musculoskeletal system, which can be quite pronounced in some individuals;
2) uneven formation of the nervous system of the heart [5], which ensures optimal regulation of the work of the cardiovascular system: primary maturity occurs in the 8th month, structural maturity in the 7th year; a certain level of functional maturity – at 11-13 years; this structure is fully formed at the age of 18-22; after 33-35 years, a certain degradation occurs;
3) sometimes there is a delay in the growth of the mitral valve from the formation of the left atrioventricular opening, which determines the development of functional insufficiency or mitral valve prolapse [21] in adolescence and young adulthood.

It is important that the phenomenon of heterochrony is normative, but, at the same time, from an anthropobiological point of view, it should be taken into account in prevention as it creates systemic risks for the cardiac health of children and adolescents.

The next significant aspect that we reveal in the context of heterochrony is the analysis of the mechanisms of heart regulation, including consideration of the nervous mechanism. It is the nervous mechanism of regulating the heart's work, together with the conducting system of the heart, that provides fine, differentiated regulation of the heart's work, adapting it to different loads. This ensures adaptation of both the heart and the body to different movement modes. A defining phenomenon that must be taken into account in the prevention of sudden cardiac death is the insufficient formation of the nervous mechanism of heart regulation [5] and its imperfection in children. This is due to the heterochronic specificity of the development of the nervous system of the heart (first of all, cardiac sympathetic nerve plexuses) [5]. The specified heterochrony is a morphophysiological and ontogenetic prerequisite of heart disorders, which, in turn, underlies the increased risk of sudden cardiac death in childhood and adolescence.

To implement the second epistemological direction – the actualization of anthropocultural knowledge – the method "Heart as a world of harmony, humanity and tolerance" (described in the thesis in the "Methods" section) is used, which is health-forming, developmental, ethically, anthropologically and culturally oriented. The defining and systemic aspect of this methodology is that it is aimed at the pedagogical integration of knowledge, values, meanings, skills of various nature and direction (medical, biological, humanitarian) into the system of health-preserving competence of the physical education teacher. In the system of the specified competence, the anthropocultural component is distinguished as integrative and socioculturally and humanistically oriented.

The goal of the anthropological stage is the formation of the listener's knowledge and holistic ideas about the heart and man, both about biological and anthropocultural and ethical phenomena. This stage is essentially integrative – anthropo-bio-psycho-socio-cultural. This stage realizes the reception and pedagogical integration of the system of ideas: humanization and humanitarianization; anthropologization (forming the teacher of broad multidisciplinary knowledge about man as a biological, psychological, and cultural being); search and formation of existential meanings – existentialization and others. The result of the implementation of this stage, in addition to the acquisition of systematic knowledge about a person as a multidimensional, compassionate being, is the formation of the teacher's ability to understand the existential problems of students, through which the state of the heart is manifested. At this stage, there is an actualization of the teacher's ability to care about children about their life and health, to be merciful, tolerant, kind, humane, compassionate, as well as to devote his time to this, including reflection.

The implementation of this stage of training contributes to the formation of an *anthropocultural matrix of health-preserving competence*, which is a humanitarian and partly anthropobiological basis for the implementation of both the next stages of prevention of sudden cardiac death and the professional activity of the teacher itself. The indicated matrix, which, in addition to humanitarian knowledge about the heart, also contains other aspects of human nature in the system of the anthropological model of the health-preserving competence of the physical education teacher, is represented by its *anthropocultural component*.

The II stage is patho-pedagogical. At this stage, the phenomenon of a person and the cardiovascular system is represented in the format of a special "edge form" – nosology (that is, in the format of pathology) – sudden cardiac death. At the previous anthropological stage, a person and his heart were considered normal. This is the qualitative and fundamental difference between the mentioned stages. The phenomenon of sudden cardiac arrest at this stage is represented systematically and practically oriented. The specified examination of the problem is carried out in accordance with the cognitive scheme available in pathopedagogy, which makes it possible to fully represent and structure the pathological phenomenon, revealing significant aspects for the practice of its prevention. An example of the application of the specified cognitive scheme for the prevention of bronchitis in the conditions of the educational process [33]. Current cognitive-conceptualizing tools of cognition are used, which present the investigated problem (in this case, sudden cardiac death) conceptually, procedurally, phenomenologically, stepwise, structured, systematically, representatively and practically oriented. The specified cognitive tools represent separate areas of pathology, which can be formally presented as components of this scheme. For example, etiology is the study of the causes of diseases, pathogenesis is the study of the mechanisms of the development of pathologies, etc. Thus, we will present the main cognitive and conceptualizing tools of patho-pedagogy in the form of a cognitive scheme, in which an important technological feature is the sequence and logic of application:

1) a general description of the pathology (in the sense of the disease – sudden cardiac death);
2) significance (relevance) for a person and his health and life;
3) etiology (causes, conditions and risks);
4) pathogenesis (main mechanisms of pathology formation);
5) course (including temporality, speed, stages of pathology development);
6) complications;
7) prognosis (prognosis for health and prognosis for life).

The presented concepts, which are intellectual and conceptualizing tools at the same time, represent the methodological and technological basis of pathology. Let's review the phenomenon of sudden cardiac death using the indicated cognitive tools of pathology:

1. *General description of pathology (in the sense of disease).* Sudden cardiac death is a cardiac pathology that occurs in different age groups – children, teenagers, people over 40 years old, which: occurs acutely – from a few minutes to one hour; develops mainly quickly, "landslide", unpredictably and often against the background of complete well-being or in the presence of undiagnosed pathology (especially cardiac) [10]; without the use of an electric defibrillator, this pathology mostly ends in death; diagnosis is problematic due to a vague clinical picture (system of disease signs), an important criterion of which is general weakness that develops quickly; the pathological development of the disease (in the sense of an arrhythmic form) is associated with a violation of the regulatory mechanisms of the heart, in particular, the nervous system, as a result of systemic effects on the cardiovascular system of various causes, among which physical exertion, which can act as a trigger, is significant.
2. *Significance (relevance) for a person and his health and life.* Sudden cardiac death is a significant pathology due to the fact that: occurs in all countries and is epidemiologically significant [2, 3]; occurs unpredictably [10] and acutely: it is present in different age groups, including children and adolescents; without assistance with the use of an electric defibrillator, it mostly ends in death; one of the causes of this pathology can be physical exertion.
3. *Etiology (causes, conditions and risks).* Etiological factors (we will consider the main and actual ones in the conditions of the educational process) and prerequisites represent a complex system that we structure into groups for educational purposes. The following groups of factors can be identified in this system:
    1) Factors that are caused by heterochrony [5] and reflect the morphophysiological and ontogenetic features of children: uneven development of the nervous system of the heart in childhood and adolescence, as well as the growth of the heart itself relative to the body.
    2) Traumatic factors: cardiac injury end Commotio Cordis [27].
    3) Infectious factors: herpetic infection, flu including COVID-19 [11], other infections.

4) Non-infectious diseases, in particular, diabetes [18, 28].
5) Substances that have a neurotropic [22] and psychotropic effect: medicines, alcohol, drugs, smoking, as well as anabolic steroids.
6) Cardiac diseases [12,13,21,23,25,26], including heart defects, as well as cardiomyopathy, sports heart, pathological sports heart, mitral valve prolapse, non-overgrowth of the Botall's duct, as well as any cardiac pathology represents a certain risk.
7) Environmental factors and stresses [19,20] of various nature: overheating, hypothermia at particularly low temperatures, ionizing radiation in low doses.
8) Chronobiological: disturbances of biorhythms, including chronobiological stress.
9) Features of the cardiovascular system of children with special educational needs, which increase the risk of sudden cardiac death.
10) Factor of summation effects and synergistic effects, which can be formed as a result of simultaneous or sequential influence of factors of different or the same nature.
11) Features of physical exertion, which under certain conditions can be considered as risk factors for the formation of sudden cardiac death [7, 24]. In this methodology, the main and special attention is paid to the analysis of this "motor" aspect, which is determined by the motor specificity of professional activity. The specified risks, as noted above, significantly increase when various etiological factors are combined with physical exertion, creating synergistic effects.

Let's briefly present the features of physical exertion, which under certain conditions can increase the risk of sudden cardiac death.

- Physical stress, which combines physical stress and straining, which leads to a sharp increase in pressure in the chest and abdominal cavities.
- Power and speed load. For example, lifting heavy objects, running downhill, sprinting, impulse training, in particular, shuttle running, plyometric training.
- Circuit training.
- A load in which there are blows and falls, as in wrestling, boxing and martial arts.
- Load without sufficient warm-up.
- Intense exertion after a significant period of rest, sleep, in the morning.
- Abrupt termination of the load.
- Intense and/or exhausting physical activity that does not correspond to the body's functional capabilities, age, health status in general and during and before the start of motor activity.
- The load, which is combined with overheating, hypothermia, in a state of stress, exhaustion or fatigue, against the background of the use of psychoactive substances (drugs, alcohol, smoking).
- Physical activity that takes place with breath holding and total breath control.

In this method of training physical education teachers and in the prevention of sudden cardiac death itself, knowledge and understanding of etiology is a central and system-organizing factor in preserving the life and health of students. Therefore, this technique, in which the central conceptual-methodological and technological "tool" is knowledge of etiology, is accordingly called "Etiotropic technology of prevention of sudden cardiac death". Knowledge and understanding of etiological factors and conditions enables the physical education teacher to form a risk group of children whom he can purposefully observe (the concept is dynamic health-preserving observation), more carefully and individually develop and select physical exercises and training regimens, preventing risky physical exertion , and take into account the risks for children's cardiac health.

4. *Pathogenesis (main mechanisms of pathology formation).* The pathological mechanisms of sudden cardiac death are considered in an overview, among which the rapid, rapid formation

of life-threatening arrhythmias (disruption of the heart rhythm), "malignant arrhythmias", which can lead to fibrillation (uneven, asynchronous contraction of the heart muscle), heart flutter and quick death These life-threatening arrhythmias arise as a result of disturbances in the nervous system of the heart, which, in turn, are formed under the influence of various (presented above) etiological factors [14–17]. Other aspects and mechanisms of pathogenesis are also studied, among which an important role is given to hemodynamics [4].

5. *The course of the disease (including the speed and stage of development of the pathology).* Sudden cardiac death is an acute pathology, i.e. one that forms quickly, "landslide", "avalanche-like" and often without apparent reasons [10]. The duration of this disease ranges from several minutes to one hour. Stages, which could have diagnostic or therapeutic value, are not clear or absent. Clarifying, we note that the phasing, which in this pathology is almost absent (not distinct), can determine the prognostic, temporal and, accordingly, preventive aspects of the pathology. That is, knowing about the typical next stage of development of the pathology, it is possible to influence its course.
   The acute nature of the disease and its danger determine the need for quick and appropriate pre-medicinal and medical actions to save a person.
6. *Complication of the disease.* A complication of sudden cardiac death is fibrillation (uneven, unsynchronized contraction) of the heart, as a result of which death can occur in the vast majority of cases.
7. *Prognosis (prognosis for health and prognosis for life).* Such a prognosis for sudden cardiac death in the absence of special emergency cardiac treatment with mandatory use of a defibrillator is – Prognosis pessima (Latin) (bad, negative prognosis) – death.

The III stage is propaedeutic. The methodological-conceptual, content-semantic and practical-technological foundations of this stage are the ideas, contents, values and meanings of the "methodical discipline" "Propaedeutics of health" developed by us [33]. The specified "methodical discipline" is considered: cognitively-instrumentally and as an anthropocultural, ethically and health-oriented system of ways of conceptualizing professional (organization of motor activity, etc.) and anthropological (in particular health) phenomena (including disease prevention); professionally-ontologically and professionally-actively as the optimal way of professional existence and activity; axiologically and ethically, as a professional value-semantic and ethical system.

The propaedeutic stage represents and implements "Propaedeutics of health" as an integrative and integrating "ethical-communicative-diagnostic-prognostic-active-preventive" system in which, in accordance with the specifics of the prevention of cardiac diseases, we distinguish the following components (or directions): anthropocultural and ethical, prognostic – patho-pedagogical, diagnostic-prophylactic, therapeutic, communicative, temporal. The specified components can also be represented instrumentally and functionally, that is, as a function aimed at achieving a preventive goal:

1) *The anthropocultural and ethical component of propaedeutics* is considered as the personal-psychological and cognitive-valuable ability of a physical education teacher for practice-oriented, communicative, ethical and professionally oriented integration and transformation of ideas, values, meanings, knowledge, ideas, reflections, interpretations, which were formed at the "I – anthropological stage". In the formation of this stage, the technique is used – "The heart as a world of harmony, humanity and tolerance".
2) *The prognostic-patho-pedagogical component of propaedeutics* is applied and formed as the physical education teacher's intellectual ability to apply the knowledge formed at the "II – patho-pedagogical stage" for the prevention of sudden cardiac death. The specified knowledge formed at the "II – patho-pedagogical stage" is presented as an epistemological

basis and an interpretive prerequisite for the development of the health-preserving thinking of a physical education teacher. To clarify, we note that health-preserving thinking is considered as a defining system that organizes a specific professional cognitive tool for health preservation. Health-preserving thinking in the context of this issue of prevention of sudden cardiac death includes the cognitive ability to operate with certain algorithms, cognitive and metacognitive (goal setting, reflection, interpretation) schemes, strategies. This is necessary for the analysis and forecast of situations dangerous to health and life, as well as for the purpose of planning health-saving and life-saving strategies and safe organization of students' motor activity, which includes selection and adaptation to the anthropobiological (including age) characteristics of students of various educational (movement, body, health-preserving) technologies and practices. The prognostic-pathopedagogical component of propaedeutics, which is formed on the prognostic and anthropological understanding of pathology, is central to the prevention of sudden cardiac death.

3) *The diagnostic and preventive component of propaedeutics* is formed as the physical education teacher's intellectual ability to apply general knowledge of diagnosis of sudden cardiac death and determine the risks of its formation in order to prevent the specified pathology in the conditions of the educational process. This also applies to the provision of emergency medical care. This component of propaedeutics also includes updating the operational and ethical aspects of the prevention of this pathology.
Special knowledge of diagnosis of sudden cardiac death is also being updated, including a practice-oriented analysis of risk factors and conditions of its formation. Special attention is paid to the need to take into account such a general symptom (sign of the disease) of the disorder as general weakness. This has a special diagnostic value in the case of rapid formation of general weakness during physical exertion. Accordingly, in the presence of precursor symptoms (among which general weakness is significant) of a possible disturbance (sudden cardiac death), motor activity should be stopped in a timely manner.

4) *The therapeutic component of propaedeutics (pre-medical care)* is formed as an integrative professional ability of the physical education teacher to carry out basic pre-medical measures to provide emergency care in case of sudden cardiac death. This also includes assistance with such a complication as clinical death. Such pre-medical treatment measures include: stopping the movement of the victim and providing him with a comfortable position (preferably semi-lying or sitting), calling for emergency medical help, psychological help, using ammonia (give it to sniff), and in the case of clinical death, artificial respiration and closed heart massage.
The medicinal component is considered as a significant and, at the same time, as an exclusive and extreme strategy. This is due to the fact that the main idea and meaning of this preventive system is to prevent the development of sudden cardiac death as a pathology that has its own specific development, which determines – prognosis passima (Latin). First of all, this is due to the insignificant (practically absent) effectiveness of medical measures without the use of a defibrillator and special medical assistance. Although, of course, we recommend providing full medical care.

5) *The communicative component of propaedeutics* is formed as a communicative and ethical-communicative skill of a physical education teacher, delicately, preventively aimed at communicating with students on the topic of maintaining cardiac health and preventing heart diseases. At the same time, it is important to use non-violent communication and reveal the narrative, ethical, cultural and aesthetic potential of the teacher's personality in the process of communicating with students. The communicative component of propaedeutics includes the formation of a health-preserving discourse as one of the significant components of the formation of a safe and healthy educational environment. Such health-preserving communication can be both dialogical and polylogical. An important

technological aspect of communication is the teacher's knowledge of typical and specific questions that he should use for diagnosis in the case of a threat of sudden cardiac death or the presence of distinct risk factors for its occurrence. For example, these are the following questions: How do you feel? What worries you? Do you have a weakness? Is there pain or discomfort in the heart area? That is, the questions determine both the general condition and specify the problem, narrowing it down to a cardiac one. The communicative dimension of propaedeutics is a mandatory pedagogical and personal-psychological condition for the implementation of diagnostic-prophylactic and prognostic-patho-pedagogical components.

6) *The temporal component of propaedeutics* is formed as the ability, orientation and desire of the physical education teacher to structure time and his professional activity in such a way as to purposefully allocate time for: studying the basics of prevention of sudden cardiac death; the organization of health care discourse, which includes the prevention of cardiac disorders and the understanding and representation of the heart as an anthropocultural phenomenon; analysis and interpretation of the problem of maintaining cardiac health and prevention of sudden cardiac death in ethical, cultural, professional, existential formats; a humane, cordial, delicate, attentive, tolerant and preventively oriented attitude to the problem of prevention of cardiac problems; concern for the preservation of life and health of students. We purposefully single out the temporal factor as vitally important, first of all, because such psychological components of prevention as the presence of attention, care, and humanity may not be enough to prevent the problem. To implement the psychological aspects of prevention indicated above, a certain time resource is necessary, including internal motivation and willingness to spend time on care and attention.

The specified propaedeutic stage is aimed at the professional improvement of the physical education teacher based on systemic influences on various spheres of the teacher, namely: on the intellectual – in the formats of improving the intellectual-value and anthropocultural components of health-preserving competence; on emotional, value-semantic, motivational, ethical, behavioral – in the format of improving the personal-existential and activity-discursive components of health-preserving competence. In the implementation of this stage, the disclosure of the phenomenology of the heart in the content-meaning system of humanitarianism is relevant. The heart, within the framework of humanitarian sciences, is considered as an anthropocultural phenomenon. And what is especially significant – as an ethical and human-forming phenomenon. A person is considered as a being in whom spiritual arete (ancient Greek $\alpha\rho\epsilon\tau\eta$) – benevolence) are revealed, which are connected with the heart – cordiality, humanity, mercy, compassion, tolerance, caring, kindness.

In the intellectual sphere, the formation of typical cognitive and metacognitive strategies (the ability to set goals and reflect and self-assess one's abilities to prevent sudden cardiac death) and schemes and algorithms, as well as intellectual intentions, technological values and meanings, takes place.

In the emotional sphere, emotional intelligence is improved in a professionally oriented way, and empathy, compassion, and spirituality are actualized. Intuitive, figurative-emotional, sensory-emotional, emotional-aesthetic perception, comprehension and understanding of the phenomenon of the heart in the context of the prevention of sudden cardiac death as a significant existential and deep professional problem are updated. In this way, a life-saving oriented problematization and understanding of cardiac pathology, as well as a relative consideration of the heart as an anthropocultural phenomenon, is realized. This determines the actualization of emotional-volitional, emotional-cognitive, image-emotional, emotional-aesthetic, emotional-ethical aspects of the emotional sphere. The integrative influence of the specified aspects of the emotional sphere, included in the system of health-preserving competence, is primarily aimed at the development of life-saving, health-preserving and essentially life-creating emotional phenomena. Such professionally oriented phenomena are emotional: intentions, meanings, attitudes and emotional-semantic contexts, the purpose of which (as noted) is to preserve life by preventing sudden cardiac death. This is implemented on the basis of the formation of ideas about the complications and prognosis of sudden cardiac death (”II stage – patho-pedagogical”) in relation to the actualization of anthropocultural aspects (”I stage – anthropological” and “III stage – propaedeutic”).

Threats, risks, “fears” and anxieties, which are considered in the analysis of complications and prognosis of sudden cardiac death during the implementation of this stage, are interpreted in a positive and activity-oriented manner. Accordingly, in the emotional sphere, they are transformed into stable emotional intentions, attitudes, values (emotional values), meanings, moods, and emotional states aimed at preserving life and cardiac health, and not being understood only as dangers. Thus, the emotional background and emotional mood necessary for the optimal implementation of both health-preserving thinking and activity is formed.

Thus, at the propaedeutic stage of physical education teacher training, the following are formed: knowledge, skills, intentions, values and meanings aimed at preventing sudden cardiac death based on an understanding of the causes and mechanisms of its formation (the ability, formed on “Stage I – pathogenetic”); knowledge and ability to diagnose sudden cardiac death and determine its risks; knowledge of strategies for providing pre-medical care; knowledge and ability to communicate about the problem of prevention of sudden cardiac death and form a health-preserving discourse aimed at preserving cardiac health; knowledge and ability to apply knowledge of propaedeutics of sudden cardiac death for effective and safe organization of the training process and application of educational technologies and practices (health-preserving, motor, etc.). At this stage, the following are actualized: professional ethics and care for students; humanity, tolerance, cordiality, kindness and the ability and desire to devote time to the prevention of the indicated problem, the central dimension of which is the problem of the heart.

The IV stage is therapeutic. This stage is formed on the basis of the application of the “methodical discipline” (or “integrative discipline”) of “Health Therapy” [33] for the prevention of sudden cardiac death. Health therapy is developed on the basis of ideas that are clearly revealed in ancient maxims: ad hominem (Latin) (to a [specific] person), hic et nunc (Latin) (here and now), in esse (Latin) (in fact), factum probans (Latin) (evidential material). These ideas reveal the practical orientation of a therapeutic approach aimed at solving specific health problems in a certain “specific” person in a “specific” city at the present time, based on objective and evidentiary factors (data). The conceptual basis of “Health Therapy” and, accordingly, of “IV stage” are system-organizing ideas about: individualization and, accordingly, psychologization, existentialization of health-preserving influences, including preventive, corrective, and curative (in the sense of providing pre-medical care); specification and further practical-technological orientation of both general and special knowledge about health and pathological phenomena (in this case, sudden cardiac death); the transformation of anthropology, culture and ethics from idealized socio-culturally and professionally significant doctrines, ideas, strategies into a practical psychological-ethical and communicative-ethical toolkit (professional attitudes, stereotypes, schemes) of influence, actions, communication; psychologized and dialogically oriented communication aimed at solving a specific problem in a certain person on the basis of taking into account individual, age, gender and other personality characteristics.

The therapeutic stage represents and implements “Health Therapy” as a personal-psychological and practical-technologically oriented “communicative-psychological-active-preventive” system. In the specified system, according to the specifics of the prevention of cardiac diseases, we distinguish the following components (directions that can be represented as functions): diagnostic-prophylactic, communicative-psychological, therapeutic, temporal.

1) *The diagnostic and preventive component of health therapy* is considered as the ability of

a physical education teacher to carry out prevention and, if necessary, to provide pre-medical care based on: diagnosis of risks and signs (symptoms) of acute cardiac diseases, including sudden cardiac death in a certain person, and by applying knowledge pathology (patho-pedagogy), health propaedeutics, health-preserving observation and communication and actualization of health-preserving thinking. The main direction of the diagnostic and preventive component is prevention. Prevention is also based on the application of the *health-preserving protocol* developed by us. This protocol is a formalized matrix for technological intellectual activity, formed on the basis of the application of typical cognitive strategies and algorithms.

2) *The communicative and psychological component of health therapy* is considered as the ability of a physical education teacher to prevent sudden cardiac death based on his skills and dialogic communication skills. This includes knowledge of specific questions (partially presented above in the "III – propaedeutic stage"), which must be able to be asked delicately, correctly and appropriately to a person with a diagnostic purpose. Of particular importance is the psychological, existential and ethical component of dialogic communication, which determine the effectiveness of communication and, accordingly, the effectiveness of prevention or pre-medical care.
3) *The curative component of health therapy* is considered as the ability of a physical education teacher to provide pre-medical care in case of sudden cardiac death. The specified component is hypothetical, but not excluded, so the teacher must have the appropriate readiness.
4) *The temporal component of health therapy* is considered as the ability, orientation and desire of the physical education teacher to allocate time for: observation and analysis of probable risks for the cardiac health of certain students (i.e., specific individuals); preventive communication with students who are at risk (including children with special educational needs) for cardiac health, as well as with their parents; making changes to the training process of certain students who are at risk of developing cardiac disorders.

The time factor is particularly significant because the teacher's focus on the training process can crowd out the problem of maintaining cardiac health (and its most pressing aspect, sudden cardiac death). Therefore, despite the specialist's understanding of the specified problem, under the condition of minimizing time spent on it, it may become de-actualized and not significant. For us, what we spend our time on is significant and valuable. It is not for nothing that ancient wisdom indicates – Tempus rerum imperator (Latin) (Time is the ruler of things).

V stage – practical and technological. The purpose of this stage is the application of the previous 4 (stages and/or components) of the disciplinary-methodological matrix of health-preserving competence for: optimal implementation of health-preserving, physical culture and health, recreational, rehabilitation, pedagogical technologies and practices; to create a safe and healthy educational environment; organization of health care discourse in the conditions of the educational process; individualization of preservation and formation of health in a certain (concrete) person (student); development of individual (own) health care competence of participants in the educational process – students, teachers, educational managers; formation of health culture; greening of the cultural and educational space, including physical culture and sports, which is due to the need to implement the goals of sustainable development, namely "Goal 3 – Good health and well-being" and "Goal 4 – Quality education" ; humanitarianization, humanization, anthropology, existentialization of the cultural and educational space; formation of the psychology of peace; the development of intercultural communication based on the ideas of preserving health as a cultural and universal value; formation of tolerance and disclosure of kindness and mercy as manifestations of human nature.

The optimal implementation of health-preserving, physical culture and health, recreational, rehabilitation, pedagogical technologies and practices includes their selection, modification, improvement, and integration. Individualization of these technologies and practices is also an important aspect. Optimal implementation of the indicated technologies and practices based on the application of the disciplinary-methodological matrix of health-preserving competence is possible from both methodological and practical-technological positions. This is due to the fact that a significant part of important scientific disciplines, problem areas, practices, technologies, intentions, values, meanings, which reveal the nature of man in many dimensions as educational, cultural, anthropological, medical, pathological, normative, valuable and other phenomena. This matrix was developed as an innovative and anthropoculturally oriented cognitive system. Therefore, it can be both an anthropocultural and health-preserving basis for the implementation of the indicated educational (first of all, physical culture and health) practices and technologies, as well as a cognitive tool for their selection, improvement, modification, adaptation, integration.

The VI stage is control-reflexive. From the point of view of this pedagogical system, the goal of the control-reflexive stage is control and the following analysis and interpretation of the level of formation of the physical education teacher's ability to prevent sudden cardiac death. This ability, as a professional-personal and cognitive-value quality, is represented by the development of special knowledge, health-preserving thinking, values, meanings, intentions, attitudes, interpretations, reflections, which, according to their nature, are included in various components of the health-preserving competence of a physical education teacher. Control of the level of formation of the ability to prevent sudden cardiac death is not determined separately by us. This ability is considered as part of the health-preserving competence of a physical education teacher. At the same time, we conduct a certain idea about the formation of the physical education teacher's ability to prevent sudden cardiac death by applying test tasks.

From professional-personal, reflective and cognitive positions, the purpose of the control-reflexive stage is intellectualization, axiologisation, existentialization and professionalization of the specialist. This is realized by actualizing the physical education teacher's intellectual ability to analyze, interpret and understand the problems of preventing sudden cardiac death. This also includes the formation of appropriate metacognitive strategies, understanding of the existential and vital significance of this problem, valuable reflection of the issue, intellectual and emotional experience of this problem as professionally and vitally important. Accordingly, the result of this stage is the inclusion of the prevention of sudden cardiac death in the system of health-preserving competence of the physical education teacher as a significant professional tool of health-preserving activities and a way of conceptualizing, interpreting and making sense of normative and pathological phenomena significant for the educational process.

In this pedagogical system, the formation of the teacher's ability to prevent sudden cardiac death is carried out on the basis of the "Etiotropic technology of prevention of sudden cardiac death" including the use of a disciplinary-methodological matrix of health-preserving competence and a system of methods and technologies, which includes – dialogical practices, narratives with of this issue, systems of questions, pedagogical tasks, analysis of pedagogical situations and experiences, flipped learning, digital models of hemodynamics, cognitive maps, illustrative and video material.

4. Results and discussion

Prevention of sudden cardiac death in the conditions of the educational process is formed on the basis of traditional medical and hygienic approaches, in the system of which primary and secondary prevention of diseases are distinguished as defining and foundational. Primary prevention is decisive in this preventive system, which is based on the etiological principle, that is, on knowledge of the causes, risk factors and conditions for the development of diseases (in this case, sudden cardiac death). Accordingly, the effectiveness of disease prevention systems is largely determined by the maximum consideration of etiological factors in the organization of preventive measures. Elements of secondary prevention are also used, which is aimed at early detection of a certain disease or its prerequisites and precursors. For example, it is important for a physical education teacher to detect and take into account the state of overwork, stress or previous illness, which are considered as risks of sudden cardiac death in combination with intense physical activity. And on the basis of this stage of prevention, organize the motor activity of the student taking into account risk factors, which should include individualization of physical activity and/or reduction of its intensity and volume.

Fedorets test "Analysis of etiological risk factors for the development of sudden cardiac death during physical exertion" was applied in order to determine the dynamics of the formation of the physical education teacher's intellectual ability to prevent sudden cardiac death based on knowledge of the causes and mechanisms of the development of this disorder. The research was conducted in the process of improving the qualifications of physical education teachers in the conditions of postgraduate education. 411 physical education teachers took part in the study. The experimental study was conducted in 9 institutions of higher education: Municipal Higher Educational Institution Nikolaev Regional Institute of Postgraduate Pedagogical Education, Municipal Higher Educational Institution Donetsk Regional Institute of Postgraduate Teacher Education, Municipal Higher Educational Institution "Kherson Academy of Continuing Education", Municipal Higher Educational Institution Sumy regional institute of postgraduate pedagogical education, Municipal Higher Educational Institution Lviv Regional Institute of Postgraduate Pedagogical Education, Municipal Higher Educational Institution Zhytomyr Regional Institute of Postgraduate Pedagogical Education, Drohobych State Pedagogical University of Ivan Franko, Municipal Higher Educational Institution Zaporizhzhia Regional Institute of Continuing Pedagogical Education, Municipal Higher Educational Institution Chernihiv Regional Postgraduate Institute of Postgraduate Pedagogical Education named after K. D. Ushinsky.

According to the results of the testing, a sample of the percentage of correct answers of physical education teachers was obtained before and after the study (table 1).

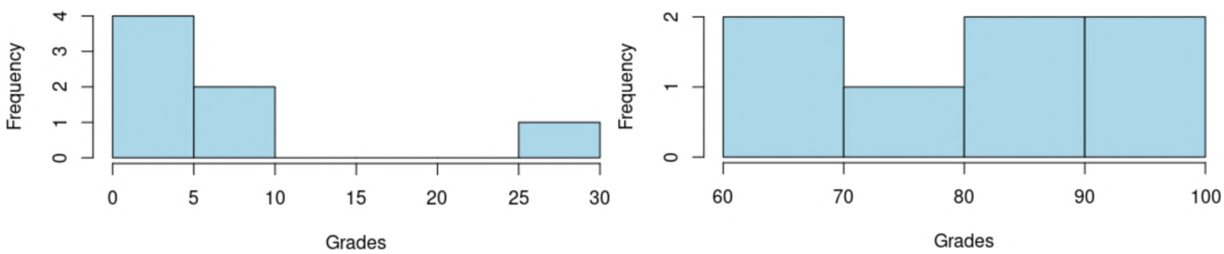
Table 1. The percentages of correct answers of physical education teachers obtained as a result of testing conducted before and after the study and the significance of their differences (figure 3).

Order number of the task, n	Before the study, x_{before} (%)	After the study, x_{after} (%)	Difference, $x_{after} - x_{before}$ (%)
1	2	95	93
2	1	83	82
3	8	88	80
4	5	71	66
5	6	67	61
6	3	61	58
7	26	97	71
Mean	7.29	80.29	73

We check whether the data samples before and after the study are normally distributed using histograms (see figure 2) and the Shapiro-Wilk test.

The Shapiro-Wilk normality test statistic was obtained using the `shapiro.test()` function of the R programming language. The following results were obtained:

1) W = 0.71606, p-value = 0.005537 – for the sample of the percentage of correct answers to the test questions obtained as a result of the testing conducted before the study; since W



1) 2)

Figure 2. Frequency distribution of percentages of correct answers of physical education teachers obtained as a result of testing conducted: 1) before the study; 2) after the study.

has a value closer to the mean and the p-value is less than 0.01 (p-value<0.01), so it does not give enough reason to believe that the data is distributed according to the normal law, at the 1% significance level, the hypothesis that data are normally distributed, refuted; the histogram also shows that the distribution does not follow a normal distribution (figure 2.1).

2) W = 0.92693, p-value = 0.5251 – for a sample of the percentage of correct answers to test questions, obtained as a result of testing conducted after the study; since W has a high value, the value is closer to the mean and the p-value is greater than 0.1 (p-value>0.1), so it gives reason to believe that the data are distributed according to the normal law, at a significance level of 10%, there are grounds for accepting the hypothesis that the data are normally distributed; however, the histogram shows that the distribution does not follow a normal distribution (figure 2.2).

Therefore, we assume that the assumption of normality is violated for both paired samples and given the small sample size, we use the Wilcoxon signed-rank test to determine that the difference between the values of the percentages of correct answers to the test questions obtained before and after the study is significant.

We correct the hypothesis X_1, taking into account that all the differences between the corresponding values of the percentages of correct answers before and after the study are positive (table 1). We get:

X_0: the results of testing before conducting the study are equal to the results of testing after conducting the study;

X_1: the results of testing before conducting the study are less than the results of testing after conducting the study.

To calculate the Wilcoxon signed-rank test criterion, we use the `wilcox.test()` function of the R programming language. We get the results of p-value = 0.0002914 (figure 3). Thus, p-value<0.01, so at the significance level of 1% we refute the hypothesis that the results of testing before conducting the study are equal to the results of testing after conducting the study. The hypothesis that the results of testing before conducting the study are less than the results of testing after conducting the study.

The significant positive dynamics of the results in the experimental group is explained by the fact that the problem of sudden cardiac death is professionally and vitally significant, as well as by the fact that consideration of this issue in the educational process is given special attention. In addition to the stated reasons, we consider the use of the disciplinary-methodical matrix of the health-preserving competence of the physical education teacher and digital models of hemodynamics [4] to be important factors that determine the high level of indicators of positive dynamics of educational results.

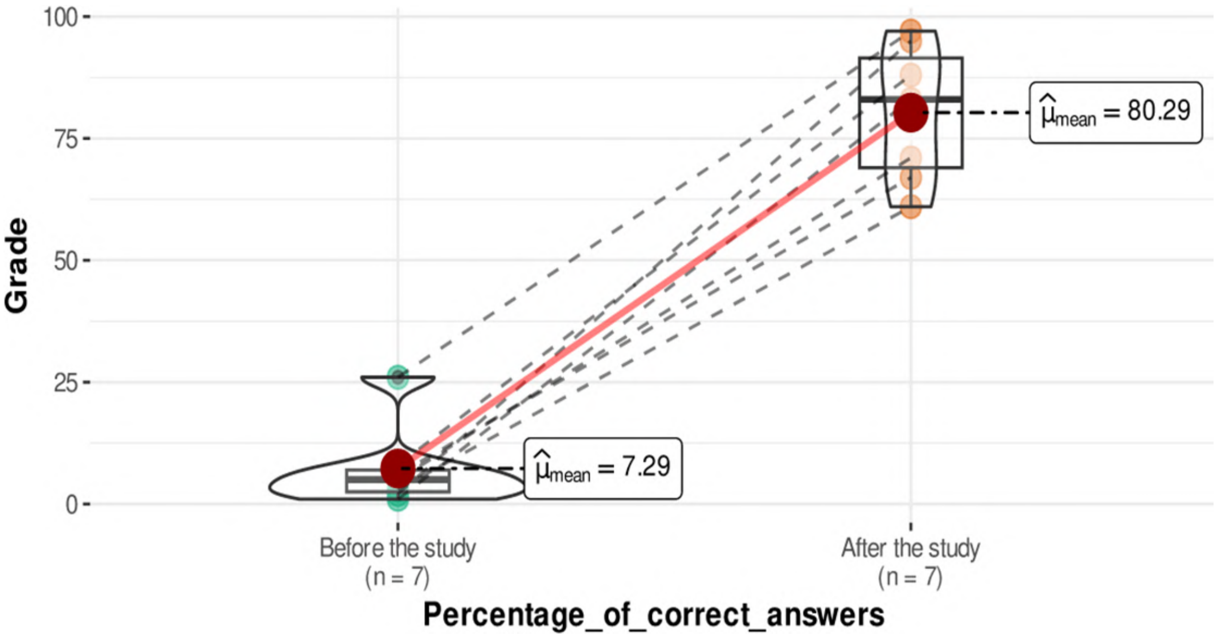


Figure 3. The percentages of correct answers of physical education teachers obtained as a result of testing conducted before and after the study, the box plot in the R programming language.

5. Conclusion

In the study, using the example of the process of forming the teacher's ability to prevent sudden cardiac death, the educational application of the disciplinary-methodological matrix of the health-preserving competence of the physical education teacher developed by us is presented. This matrix contains 6 levels represented by systems of disciplinary directions, individual disciplines, methodical disciplines (formed for educational purposes), practices, technologies, reflections and control measures. We present this matrix as a competence-oriented *methodological meta-technology of knowledge management* developed on the basis of the actualization of the specialist's cognition and the application of the ideas of knowledge transfer, autopoiesis, discursiveness, transdisciplinarity, transproblems, pedagogical integration.

Considering the specified disciplinary-methodological matrix within the framework of the discursive paradigm and ideas of social constructivism, we can note that it is presented as a discursive-narrative and cognitive-cognitive prerequisite for the formation of a professional health care discourse. At the same time, it defines the main concepts (cognitive, value) and determines the typical ways of their conceptualization. Accordingly, the specified disciplinary-methodological matrix as a knowledge-cognitive prerequisite of professional discourse is aimed at the formation of professional reality. This is realized, first of all, in the format of health-preserving discourse, which constructs health, forming it in a special social world – cultural and educational space. At the professional-personal, cognitive, mental-psychological levels, the educational result of the application of the specified matrix is the formation of a specialist's cognitive system of health preservation as a specific intellectual-value-ethical neoplasm, formally presented in the format of the intellectual-value component of health-preserving competence physical education teacher.

Disciplinary-methodological matrix is a *level cognitive-value knowledge system* formed on the basis of dynamic, targeted interaction and structuring and integration of various disciplines (and their systems) (mainly anthropologically and health care oriented), systems of knowledge, discourses and narratives, ideas, values, meanings, methods and strategies of problematization and conceptualization, etc. Disciplinary-methodological matrix of physical education teacher health-preserving competence is considered by us as a *cognitive-value-educational and anthropoculturally oriented meta-technology*, developed by structuring and integration based on: 1) target, axiological, competence approaches; 2) selection, integration and interaction of disciplinary, discursive, conceptual, procedural, practical and technological knowledge, algorithms, cognitive schemes, images, forms of actions, values, meanings, intentions; 3) transfer of knowledge, transfer of technologies and transfer of values and 4) their pedagogical integration; 5) application of epistemological, transdisciplinary, interdisciplinary, transproblematic approaches.

When forming the specified matrix, as well as available cognitive, methodological and methodical ways of developing the health-preserving competence of the physical education teacher, we use a system of strategies, the main ones of which are presented below.

Teleological strategy: it is based on consideration of the physical education teacher's professional activity as the unfolding of his high internal goal – telos (Greek $\tau\epsilon\lambda o\zeta$; Latin telos), a mission aimed at preserving life, health and human development.

The strategy of intellectualization is determined by the application of complex configurations of disciplines, problems and their solutions with synchronous, interdependent actualization of both theoretical and practical issues, as well as a focus on the development of health-preserving thinking, including metacognition, intellectual and value reflections and interpretations.

The strategy of selecting levels, which are considered as relatively autonomous and isolated stages and/or components of the development of the teacher's health-preserving competence. Based on the target principle, 6 levels are distinguished, which are also presented as metacognitive tools for improving the specified competence.

Anthropologization strategies are considered as a way of revealing the nature of man as a spiritual, psychological, ethical, cultural, existential and bodily being based on the actualization of the potential of physical anthropology, human biology and humanitarianism, which includes such disciplinary areas as anthropology, cultural studies, art, ethics, philosophy, etc. "Stage I – anthropocultural" corresponds to this strategy. This strategy is integrative and includes the following strategies: *ethnoization, axiologisation, aestheticization, existentialization, psychologization.* In the system of these strategies, a person is considered idealized as healthy and normative (the norm as an ideal of humanity, mercy, health and a prerequisite for development) (in relation to the inclusive doctrine, this corresponds or to some extent correlates with the concept of typical development). Accordingly, an inclusive paradigm is used, in the system of ideas of which we consider a person with special educational needs as a normative (idealized version), but with special educational needs, which excludes any discrimination.

The patho-pedagogical strategy is presented by considering a person in special or marginal forms – in pathological states, in marginal states, in systems of risks for health and for development. The specified strategy, which is formed by the "Stage II – patho-pedagogical" level, has such components-strategies as *etiological (etiotropic), pathogenetic, nosological, prognostic.*

The etiotropic (etiological) strategy is presented as central and determining. Its essence is to consider the causes, risks and conditions of the formation of certain disorders (in this study, sudden cardiac death) as determining and essential in their prevention and correction. Therefore, this strategy is systemic, system-organizing, end-to-end, determining, basic, dominating over others.

The epistemological axis "general – specific" is a strategy that determines the specifics of the entire disciplinary matrix, which is formed on the basis of the "development of cognition" from generalized ideas and knowledge to specific knowledge, skills, and actions. This strategy also defines the following strategies: concretization (specification) of knowledge and values, actions; technologies; professionalization.

The epistemological axis "methodologisation – technologization" is a strategy that determines the purposeful application of general and theoretical knowledge for the analysis of practical problems. This, accordingly, includes the development of conceptual, procedural knowledge and the ability to conceptualize and interpret both pathological and normative phenomena.

The propaedeutic strategy, which corresponds to "Level III – propaedeutics of health", is presented as the ability to apply general and theoretical knowledge about a person and about pathologies for the prevention and correction of educationally significant violations, as well as for the development of health, the formation of a health-preserving discourse, development of a safe and healthy educational environment, safe organization of motor activity, development and creativity.

The therapeutic strategy that corresponds to "Level IV – health therapy" is represented as the ability to apply practical and specified (specified, expanded, in-depth, targeted, practically directed) knowledge about a person and about certain pathologies for the prevention and correction of significant disorders in a certain specific person , as well as for the development of health in a specific person. The therapeutic strategy also includes the development of the abilities and skills of the physical education teacher to form dialogic communication on the issue of health preservation and prevention of pathology (in this case, acute cardiac disorders and sudden cardiac death); application of the health-preserving protocol as a specific diagnostic and preventive technology; development of an individual student's motor activity program in accordance with his state of health and taking into account the probable risks of forming violations, the student's wishes and his individual, age, and gender characteristics.

The technology strategy is decisive and system-organizing. Based on its implementation, the indicated matrix was formed. It includes consideration of: 6 levels ("metalevels") as relatively autonomous and specific stages (and, at the same time, as relatively independent components) of educational technology; the presence of intra-level structuring (and/or partially stages) in each of the 6 "meta-levels", which determines the sequence and specificity of the formation of knowledge, abilities, skills, health-preserving thinking, methods of conceptualization in the system of each "meta-level"; level structure, which determines the algorithmization of typical educational and health-preserving interactions, tactics and strategies; the targeted orientation of the system on the development of the specialist's abilities to effectively preserve life and health; implementation of transdisciplinarity and transproblems in a technological format, which is a purposeful selection of configurations (or clusters) from certain disciplinary and problem areas with the aim of developing certain abilities of a specialist.

The strategy of contextualization is a component of the strategy of technologization and consists in the purposeful creation of cognitive-knowledge, value-meaning, professional-cultural contexts, which form the contextual basis of the specialist's health-preserving activities and the development of a safe and healthy educational environment. For example, such a value-emotional context in relation to the problem of sudden cardiac death is represented by ideas about the merciful character of a person. These ideas in most cultures are contained in their value-semantic contexts and are currently reflected in the trends of humanism, humanization and the philosophy of cordocentrism.

The strategy of creating methodical disciplines is implemented as a "methodological-disciplinary" tool of technology and, accordingly, is aimed at increasing the effectiveness of education. Methodical disciplines (in this case, it is "Patopedagogy", "Propaedeutics of health" and "Health therapy") are created with the aim of highlighting certain significant educational aspects. For example, "Propaedeutics of health" focuses on general knowledge of the problem, on ethical, value, and discursive and communicative aspects. In "Health Therapy" there is a transition to concrete knowledge, to dialogic practices from monologic ones, the ethical potential of the individual is actualized and transformed into the psychology of interaction with a specific person. Without health therapy, even a high level of training will be "remote" from reality, accordingly, there will be limited application, mainly in the format of promoting general approaches, for example, a healthy lifestyle "in general", etc.

The strategy of professionalization is determined by the complex, multi-level, systematic organization of the disciplinary-methodological matrix of the physical education teacher and, above all, is connected with its practical and technological direction, which includes, first of all, the specialist's ability to effectively work with specific people, phenomena, problems based on the application of systems of approaches and cognitive tools.

An experimental study was conducted aimed at improving the health-preserving competence of a physical education teacher in the conditions of postgraduate education, which included an analysis of the dynamics of the formation of the intellectual ability of a physical education teacher to prevent sudden cardiac death based on knowledge of the causes and mechanisms of the development of this disorder. As a result of testing using the Fedorets test "Analysis of etiological risk factors for the development of sudden cardiac death during physical exertion", the positive dynamics of learning outcomes in the experimental group was determined. That is, after applying the technique "Etiotropic technology of prevention of sudden cardiac death", the mean value of the percentage of correct answers in the experimental group was 80.29%, which is 73% more than the mean value of the percentage of correct answers before the training of students using this technique. In the process of the research, the statistical significance of these results was proved using the Wilcoxon signed-rank test. The specified dynamics are due to the application of the metatechnology of the disciplinary-methodological matrix of the health-preserving competence of the physical education teacher and the significance of this problem for the professional activity of the teacher.

The specified strategies for the prevention of sudden cardiac death are relatively autonomous cognitive, cognitive-knowledge, cognitive-cultural tools, available both in the disciplinary-methodological matrix system, and such that can act relatively separately. These strategies act synergistically, systematically, interdependently, purposefully, problem-oriented. Although competitive interactions are possible between these strategies. Therefore, we present the etiotropic (etiological) strategy as the determining and dominant health-preserving strategy, which is the basis of the "Etiotropic method of prevention of sudden cardiac death". The necessary disciplinary-methodological matrix can be constructed for the formation of various competencies and goals and design of training.

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References

[1] Klochko O V and Fedorets V M 2022 *Educational Technology Quarterly* **2022**(4) 276–306 URL `https://doi.org/10.55056/etq.431`

[2] Gräsner J T, Herlitz J, Tjelmeland I B, Wnent J, Masterson S, Lilja G, Bein B, Böttiger B W, Rosell-Ortiz F, Nolan J P, Bossaert L and Perkins G D 2021 *Resuscitation* **161** 61–79 ISSN 0300-9572 european Resuscitation Council Guidelines for Resuscitation 2021 URL `https://doi.org/10.1016/j.resuscitation.2021.02.007`

[3] Kelly K L, Lin P T, Basso C, Bois M, Buja L M, Cohle S D, d'Amati G, Duncanson E, Fallon J T, Firchau D, Fishbein G, Giordano C, Leduc C, Litovsky S H, Mackey-Bojack S, Maleszewski J J, Michaud K, Padera R F, Papadodima S A, Parsons S, Radio S J, Rizzo S, Roe S J, Romero M, Sheppard M N, Stone J R, Tan C D, Thiene G, van der Wal A C and Veinot J P 2023 *Cardiovascular Pathology* **63** 107497 ISSN 1054-8807 URL `https://doi.org/10.1016/j.carpath.2022.107497`

[4] Klochko O, Fedorets V, Maliar O and Hnatuyk V 2020 *E3S Web of Conferences* **166** 10033 URL `https://doi.org/10.1051/e3sconf/202016610033`

[5] Yevtuch M, Fedorets V and Klochko O 2020 Methodological reflection on the heterochronia in the context of development of a health preserving competence of a physical education teacher *Society. Integration. Education. Proceedings of the International Scientific Conference* vol 2 pp 467–483

[6] Boden B P, Fine K M, Breit I, Lentz W and Anderson S A 2020 *Orthopaedic Journal of Sports Medicine* **8**(8) 2325967120942490 URL `https://doi.org/10.1177/2325967120942490`
[7] Peterson D F, Kucera K, Thomas L C, Maleszewski J, Siebert D, Lopez-Anderson M, Zigman M, Schattenkerk J, Harmon K G and Drezner J A 2021 *British Journal of Sports Medicine* **55**(21) 1196–1203 ISSN 0306-3674 URL `https://doi.org/10.1136/bjsports-2020-102666`
[8] Clarivate 2023 Web of Science URL `https://www.webofscience.com/wos/woscc/basic-search`
[9] Centre for Science and Technology Studies, Leiden University, The Netherlands 2023 VOSviewer - Visualizing scientific landscapes URL `https://www.vosviewer.com/`
[10] Bagnall R D, Singer E S and Tfelt-Hansen J 2020 *Heart, Lung and Circulation* **29**(4) 498–504 ISSN 1443-9506 genetic Heart Diseases 2020 URL `https://doi.org/10.1016/j.hlc.2019.11.007`
[11] Teoh S E, Masuda Y, Tan D J H, Liu N, Morrison L J, Ong M E H, Blewer A L and Ho A F W 2021 *Annals of Intensive Care* **11**(1) 169 ISSN 2110-5820 URL `https://doi.org/10.1186/s13613-021-00957-8`
[12] Dorian P, Allan K S and Connelly K A 2022 *Canadian Journal of Cardiology* **38**(11) 1693–1696 URL `https://doi.org/10.1016/j.cjca.2022.09.014`
[13] McKinney J, Connelly K A, Dorian P, Fournier A, Goodman J M, Grubic N, Isserow S, Moulson N, Philippon F, Pipe A, Poirier P, Taylor T, Thornton J, Wilkinson M and Johri A M 2021 *Canadian Journal of Cardiology* **37**(8) 1165–1174 ISSN 0828-282X URL `https://doi.org/10.1016/j.cjca.2020.11.007`
[14] Kaye D M, Nanayakkara S, Wang B, Shihata W, Marques F Z, Esler M, Lambert G and Mariani J 2022 *JACC: Basic to Translational Science* **7**(2) 116–127 ISSN 2452-302X URL `https://doi.org/10.1016/j.jacbts.2021.11.007`
[15] Manolis A A, Manolis T A, Apostolopoulos E J, Apostolaki N E, Melita H and Manolis A S 2021 *Trends in Cardiovascular Medicine* **31**(5) 290–302 ISSN 1050-1738 URL `https://doi.org/10.1016/j.tcm.2020.04.011`
[16] Depes D, Mennander A, Paavonen T and Kholová I 2022 *Cardiovascular Pathology* **59** 107426 ISSN 1054-8807 URL `https://doi.org/10.1016/j.carpath.2022.107426`
[17] Tse R, Garland J, McCarthy S, Ondruschka B, Bardsley E N, Wong C X, Stables S and Paton J F R 2022 *Forensic Science, Medicine and Pathology* **18**(2) 156–164 ISSN 1556-2891 URL `https://doi.org/10.1007/s12024-022-00466-5`
[18] Chang Liu M, Tester M A, Franciosi S, Krahn A D, Gardner M J, Roberts J D and Sanatani S 2021 *CJC Open* **3**(3) 285–291 ISSN 2589-790X URL `https://doi.org/10.1016/j.cjco.2020.10.016`
[19] Maturana M A, Glover E A, Raja J, Dornbush S R, Alexander J, Blount C, Khouzam N R, Khouzam A R and Khouzam R N 2021 *Current Problems in Cardiology* **46**(3) 100743 ISSN 0146-2806 URL `https://doi.org/10.1016/j.cpcardiol.2020.100743`
[20] Esler M 2022 *Autonomic Neuroscience* **237** 102925 ISSN 1566-0702 URL `https://doi.org/10.1016/j.autneu.2021.102925`
[21] Boudoulas K D, Pitsis A, Triposkiadis F, Han Y, Savona S J, Stefanadis C and Boudoulas H 2022 *Progress in Cardiovascular Diseases* **74** 89–98 ISSN 0033-0620 URL `https://doi.org/10.1016/j.pcad.2022.10.010`
[22] Čulić V, AlTurki A and Proietti R 2021 *Resuscitation* **162** 154–162 ISSN 0300-9572 URL `https://doi.org/10.1016/j.resuscitation.2021.02.036`
[23] Javalkar V, Amireh A and Kelley R E 2021 Neurological complications of syncope and sudden cardiac arrest *Heart and Neurologic Disease* (*Handbook of Clinical Neurology* vol 177) ed Biller J (Elsevier) chap 18, pp 189–192 URL `https://doi.org/10.1016/B978-0-12-819814-8.00025-1`
[24] Corrado D and Zorzi A 2023 *International Journal of Cardiology* **370** 472–475 URL `https://doi.org/10.1016/j.ijcard.2022.10.006`
[25] Monda E, Lioncino M, Rubino M, Caiazza M, Cirillo A, Fusco A, Pacileo R, Fimiani F, Amodio F, Borrelli N, Colonna D, D'Onofrio B, Frisso G, Drago F, Castelletti S, Sarubbi B, Calabrò P, Russo M G and Limongelli G 2022 *Heart Failure Clinics* **18**(1) 115–123 URL `https://doi.org/10.1016/j.hfc.2021.07.002`
[26] D'Ascenzi F, Valentini F, Pistoresi S, Frascaro F, Piu P, Cavigli L, Valente S, Focardi M, Cameli M, Bonifazi M, Metra M and Mondillo S 2022 *Trends in Cardiovascular Medicine* **32**(5) 299–308 ISSN 1050-1738 URL `https://doi.org/10.1016/j.tcm.2021.06.001`
[27] Lee R N, Rodrigues T S, Gan J T, Han H C, Mansour R, Sanders P, Farouque O and Lim H S 2023 *JACC: Clinical Electrophysiology* URL `https://www.jacc.org/doi/abs/10.1016/j.jacep.2023.01.010`
[28] Ha A C T, Doumouras B S, Wang C N, Tranmer J and Lee D S 2022 *Canadian Journal of Cardiology* **38**(4) 465–478 ISSN 0828-282X focus Issue: Ventricular Tachycardia and Sudden Death URL `https://doi.org/10.1016/j.cjca.2022.01.007`
[29] Mehta L S, Velarde G P, Lewey J, Sharma G, Bond R M, Navas-Acien A, Fretts A M, Magwood G S, Yang E, Blumenthal R S *et al.* 2023 *Circulation*
[30] Huber A and Chapa S 2022 *Journal of Cultural Marketing Strategy* **7** 34–48
[31] Herbst J H 2023 *Religions* **14**(2) 145 ISSN 2077-1444 URL `https://doi.org/10.3390/rel14020145`

[32] Kraus A and Wulf C (eds) 2023 *The Palgrave Handbook of Embodiment and Learning* (Cham: Palgrave Macmillan) URL https://doi.org/10.1007/978-3-030-93001-1

[33] Fedorets V M, Yevtuch M B, Klochko O V, Kravets N P and Grynyov R S 2021 *SHS Web of Conferences* **104** 02006 URL https://doi.org/10.1051/shsconf/202110402006

[34] Takeuchi H and Nonaka I 2004 *Hitotsubashi on knowledge management* (Wiley)

[35] Obembe F and Obembe D 2020 Deep learning and tacit knowledge transfer: An exploratory study *European Conference on Knowledge Management* (Academic Conferences International Limited) p 556

[36] Foucault M 1988 *Technologies of the Self: Lectures at University of Vermont Oct. 1982* (Cambridge: University of Massachusets Press)

[37] Popa A 2020 Conceptualizarea libertății: critică, rezistență, artă a existenței [The conceptualization of freedom: criticism, resistance, the art of existence] *Şcoala internaţională de metodologie în ştiinţele socioumane. Chişinău, Moldova, 19-20 noiembrie 2020* pp 50–51 URL https://ibn.idsi.md/vizualizare_articol/120127

[38] Dubinsky O H 2020 *Educational Dimension* **2** 111–121 URL https://doi.org/10.31812/educdim.v54i2.3860

[39] Zhorova I, Kokhanovska O, Khudenko O, Osypova N and Kuzminska O 2022 *Educational Technology Quarterly* **2022**(1) 56–72 URL https://doi.org/10.55056/etq.11

[40] Klochko O V, Tkachenko S V, Babiichuk I M, Fedorets V M and Galych T V 2022 Using Virtual Reality Technologies for Teaching Computer Science at Secondary School *ICTERI 2021 Workshops* (*Communications in Computer and Information Science* vol 1635) ed Ignatenko O, Kharchenko V, Kobets V, Kravtsov H, Tarasich Y, Ermolayev V, Esteban D, Yakovyna V and Spivakovsky A (Cham: Springer International Publishing) pp 231–246 ISBN 978-3-031-14841-5 URL https://doi.org/10.1007/978-3-031-14841-5_15

[41] Posit Software, PBC 2022 Posit Cloud URL https://posit.cloud/

[42] Bilousova L, Gryzun L and Zhytienova N 2021 *Educational Technology Quarterly* **2021**(3) 415–428 URL https://doi.org/10.55056/etq.34

Journal of Physics: Conference Series

PAPER • OPEN ACCESS

Digitization of learning environment of higher education institutions: conceptual foundations and practical cases

To cite this article: O H Kuzminska *et al* 2023 *J. Phys.: Conf. Ser.* **2611** 012024

Digitization of learning environment of higher education institutions: conceptual foundations and practical cases

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Abstract. Digital transformation involves the use of digital technologies for rebuilding processes and increasing their efficiency. It is confirmed by the results of the research on transformational processes in various spheres. This research paper deals with the development (modernization) of digital learning environments of higher education institutions, which creates conditions for creating models of real production and social processes by means of modern digital technologies. It will strengthen the competence potential of all the stakeholders of higher education institutions, which train specialists in digital technologies. The need to upgrade the existing educational environments of higher education institutions in the context of crisis situations related to global challenges (for example, COVID-19) or the specifics of a specific country (the war in Ukraine) or an educational institution is substantiated. The research paper specifies a conceptual model of the next generation digital learning environment of a higher education institution, which involves the distribution of resource distribution and provision of integration of resources, data and users according to three levels (micro, meso and macro levels), and provides the cases of its implementation in National University of Life and Environmental Sciences of Ukraine and Borys Grinchenko Kyiv University. The monitoring data are presented both at the level of external (development of the component composition of the environment) and internal (change of organizational processes according to the students' demand) design of the environment. The need for designing a change management system at the level of a higher education institution or its structural subdivisions is identified.

1. Introduction

The idea of digitalization is aimed at the use of the technologies not only for the automatization of the existing business processes of production and the sphere of service sector, but also for the creation of the fundamentally new ones. Accordingly, the economic development and competitiveness of modern states largely depend on the availability of educated and competent specialists as well as technologies that increase the productivity of their activities. Thus, in the report on global competitiveness for 2020, the upgrade of infrastructure and education curricula, investment in research and innovation in order to create "markets of tomorrow" [1] are identified as priorities for expanding the capabilities of human capital which, as a result, will stimulate the long-term digital transformation of the economy.

In the other document "World Economic Forum Annual Report 2021-2022" [2], experts focus on learning, development and growth. In particular, this document states the necessity to cultivate a learning organization, as well as to design courses on change management and targeted programs for managing people and teams in higher education institutions.

Every year Horizon experts identify trends, technologies and practices that shape the future of technologies affecting the development of higher education [3, 4], the digital transformation (DT) of higher education is at hand [5,6] is not being currently implemented, but it is extremely relevant, as these approaches allow us to describe complex relations between subjects in the technologically supported educational sphere [7].

If for business the need and adoption of digital transformation is rather a question of survival, for educational organizations the introduction of digital technologies can help institutions become more competitive [8]. However, as it is evidenced by the results of the research by Rodríguez-Abitia and Bribiesca-Correa [9] regarding the assessment of the state of digital transformation of higher education institutions, universities in this process are significantly inferior to institutions of other industries. At the same time, Rof et al. [10] emphasize that the future of higher education depends on the ability of its managers to foresee the process of digital transformation and manage it in a new competitive environment.

According to the systematic literature review of digital transformation in higher education institutions, carried out by Benavides et al. [11], the following DT dimensions were highlighted: Research (RE), Teaching (TE), Business Process (BP), Human Resource (HC), Curricula (CU), Infrastructure (IN), Administration (AD), Marketing (MK), Information (INF).

Comparing digital innovations and digital transformation, Drechsler et al. [12] propose to consider digital transformation (and we share this assumption) from the point of view of the relationship between changes in the structure, strategy and technologies as a response to the requirements for the modern digital educational environment, emphasizing the need for a balance between its existing and new elements. Since the authors of the study research digital transformation of higher education institutions from the technological, organizational and social points of view, the need for the development (modernization) of the institutional digital learning environments becomes an actual one.

This research paper aims to provide a rational behind a conceptual model of the structure of the next generation university digital learning environment (NGDLE) and illustrate the practical cases of its implementation in Ukrainian universities.

2. Conceptual model of the structure of the next generation university digital learning environment

Although higher education institutions still use centralized models of supporting learning process, for example, ones based on learning management systems, massive digitalization and modern students' needs actualize the necessity to create next generation digital learning environments (NGDLE) [13].

Lane and Goode [14] define NGDLE as a distributed, loosely coupled component model consisting of free and open source software designed to provide:

- constant integration and interaction of various teaching aids and research tools;
- encouragement and support of the personalization and collaboration of all users or separate groups;
- availability of educational tools for the analysis of students' data and course information used by the teachers and learning design support staff.

The expectations of modern students regarding the increased integration of digital technologies in their learning environments laid the foundation for the design of the NGDLE models. A description of cases of design and implementation of the NGDLEs in the learning process, namely Motivational Active Learning (MAL) and Task-Test-Monitor (TTM) is presented in [15].

In the Netherlands and Denmark the effectiveness of using the NGDLEs for further integration into the social context, such as social interactions outside of formal institutional settings and social media, aimed at the improvement of new digital learning practices is confirmed in [16]. In particular, Ossiannilsson et al. [16] the impact of the NGDLEs on the development of personal learning environments (PLE) of the stakeholders of higher education institutions. Under the conditions of the NGDLEs the students study with other people, control their own educational resources, integrate their learning in different institutions, get knowledge from various sources and manage their own activities as well. Basically, faculties and students will use the NGDLE to design their personal learning environments (CLEs) so that each participant will be able to maximize their own potential.

The idea is confirmed by the results of studies, carried out by non-profit educational organizations. These studies deal with the design and development of learning environments as well as with monitoring and evaluation of their effectiveness:

- according to Edutainme the aim of the digital learning environment is to declare the principles of creating digital learning environments where a student will be the subject of learning process and will be responsible for his or her own development [17];
- within the framework of the concept of the "Next Generation Digital Learning Environment" (NGDLE), EDUCAUSE looks for a balance between the openness of education and the need for connection of education with environment; emphasizes personalization, collaboration, accessibility and universal learning design [18].

At the same time, the issue of upgrading the existing learning environments of higher education institutions [19] for the creation of NGDLEs with subsequent expansion to digital learning ecosystems remains uncovered. The specified need is actualized due to the fact that modern environments of higher education institutions function in crisis situations related, for example, to COVID-19 (global challenges) or the war on the territory of Ukraine (the local context).

In our opinion, in order to ensure flexibility within the existing digital learning environments at the level of individual components, academic program or individual learning trajectory of a separate student, it is necessary to ensure sufficient control and support provided at the level of higher education institution. One of the ways to solve this task is to manage the content of programs and services at the institutional level by means of ensuring a high level of reliability, security and freedom of users' choice. In the Netherlands, as part of the SURFnet project, the metaphors of "fortress" and "open city" were introduced [20]. It is necessary to decide on the definition of components (functional elements, programs, services) for centralized and decentralized management, as well as tools that are not subjects of the institutional management. In order to make an appropriate decision, the manifestation of each functional component of the environment is evaluated according to a three-point scale (low, medium, high) against the following criteria: confidentiality, integrity and availability of data inside the component. Components with a high level of manifestation against one or more criteria are placed in the "fortress". These are components which the institution has the greatest control over (centralized management). As a rule, these components include business processes and, accordingly, the tools for learning content design, management of educational analytics data, evaluation of learning outcomes of educational activities, etc. Components that are located in the "city" have a medium or low level of manifestation against the specified criteria. Formal and informal learning, conducting research, educational and scientific communication take place in the "city" but with the use of resources and data from the "fortress". There is more freedom in the "city"; management, in most cases, is decentralized (occurs at the level of separate departments, structural divisions, academic programs and project teams), however, at the institutional level, performance criteria of evaluation are determined, monitoring and control are carried out. In the "country", surrounding the "fortress" and "city", processes of external communication, cooperation, implementation of academic and scientific mobility take place. Maximum freedom of the users is guaranteed.

If we take the approaches of the SURFnet project regarding the creation of the NGDLEs of higher education institutions, when designing the IT infrastructure, as a basis (figure 1), let's distribute the resource provision according to the following levels:

- micro-level (corresponds to the "fortress" metaphor) involves centralized institutional management, increased confidentiality and security, integration of both resources and users; it takes place at the level of one institution;
- meso-level (corresponds to the "city" metaphor) includes institutional re-sources and services external users have access to;
- macro-level (corresponds to the "country" metaphor) at the institutional level involves the integration of external resources (services, platforms) into the institutional NGDLE in order to solve educational tasks with the subsequent integration of stakeholders of learning process into a single educational and scientific environment (personal learning environments tend to expand due to the implementation of active personal learning and scientific activities); it presupposes a subsequent expansion of the functionality and resource provision of the institutional digital environment (if necessary) according to the users' demand.

At the same time, it should be noted that the proposed distribution is a quite conditional one. For example, Google Workspace or MS Office 365 cloud services can be used at all levels, as it depends on the category of participants, educational tasks and pedagogical technologies used for their fulfillment. As a kind of example we can mention a joint work on the creation of electronic documents or implementation of joint projects within the framework of the course "Information Technologies" [21]. It is a case that illustrates the development of students' approximate set of actions necessary for the effective group work. Therefore, the use of the corporate cloud occurs at the micro-level.

In case when the third-party users join the work (mesolevel), the access to joint work with certain shared documents or services can be given by the students themselves or the registration in the corporate segment at the administrator level may be allowed. The case illustrating the tasks which require such actions is the use of the corporate community for professional development or the creation of shared knowledge using Wiki platforms (e.g., `http://wiki.kubg.edu.ua`). An example of the integration of resources (technical, human) at the macro-level is an institutional subscription to Google Workspace or MS Office 365, as well as joining external cloud services.

It is obvious that not all the resources can be used at different levels. In fact, the component composition of such environments varies depending on the tasks and capabilities of a separate higher education institution. On one hand, University of Wisconsin-Madison uses Canvas as the main LMS, and the DLE component composition is more focused on supporting the learning process (`https://kb.wisc.edu/page.php?id=65466`). On the other hand, digital learning environment of Borys Grinchenko Kyiv University is larger (`https://digital.kubg.edu.ua/`) and LMS Moodle is used to support e-learning.

3. Case study of the NGDLE model implementation

While exploring learning environments from the point of view of pedagogy, scientists reveal the specific effects of their influence on the subjects of the educational process. These stakeholders are carriers of certain experiences and tools (in particular, it goes about personal learning environment). Therefore, it is advisable to monitor and adjust the components of DLE at

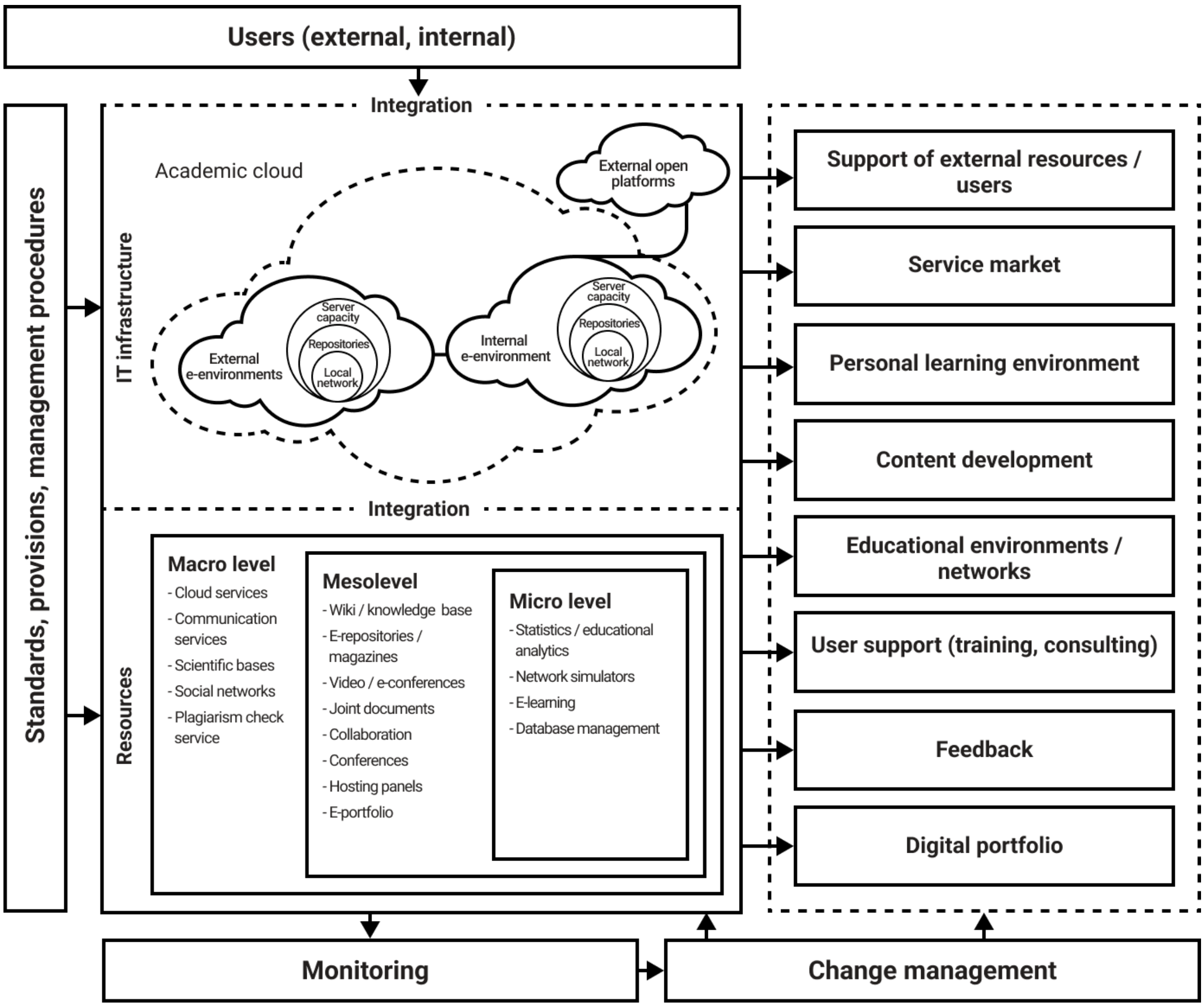

Figure 1. Conceptual model of the next generation university digital learning environment.

the level of external design with the involvement of project team representatives from among institutional and external experts. This process should be based on the analysis of technological and educational trends, requirements for the organization and digitalization of educational and scientific activities of higher education institutions, in particular, standards of higher education (figure 1). There is one more factor in the improvement (transformation) of the institutional digital learning environment. There should be relevant results of evaluating the effectiveness of the environment application for further formation (internal design). In this case, subjects of educational and scientific activity of a higher education institution act as experts [22].

For example, based on the results of an expert evaluation of the effectiveness of the designed DLE application [22], the project teams of Borys Grinchenko Kyiv University and the National University of Life and Environmental Sciences of Ukraine initiated the expansion of the component composition of the institutional digital learning environments (table 1) in accordance with the requirements of strengthening the scientific share, in particular, according to the results of the rating of higher education institutions [23].

Accordingly, certain steps were taken regarding the integration of resources, data and subjects of educational and scientific activity, namely:

- institutional means of supporting scientific communication (improvement of resource

Table 1. Means of scientific communication in the structure of the institutional learning and scientific environment.

Category	National University of Life and Environmental Sciences of Ukraine	Borys Grinchenko Kyiv University
Institutional repository	Institutional repository of National University of Life and Environmental Sciences of Ukraine `http://elibrary.nubip.edu.ua`	Institutional repository of Borys Grinchenko Kyiv University `http://elibrary.kubg.edu.ua`
Repository of Master's theses	Repository of Master's theses `http://studtheses.nubip.edu.ua`	Database of Master's theses `http://studbase.kubg.edu.ua`
E-journals	E-journals of National University of Life and Environmental Sciences of Ukraine `http://journals.nubip.edu.ua`	Open educational e-environment of modern University `http://openedu.kubg.edu.ua`
E-conferences	Online scientific conferences `http://econference.nubip.edu.ua`	Scientific conferences and seminars of the Borys Grinchenko Kyiv University `http://conf.kubg.edu.ua/`

support according to the students' demand) were created; it was done with a purpose of modeling business processes of scientific communication [24] and acquisition of relevant experience by young researchers (Master's students, postgraduate students); in particular, Master's students submitted their scientific publications to the institutional e-journal (e.g., `http://masters.kubg.edu.ua`) and passed the stage of scientific paper review; this is the way how the DLE components were improved in technological and organizational aspects before being integrated at the micro-level (in the higher education institution);

- scientific e-conferences were held (e.g, `http://econference.nubip.edu.ua`), including conferences for young scientists [25] and publications in the open access journals (e.g, `https://openedu.kubg.edu.ua`) with the involvement of other scholars, external experts (reviewers, key speakers); educational and scientific communication was expanded due to the involvement of leading experts; it ensured the integration of scientific communication tools at the meso-level;
- source base of research was expanded by providing access to scientometric databases such as Scopus and Web of Science (institutional subscription), students were involved in project activities and academic mobility through the organization of internships and dual degree studies. Implementation of the proposed functionality creates conditions for ensuring integration at the macro-level, however, the implementation of these conditions depends on the activity of Master's students, the scientific potential of higher education institutions and level of competence of scientific and scientific-pedagogical staff.

Improvement of the NGDLE concept and implementation of the proposed model (figure 1) in 2 universities prove the relevance of similar projects which meet the requirements of the transformational challenges of modern society [26] namely:

- strengthening the competence potential of the digital environment, which not only enhances the improvement of digital literacy but also promotes digital equity;
- increased requirements to resource support, which can be considered the basis for the implementation of individual learning trajectories, a transformation of educational activities taking into account individual learning styles and authentic learning experiences;

- leading role of educational and scientific communication as a learning technology can be explained by the readiness to use digital environment for collaborative learning, in particular, for the establishment of cross-institution and cross-sector collaboration);
- initiation and support of external communication, which contributes to the dissemination of experience, promotes new professional ties and stimulates an active search for partners, experts, etc. It confirms the need for cross-institution and cross-sector collaboration and adaptation of the learning process to real (production) business processes of the digital economy.

At the same time, change management is an important aspect of the development of learning environments in the digital age (figure 1). It is a systematic approach aimed at the creation of strategies and methods that will be used to implement changes and develop the ability of subjects of the learning process of a higher education institution to effectively respond to these changes and adapt to them [27]. We agree with Sartori et al. [27] that "training, development, and innovation are three different but interconnected functions by which organizations manage change". We consider this direction as a perspective for further research. In particular, there are some other areas of research that require more detailed attention – monitoring changes in the implementation of e-learning with a focus on the use of digital technologies and tools for modeling the dynamics of industrial and social contexts (including individual behavior and group dynamics), as well as strengthening the competence potential of the subjects of the educational process of higher education institutions.

4. Conclusions

While working in the dynamic and interconnected internal and external environments of the modern digital age, organizations in general and higher education institutions, in particular, are faced with increasingly complex challenges trying to achieve sustained success.

Solution to these problems requires constant monitoring of the organizational context and control over it. It involves analysis and identification of risks and opportunities, as well as effective change management. In the case of higher education institutions, these processes are taking place in the digital learning environment, which is a complex project containing three main components: administrative, technological and educational. Moreover, the implementation of this project is ensured by different groups of specialists.

The need to create a next-generation digital learning environment (NGDLE) or to upgrade the existing educational environments of higher education institutions to the ecosystem consisting of learning tools and other components that adhere to common standards meets the requirements of digital transformation in a broad context and is amplified by the consequences of the pandemic for higher education in general, and there is an urgent need to preserve the quality of education in Ukraine under the conditions of military operations.

The functional model that implements a modular approach in the process of creating a digital educational environment is taken as the basis of the conceptual model of a new generation digital educational environment. The use of this model, namely the distribution of resource distribution and the provision of integration of resources, data and users according to three levels (micro, meso and macro levels), allows to respond flexibly to external challenges and monitor the effectiveness of both external and internal design.

Examples of the application of the proposed NGDLE conceptual model at two universities of Ukraine can be useful both to representatives of the administration of higher education institutions and to scientific and pedagogical workers and educational analysts for the development of modern digital educational environments of a specific educational institution.

Since the future of higher education depends on the ability of its managers to foresee the process of digital transformation and manage it in the modern competitive environment, it is the analysis and development of change management processes in the digital educational environment that can be referred to the prospects for further research.

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References

[1] Schwab K, Zahidi S and World Economic Forum 2020 The Global Competitiveness Report 2020 URL https://www3.weforum.org/docs/WEF_TheGlobalCompetitivenessReport2020.pdf
[2] World Economic Forum 2022 Annual Report 2021-2022 URL https://www3.weforum.org/docs/WEF_Annual_Report_2021_22.pdf
[3] Brown M, McCormack M, Reeves J, Brooks D C, , Grajek S, with Bryan Alexander, Bali M, Bulger S, Dark S, Engelbert N, Gannon K, Gauthier A, Gibson D, Gibson R, Lundin B, Veletsianos G and Weber N 2020 *2020 EDUCAUSE Horizon Report, Teaching and Learning Edition* (Louisville, CO: EDUCAUSE) URL https://library.educause.edu/resources/2020/3/2020-educause-horizon-report-teaching-and-learning-edition
[4] Pelletier K, Brown M, Brooks D C, McCormack M, Reeves J, , Arbino N, with Aras Bozkurt, Crawford S, Czerniewicz L, Gibson R, Linder K, Mason J, and Mondelli V 2021 2021 EDUCAUSE Horizon Report, Teaching and Learning Edition URL https://www.educause.edu/horizon-report-teaching-and-learning-2021
[5] EDUCAUSE 2023 Dx: Digital Transformation of Higher Education URL https://www.educause.edu/focus-areas-and-initiatives/digital-transformation
[6] Osadcha K, Osadchyi V, Kruglyk V and Spirin O 2021 *Educational Dimension* **5** 109–125 URL https://doi.org/10.31812/educdim.4721
[7] Alenezi M 2021 *Education Sciences* **11** 770 ISSN 2227-7102 URL https://doi.org/10.3390/educsci11120770
[8] Hashim A M, Tlemsani I and Matthews R D 2022 *Education and Information Technologies* **27** 8961–8996 URL https://doi.org/10.1007/s10639-022-10968-y
[9] Rodríguez-Abitia G and Bribiesca-Correa G 2021 *Future Internet* **13** 52 ISSN 1999-5903 URL https://doi.org/10.3390/fi13020052
[10] Rof A, Bikfalvi A and Marques P 2023 Digital Transformation in Higher Education: Intelligence in Systems and Business Models *Intelligent Systems in Digital Transformation: Theory and Applications* ed Kahraman C and Haktanır E (Cham: Springer International Publishing) pp 429–452 ISBN 978-3-031-16598-6 URL https://doi.org/10.1007/978-3-031-16598-6_18
[11] Benavides L M C, Tamayo Arias J A, Arango Serna M D, Branch Bedoya J W and Burgos D 2020 *Sensors* **20** 3291 ISSN 1424-8220 URL https://doi.org/10.3390/s20113291
[12] Drechsler K, Gregory R W, Wagner H T and Tumbas S 2020 *Communications of the Association for Information Systems* **47** 521–538 URL https://doi.org/10.17705/1CAIS.04723
[13] Baule S 2019 From LMS to NGDLE: The acronyms of the future of online learning URL https://www.ecampusnews.com/2019/04/09/lms-ngdle-future-online-learning
[14] Lane D C and Goode C 2021 *The International Review of Research in Open and Distributed Learning* **22** 146–163 URL https://doi.org/10.19173/irrodl.v23i1.5763
[15] Cheong C, Filippou J, Cheong F, Pirker J and Gütl C 2017 Using Persuasive System Design Principles to Evaluate Two Next Generation Digital Learning Environments *Interactive Collaborative Learning* ed Auer M E, Guralnick D and Uhomoibhi J (Cham: Springer International Publishing) pp 255–268 URL https://doi.org/10.1007/978-3-319-50340-0_22
[16] Ossiannilsson E, Eriksen N E and Rung-Hoch N 2017 Inspired Learning - The Next Generation Digital Learning Environment (NGDLE) *Proceedings of the 9th International Conference on Computer Supported Education - Volume 2: CSEDU* INSTICC (SciTePress) pp 263–267 ISBN 978-989-758-240-0 ISSN 2184-5026 URL https://doi.org/10.5220/0006378202630267
[17] Edutainme 2015 Digital Learning Environment Manifesto URL http://web.archive.org/web/20210724045546/http://manifesto.edutainme.ru/en
[18] Lynch M 2019 What is the next generation of digital learning environments? URL https://www.thetechedvocate.org/what-is-the-next-generation-of-digital-learning-environment
[19] Morze N V, Kuzminska O and Protsenko G 2013 Public Information Environment of a Modern University

Proceedings of the 9th International Conference on ICT in Education, Research and Industrial Applications: Integration, Harmonization and Knowledge Transfer, Kherson, Ukraine, June 19-22, 2013 (*CEUR Workshop Proceedings* vol 1000) ed Ermolayev V, Mayr H C, Nikitchenko M S, Spivakovsky A, Zholtkevych G, Zavileysky M, Kravtsov H, Kobets V and Peschanenko V S (CEUR-WS.org) pp 264–272 URL `https://ceur-ws.org/Vol-1000/ICTERI-2013-p-264-272.pdf`

[20] van Dompseler H, Ham R and de Wit M 2019 A flexible and personal learning environment: a modular functional model URL `https://www.surf.nl/files/2019-04/a-flexible-and-personal-learning-environment---a-modulair-functional-model.pdf`

[21] Glazunova O G, Kuzminska O G, Voloshyna T V, Sayapina T P and Korolchuk V I 2017 *Information Technologies and Learning Tools* **62** 98–113

[22] Cybermetrics Lab 2023 NEW: 20th Anniversary Edition (2004-2023) URL `https://www.webometrics.info/en/current_edition`

[23] Kuzminska O, Mazorchuk M, Morze N and Kobylin O 2019 Attitude to the Digital Learning Environment in Ukrainian Universities *Proceedings of the 15th International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer. Volume II: Workshops, Kherson, Ukraine, June 12-15, 2019* (*CEUR Workshop Proceedings* vol 2393) ed Ermolayev V, Mallet F, Yakovyna V, Kharchenko V S, Kobets V, Kornilowicz A, Kravtsov H, Nikitchenko M S, Semerikov S and Spivakovsky A (CEUR-WS.org) pp 53–67 URL `https://ceur-ws.org/Vol-2393/paper_245.pdf`

[24] Glazunova O G, Kuzminska O and Voloshyna T 2018 Scientific E-conference as a Tool of Development Students Research Competences: Local Study *Proceedings of the 14th International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer. Volume I: Main Conference, Kyiv, Ukraine, May 14-17, 2018* (*CEUR Workshop Proceedings* vol 2105) ed Ermolayev V, Suárez-Figueroa M C, Lawrynowicz A, Palma R, Yakovyna V, Mayr H C, Nikitchenko M S and Spivakovsky A (CEUR-WS.org) pp 379–393 URL `https://ceur-ws.org/Vol-2105/10000379.pdf`

[25] Becker S, Brown M, Dahlstrom E, Davis A, DePaul K, Diaz V and Pomerantz J 2018 *NMC Horizon Report 2018: Higher Education Edition* (Louisville, CO: EDUCAUSE) URL `https://library.educause.edu/~/media/files/library/2018/8/2018horizonreport.pdf`

[26] Fonseca L M and Domingues J P 2017 *Management & Marketing. Challenges for the Knowledge Society* **12** 443–455 URL `https://doi.org/10.1515/mmcks-2017-0027`

[27] Sartori R, Costantini A, Ceschi A and Tommasi F 2018 *Frontiers in Psychology* **9** 00313 ISSN 1664-1078 URL `https://doi.org/10.3389/fpsyg.2018.00313`

STEM education and personnel training: systematic review

STEM education and personnel training: systematic review

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Abstract. This article focuses on the generalization of foreign experiences in implementing STEM education and places particular emphasis on the areas of professional training for future teachers of STEM disciplines. By conducting bibliometric analyses of sources from Scopus (93 sources) and Web of Science (42 sources) scientometric databases, four clusters were identified using VOSviewer: 1) STEM education and training; 2) teacher training and primary education; 3) surveys on STEM education; and 4) e-learning and computational thinking in the training of future teachers of STEM disciplines. The research results demonstrate the importance and relevance of STEM education in various fields, and the leading role of the cluster "STEM education and training" has been determined based on the number and strength of links within the network of keyword links of sources on professional training of future STEM teachers. The discussion of the research findings highlights views on the prospects for STEM development in different countries. It is determined that: a) the professional training and social status of teachers are strategically important links in STEM education; b) teachers of "traditional" STEM disciplines (mathematics and natural sciences) require an increased level of knowledge in the field of information technology, particularly through the integration of programming as a component of STEM education; and c) social virtual reality platforms, hyperrealistic modeling, virtual laboratories, educational robotics, augmented, and mixed reality technologies are recommended to increase the motivation of pupils and students to study STEM disciplines.

1. Introduction

"The Concept of Development of Science and Mathematics Education (STEM Education)" [1] (hereinafter the Concept) defines that there are problems in science and mathematics education that are the result of general problems in general secondary education, in particular, the decline in the level of teaching of science and mathematics, imperfect educational content, the lack of relevance of the content of science and mathematics disciplines to the requirements of the present, the imbalance in the scope and content of curricula, etc.

The goal of developing STEM education is to comprehensively disseminate innovative teaching methods and combine the efforts of educational stakeholders and social partners in developing the necessary competencies of students to offer solutions to society's problems by combining science, technology, engineering, and mathematics. The implementation of the Concept is carried out taking into account the principles of ensuring the continuity of educational content and the introduction of course (adaptation, introductory) training of teachers of relevant specialties and the essential role of mathematics in the integrative approach to the implementation of STEM education.

STEM education can be realized at the primary, basic, and higher (professional) levels. The latter is implemented at the level of higher education, and its main task is to train specialists in various scientific, technical, and engineering professions at higher education institutions, as well as to improve the professional skills of teachers by introducing new teaching methods, relevant courses, and implementing innovative projects. The implementation of STEM education requires teachers and researchers to actively use the latest pedagogical approaches to teaching and assessment, innovations in education, practice of interdisciplinary training, and learning methodologies that promote to develop research and inventive competences of students [2, 3].

The Concept was adopted on 5 April 2020, and its implementation began during the COVID-19 pandemic and military operations [4], which significantly complicated its implementation at all levels and showed that a qualified teacher is a key element of the Concept implementation. Given that systematic work on the development of STEM education in Ukraine began much later than in other countries, the task of summarising foreign experience in STEM education and personnel training – the professional training of STEM teachers – is relevant.

2. Methodology

To identify the key concepts of the study of the problem of professional training of STEM teachers, a bibliometric analysis was conducted using VOSviewer [5] – a tool for building and visualising bibliometric networks.

The initial data for the analysis were sources from two leading scientometric databases: Scopus and Web of Science.

Search in Scopus on 13 January 2023 by query

```
(TITLE(teacher AND training) AND TITLE-ABS-KEY(stem))
```

provided 93 results.

Search in Web of Science on 13 January 2023 by search query

```
teacher training (Title) and STEM (Topic)
```

provided 85 results, 43 of which are a subset of Scopus results, and 42 are unique (available only in Web of Science).

The type of analysis in VOSviewer is co-occurrence and the unit of analysis is all keywords. The selection limit (the minimum number of occurrences of keywords) was set at 5, which made it possible to select 21 keywords out of 656. As a result of the analysis, a network of keyword links was built, shown in figure 1.

There are 6 standard weight and count attributes were used [5, pp. 34–35]: w_l is the weight of links: the number of links between the element and other elements; w_{tls} is the weight of the total link strength: the total strength of the element's links with other elements; w_o – when working with keywords, indicates the number of documents in which the keyword occurs; s_{apy} is the average year of publication of documents in which this keyword occurs; s_{ac} is the average number of citations of documents in which a given keyword appears; s_{anc} is the average normalised number of citations of documents in which a given keyword occurs.

3. Results

Table 1 shows the above weights and scores for each keyword. Clusters 1-4 from table 1 in figure 1 are visualised as follows: 1 (red): STEM education and training; 2 (green): teacher training and primary education; 3 (blue): surveys on STEM education; 4 (yellow): e-learning and computational thinking in the training of STEM teachers. Let's analyze the keywords in each cluster by the strength of the links.

In the first cluster "STEM education and training" the concepts of *personnel training* and *teaching* have the greatest number of links (19) – they are related to all other concepts except the

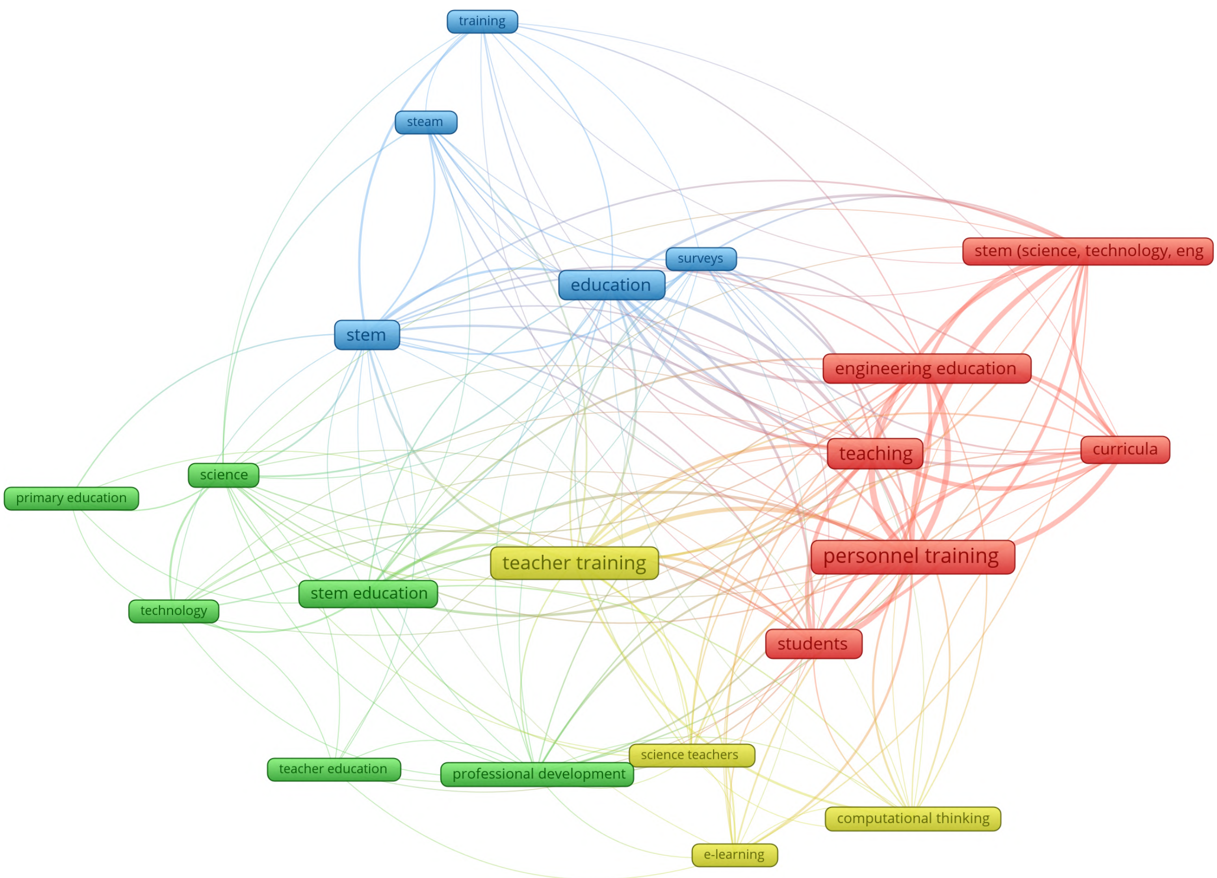

Figure 1. Network of keywords links for sources on professional training of STEM teachers in Scopus and Web of Science.

concept of primary education in the second cluster. A possible reason for this is that, according to the International Standard Classification of Education (ISCED) [6], primary education is classified as specialty 0113 – Teacher training without subject specialization, while the training of STEM teachers for specialties 014 and 015 in Ukraine corresponds to specialty 0114 – Teacher training with subject specialization. The next most connected concepts are engineering education and students, each with 18 links. The concept of *engineering education* is linked to all the concepts of clusters 3 and 4 and partially to the second cluster (there are no links to the concepts of primary education and teacher education). This can be explained by the fact that they belong to different fields of knowledge according to ISCED. The concept of *students* is also not related to the concept of primary education in the second cluster and STEAM in the third cluster. The latter may be due to the fact that the "A" component of STEM education is much more prevalent in primary and secondary education than in higher education. Curricula and STEM (science, technology, engineering and mathematics) concepts have 16 links each. *Curricula* are linked to all concepts of clusters 3 and 4, and in the second cluster – only to the concepts of professional development and science. *STEM (science, technology, engneering and mathematics)* is linked to all concepts of cluster 3, and also has links in cluster 2 – to the concepts of professional development, 3 – to the science and STEM education, and 4 – to the teacher training, e-learning and computational thinking. Thus, the concepts of the first cluster (STEM education and training) have the most connections with the third (surveys on STEM education) and fourth (e-learning and computational thinking in the training of STEM teachers) clusters.

Table 1. Distribution of keywords by clusters.

Keywords	Cluster	w_l	w_{tls}	w_o	s_{apy}	s_{ac}	s_{anc}
personnel training	1	19	165	37	2016.9189	3.7568	1.3322
teaching	1	19	122	26	2016.1154	9.2308	0.9856
engineering education	1	18	108	23	2015.2609	3.2609	1.235
students	1	18	93	21	2016	3.5714	1.1567
curricula	1	16	87	17	2017	4.1765	1.4054
stem (science, technology, engineering and mathematics)	1	16	86	18	2017.8333	5.7778	1.3583
science	2	18	31	10	2018.2	0.1	0.0189
professional development	2	17	27	7	2019	2.1429	2.5317
stem education	2	16	44	18	2019.2222	1.5556	1.2956
technology	2	12	19	6	2017.3333	0	0
teacher education	2	8	8	6	2017.3333	30.5	0.8464
primary education	2	5	7	6	2019.5	0	0
stem	3	20	52	22	2019.2273	3.5455	1.2143
education	3	17	69	22	2017.5714	1.5455	0.5902
surveys	3	17	36	5	2017.8	5.6	2.5784
steam	3	12	20	5	2021	0.4	0.7235
training	3	11	18	5	2018.2	0.8	0.249
teacher training	4	18	80	33	2018.5758	1.8182	1.0511
computational thinking	4	14	27	8	2020.125	2.375	1.5525
science teachers	4	14	24	5	2016.6	0.6	1.4714
e-learning	4	13	25	5	2020.6	5	2.2403

In the second cluster, "Teacher training and primary education", the concept of *science* has the highest strength of connections (18), being linked to all concepts in clusters 1 and 3, as well as to the endpoints of cluster 4, such as teacher training and science teachers. The concept of *professional development* has 17 links: to all the concepts of clusters 1 and 4, as well as to the concepts of cluster 3, such as STEM, education and surveys. The concept of *STEM education* in each cluster is not linked to one of the concepts: curricula (cluster 1), teacher education (cluster 2), training (cluster 3) and e-learning (cluster 4). The concept of *technology* is linked to all the concepts in the second cluster, as well as the concepts of students, training, teaching, and engineering education in the first cluster, STEM and education in the third cluster, and teacher education in the fourth cluster. *Teacher education* is related to technology, science, and professional development in the second cluster, students, teaching, and training in the first, STEM in the third, and e-learning in the fourth. *Primary education* is linked to the three concepts of the second cluster (science, technology, and STEM education), as well as to STEM (cluster 3) and teacher education (cluster 4). The latter allows for separate consideration of STEM education in the preparation of primary school teachers and STEM education in the preparation of teachers and lecturers. Thus, the concepts of the second cluster (teacher training and primary education) have the most connections with the first cluster (STEM education and training).

In the third cluster "Survey on STEM education", the strongest linkage strength (20 – the maximum possible value) is for the *STEM* concept, which is central to the analysed sample of sources. The concepts of education and surveys have 17 links each: the concept of *education* is related to all concepts in clusters 1 and 3, as well as to individual concepts 2 (science, STEM education, professional development, technology) and 4 (teacher training, science teachers, computational thinking); the concept of *surveys* is related to all the concepts of clusters 1, 3, and 4, as well as to some concepts of the second cluster: science, STEM education, and professional development. The *STEAM* concept is related to all 3 concepts, as well as to the concepts of the first cluster (except the students), the second (science, STEM education), and the fourth (teacher training). The concept of *training* is linked to all concepts of clusters 1 and 3, as well as to science (cluster 2). Thus, the concepts of the third cluster (surveys on STEM education) have the most connections with the first cluster (STEM education and training).

In the fourth cluster, "E-learning and computational thinking in the training of STEM teachers", the strongest links are (18) has the concept of *teacher training*, which is linked to all concepts in clusters 1 and 4, as well as to individual concepts in cluster 2 (science, professional development, STEM education, technology, primary education) and 3 (STEM, STEAM, education, surveys). The next strongest links are the concepts of "computational thinking" and "science teachers": *computational thinking* is linked to all concepts of clusters 1 and 4, as well as to individual concepts 2 (professional development, STEM education) and 3 (STEM, education, surveys); *science teachers* are linked to all concepts in the 4 clusters, as well as to individual concepts 1 (training, teaching, engineering education, students, curricula), 2 (professional development, STEM education, science) and 3 (STEM, education, surveys). *E-learning* is related to all concepts in clusters 1 and 4, as well as to some concepts in cluster 2 (professional development, teacher education) and 3 (STEM, surveys). Thus, the concepts of the fourth cluster (e-learning and computational thinking in the training of STEM teachers) also have the most connections with the first cluster (STEM education and training).

4. Discussion

According to the Concept, science, and mathematics education (STEM education) is an integral system of natural and mathematical education, which aims to develop a personality through the formation of competencies, a natural and scientific picture of the world, worldview positions and life values using a transdisciplinary approach to learning based on the practical application of scientific, mathematical, technical, and engineering knowledge to solve practical problems for the further use of this knowledge and skills in professional activities [1]. The concept proposes policy approaches to promoting the development of knowledge-intensive and high-tech industries aimed at encouraging children and young people to conduct research and master scientific, technical and engineering professions, in particular, to encourage students to choose scientific and technical activities. This involves the implementation of measures to address the problems of social perception of science and scientific, technical and engineering professions, as well as career guidance aimed at developing partnerships between educational institutions and employers.

Knowledge-intensive and high-tech industries are important drivers of economic development. Banks-Hunt et al. [7] argue that attracting young people to careers in STEM is critical to meeting the needs for clean water, less pollution, adequate food, housing, communications, and technological leadership. The authors describe a partnership between a high-tech corporation and university to create programs to train teachers and students in engineering education.

The lack of specialists in knowledge-intensive and high-tech industries is noticeable in Ukraine and around the world. Even-Zahav [8] conducted a study aimed at developing a risk management plan for STEM education in Israel, based on the participation of five stakeholder groups. The study identified a strategic risk in the category of "Teachers – opportunities, training and social status" and proposed cooperation between stakeholders as a means of mitigating risks.

The main reason for these risks is the loss of popularity of STEM professions. According to Ragusa [9, 10], the insufficient number of students obtaining degrees in STEM can lead to significant problems. The author focuses on the problem of declining interest in STEM among students. He suggests that these problems can be solved by improving the quality of STEM education in middle and high schools through university-school partnerships, focusing on teacher training and the introduction of new curricula aimed at increasing students' interest and success in STEM. The decline in interest in STEM disciplines is evidenced, in particular, by the negative dynamics of the number of secondary school graduates who pass external independent assessments in mathematics, physics, chemistry and biology. This is a problem not only in Ukraine: Seals and Valdiviejas [11] examine the impact of a program to motivate African American, Latin American, and Indigenous students to study mathematics, while Symaco and Daniel [12], studying the dynamics of science education in Asia, note the need to develop student's creative thinking and use STEM education as a tool for shaping values, skills, and abilities in students.

Another approach proposed by the Concept is to improve the training of pedagogical staff and ensure their professional development and incentives. Green and Anid [13] argue that it is necessary to increase the number of teachers teaching STEM disciplines to ensure the country's economic stability and remain globally competitive. Using the Advanced Certificate in STEM program as an example, the authors examine the effectiveness of a multidisciplinary approach to STEM teacher education and evaluate the results in improving teachers' knowledge and skills in training STEM disciplines.

The main idea of Fuentes Hurtado and Gonzalez Martinez [14] is that competency training of STEM teachers using gamification can increase students' interest and motivation to study STEM disciplines. The article provides an analysis of three areas of competence (content, methodology and technology) that STEM teachers need to develop in order to successfully implement gamification in their teaching. Salleh et al. [15] investigated the perceptions of future STEM teachers regarding their role as training program facilitators and the impact on their personalities. The study found that the program had a positive impact on the personal development of future teachers.

Demir [16] analyzed the opinions of mathematics teachers on STEM education and identified the need to prepare future teachers to integrate STEM education into their lessons. Galadima et al. [17, 18] propose integrated STEM education for future mathematics teachers. Tumasheva et al. [19] present the results of a study on the preparation of mathematics teachers for STEM education in schools and other educational institutions. The authors recommend the use of elective courses to prepare future mathematics teachers to implement STEM education, taking into account the principles of practical orientation, multidisciplinarity, professional orientation, and application of the regional context.

Elías et al. discuss the need to develop digital and STEM skills in students aspiring to become chemistry teachers [20]. Ortega-Torres [21] investigates the readiness of future teachers to STEM learning using the project-based methodology. The article [22] presents a project-based methodology for training future chemistry teachers in informal educational environments, including science museums. Using this approach allows them to achieve positive results in terms of students' motivation and interest in studying chemistry.

Tillinghast et al. [23] discuss the feasibility of preparing teachers to teach earth sciences in schools through a teacher training program conducted at the Sterling Hill Mining Museum. The article presents the results of a survey of teachers who participated in the program on how they used the knowledge gained in the classroom to increase the quality of geology teaching in schools.

The study by Lantau et al. [24] is aimed at implementing interdisciplinary STEM projects based on the modeling method. Dibarbora [25] describes the methodology of teaching information technologies to future physics teachers, in which modeling is a key topic. The author suggests the use of learning tools, focusing on physical models, as well as experimental verification with Tracker video analysis software or Arduino boards and sensors.

Sundaram [26] discusses a program to prepare secondary and primary school teachers to use STEM education in the classroom. Yildirim [27] proposes a model of professional development in STEM education for teachers, which aims to improve their training and competence in these areas, including the integration of STEM approaches into curricula. The study identified the problems that teachers face when teaching STEM disciplines and proposed solutions to these problems using the proposed model.

Ferrando Palomares et al. evaluate the effectiveness of the use of ICT in teaching science and mathematics at the university level [28]. The results revealed some difficulties in the interdisciplinary teaching of science and mathematics at the primary level. The use of ICT in STEM education is an opportunity to develop the teaching skills of future teachers. Ezzeldin [29] investigates the impact of web-based learning on the development of secondary school teachers' STEM competence. Tijani et al. [30] implemented the "Virtual STEM" project in Nigeria and Kenya to support teachers in STEM learning through distance education and inquiry-based learning.

The main idea of Madahae et al. [31] is that teachers play an important role in creating learning materials and situations that promote the development of higher-order thinking skills and integrate science into everyday life. The authors offer various workshops and practical exercises for teachers to improve their professional development. Weiner et al. [32] analyzed how a workshop on the principles of maker innovation influences the views of future STEM teachers on the lesson planning process. It was found that students who were familiar with maker principles and practices could plan a lesson that was more student-centered and active than usual.

Barana et al. [33] investigated the effectiveness of a 32-hour in-service training course for secondary school STEM teachers. The aim of the course was to generalize the culture of setting and solving problems with the use of ICT tools.

The main idea of the article [34] is that the use of robotics, programming, and technologies is effective in education, but practitioners are not always ready to implement them. The article describes a teaching methodology designed to train teacher practitioners in robotics and programming and to evaluate the results of its implementation among 184 teachers.

A study [35] showed that static and adaptive support can help develop design thinking competencies in STEM teachers.

Martinez-Borreguero et al. [36] identified the need to improve the scientific, methodological, and emotional competence of future primary school teachers in teaching STEM disciplines. Punsrigate Khonjaroen and Srikoon [37] developed and proved the effectiveness of a training course aimed at improving the STEM competence of primary school teachers. Martinez-Borreguero et al. [38] suggest using active and practical methods of teacher training to increase the level of their knowledge and ability to integrate scientific material into STEM projects.

The main idea of the article [39] is that the successful integration of technology and engineering into primary school curricula is critical for the development of future STEM teachers and for providing better training for students in these disciplines. The paper describes the positive impact of a course that teaches to develop STEM lessons and understands their role in guiding students to engineering professions. Castro-Rodríguez and Montoro [40] investigated the possibility of introducing STEM education into the training of primary school teachers based on an analysis of the curricula used in the universities of Spain. The study showed that in most cases, the curricula include the three main characteristics of STEM education, namely problem-solving, application of knowledge in real-life situations, and interdisciplinarity, along with the integration of different subjects through a common theme.

The last policy approach proposed by the Concept is to develop effective and attractive methods of implementing curricula with teaching methods of STEM education.

Mateos-Nunez et al [41] investigate the relationship between emotional and cognitive factors in STEM education and determine that practical and experimental teaching method are more effective than traditional methods. The authors recommend strengthening positive attitudes and developing competences and emotional spheres of students at different stages of education, in particular, at the stage of secondary education, when interest in STEM disciplines begins to decline. Martinez-Borreguero et al. [42] suggest that in modern education, there is a problem of insufficient development of students' scientific skills, in particular in the field of physics, which leads to negative emotions and attitudes towards it. The authors argue that the use of hyper-realistic simulations and STEM can improve physics learning and contribute to the development of future teachers' scientific and technological competencies, increasing their confidence in their own knowledge and skills.

Elisa et al. [43] propose the use of smartphone-based virtual laboratory workshops to overcome limitations in practical physics classes in schools in the Bener Meria Regency (Indonesia), especially in the context of the COVID-19 pandemic. This can improve the quality of physics education in schools and enhance the pedagogical competence of teachers.

Acar et al. [44] investigate the impact of STEM education on fourth-grade students' academic achievement in science and mathematics, as well as their views on STEM education. The results showed that STEM education has a positive impact on academic achievement in science and mathematics, students have positive opinions about STEM education and may consider STEM fields as their future career choices.

The main idea of the article [45] is that the existing initiatives and laboratories for the use of educational robotics often lack a proper pedagogical foundation, are conducted by insufficiently trained teachers, and are not properly evaluated in terms of effectiveness. The authors propose a robotics course based on pedagogical approaches and explore teachers' views on robotics in terms of its use and impact on student development. Surveys have shown that teachers consider robotics to be an important tool for improving student motivation, planning, teamwork, problem-solving, and creative development.

Kert [46] notes that the study of programming by children is becoming increasingly popular, and, in particular, in Turkey, it is supported at the national level. The author explores the modern methodological and pedagogical requirements for teaching programming and also proposes an innovative methodology for training computer science teachers, which gives positive results. An IT club is a type of STEM laboratory – a classroom or a building of an educational institution equipped with modern teaching aids and facilities to involve students in educational, research, experimental, design, inventive, and search activities in accordance with educational standards, educational and training programs with the use of project technologies in the educational process [1]. Rursch et al [47] consider that teachers need a profound level of IT competence to help students acquire knowledge in the school IT clubs. The IT-Adventures program is designed to organize such clubs, where students are engaged in self-study on topics such as cybersecurity, game design, and robot programming, while mentor teachers help students with learning and solving complex problems.

Dinh and Nguyen [48] describe the results of a study that focuses on the role of gender in STEM education. The authors emphasize the need to take into account gender aspects in teaching STEM disciplines. The main idea of Fonseca et al. [49] is that lack of diversity in STEM, in particular gender inequality, is a global challenge that needs to be addressed by creating STEAM laboratories in secondary schools and training teachers to implement them. Toldson and Lewis [50] examine the effectiveness of a technical assistance model for improving the competitiveness of historically black colleges and universities and other US institutions serving smaller minority groups seeking funding to expand STEM teacher preparation through the National Science Foundation's Robert Noyce Teacher Fellowships program.

Hodhod et al. [51] consider the importance of introducing computational thinking in STEM education to improve students' ability to analyze problems and design solutions. The article describes the experience of conducting a workshop on computational thinking for STEM teachers presents sample lessons and projects and discusses the results of applying these lessons in teachers' practice. Pewkam and Chamrat [52] investigated how and to what level computational thinking skills of primary and secondary school teachers can be developed in computer science education and developed an online learning program to improve their competence in this area. The results show that such a program can improve the basic computational thinking skills of future teachers and that its key features are technical support, a learning management system, active engagement, and relevance of the learning content to students' needs. Knie et al. [53] describe the redesign of a teacher education program to include computational thinking in the context of STEM disciplines. The results of the study showed high satisfaction of the course participants with the online module on computational thinking, as well as positive dynamics in the use of computational thinking.

Tzafilkou et al. [54] investigate the attitudes of STEM teachers towards distance teaching, their perceptions of obstacles and training needs, and emphasize the need for targeted training of teachers in the use of digital tools in distance teaching of STEM disciplines, as well as the need for psychological support. Chirico et al. [55] investigate the impact of teaching using the social virtual reality platform on the interest in STEM learning of high school teachers delivered through it. The results showed that the author's methodology can increase interest in science and technology regardless of age. Lasica et al. [56] describe the EL-STEM project, which aims to use augmented and mixed reality technologies in the STEM education of high school students, as well as to develop a program of professional development.

5. Conclusions

1. STEM education has a positive impact on achievements in science and mathematics, which contributes to a positive attitude of students toward such education and their professional orientation towards knowledge-intensive and high-tech industries, which are important factors in economic development. At the same time, there is a shortage of specialists in these fields, which is felt in Ukraine and around the world.
2. The decline in interest in STEM disciplines is a global problem. There are a number of factors that contribute to this, including the perception of STEM disciplines as difficult and uninteresting. To address this problem, it is necessary to make STEM disciplines more attractive and relatable, to provide more support for STEM teachers, and to make STEM education more accessible to all students.
3. Inequality in STEM, including gender inequality, is a global problem that can be addressed through the creation of STEM labs in secondary schools and gender-sensitive teacher training.
4. Computational thinking is an important component of STEM education. There are different ways to introduce computational thinking in STEM education, including special workshops for STEM teachers, development and implementation of online learning programmes for the development of computational thinking, and providing teachers with methodological support for the introduction of computational thinking in STEM education.
5. The professional training and social status of teachers are strategically important links in STEM education. Collaboration between all stakeholders in this area is a way to reduce risks in STEM education. In the preparation of STEM teachers, it is advisable to: a) integration of the STEM approach into the training programs for mathematics and science teachers; b) use of elective courses in STEM education; c) development of project thinking, digital and STEM skills; d) implementation of interdisciplinary STEM projects, in particular, based on the modeling method; e) use of active and practice-oriented training methodologies for teachers to improve their knowledge and ability to integrate scientific material into STEM projects; f) integration of formal and informal educational environments, including work in the classroom and science museum; g) development of the scientific, methodological, and emotional competence of teachers in teaching STEM disciplines; h) application of an exploratory approach and experimentation.

6. Teachers of "traditional" STEM disciplines (mathematics and natural sciences) needs to develop their ICT competency, in particular, their programming competency. Thus, in teaching STEM disciplines, it is advisable to: a) use of web-based and distance learning; b) use of ICT-supported STEM workshops; c) introduction of robotics and programming.
7. To increase the interest of pupils and students and develop their motivation to study STEM disciplines, it is advisable to use ICT tools, in particular: a) the use of social virtual reality platforms, hyper-reality simulations and virtual laboratories based on mobile devices is methodologically sound in all STEM disciplines; b) a key means of strengthening positive attitudes towards STEM disciplines in secondary education, when interest in them begins to decline, is educational robotics. The use of robotics can be an important tool for increasing students' motivation, developing planning, teamwork, problem-solving and creative skills; c) augmented and mixed reality technologies can be used to increase students' interest in STEM disciplines and engage them in learning.

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References

[1] Cabinet of Ministers of Ukraine 2020 On approval of the Concept for the development of science and mathematics education (STEM education] URL `https://zakon.rada.gov.ua/laws/show/960-2020-%D1%80#Text`
[2] Martyniuk O O, Martyniuk O S, Pankevych S and Muzyka I 2021 *Educational Technology Quarterly* **2021** 347–359 URL `https://doi.org/10.55056/etq.39`
[3] Hrynevych L, Morze N, Vember V and Boiko M 2021 *Educational Technology Quarterly* **2021** 118–139 URL `https://doi.org/10.55056/etq.24`
[4] Kovalchuk V I, Maslich S V and Movchan L H 2023 *Educational Technology Quarterly* **2023** 1–17 URL `https://doi.org/10.55056/etq.49`
[5] van Eck N J and Waltman L 2018 VOSviewer Manual URL `https://www.vosviewer.com/documentation/Manual_VOSviewer_1.6.8.pdf`
[6] UNESCO Institute for Statistics 2015 *International Standard Classification of Education: Fields of education and training 2013 (ISCED-F 2013) – Detailed field descriptions* (Montreal: UNESCO) URL `https://doi.org/10.15220/978-92-9189-179-5-en`
[7] Banks-Hunt J M, Adams S, Ganter S and Bohorquez J C 2016 K-12 STEM Education: Bringing the engineering maker space, student-centered learning, curriculum, and teacher training to middle schools *Proceedings - Frontiers in Education Conference, FIE* vol 2016-November p 7757531 URL `https://doi.org/10.1109/FIE.2016.7757531`
[8] Even-Zahav A 2019 *Advances in Intelligent Systems and Computing* **861** 73–89 URL `https://doi.org/10.1007/978-3-030-01406-3_7`
[9] Ragusa G 2011 Teacher training and STEM student outcome: Linking teacher intervention to students' success in STEM middle and high school classes *American Society for Engineering Education Annual Conference and Exposition, Conference Proceedings*
[10] Ragusa G 2012 Teacher training and student inquiry and science literacy: Linking teacher intervention to students' outcomes in STEM courses in middle and high school classes *American Society for Engineering Education Annual Conference and Exposition, Conference Proceedings*
[11] Seals C and Valdiviejas H 2021 *Journal of Higher Education Theory and Practice* **21** 53–74 URL `https://doi.org/10.33423/jhetp.v21i15.4891`
[12] Symaco L P and Daniel E G S 2018 *Contemporary Trends and Issues in Science Education* **47** 215–228 URL `https://doi.org/10.1007/978-3-319-97167-4_11`
[13] Green S L and Anid N M 2013 Training K-12 teachers in STEM education: A multi-disciplinary approach *ISEC 2013 - 3rd IEEE Integrated STEM Education Conference* p 6525206 URL `https://doi.org/10.1109/ISECon.2013.6525206`
[14] Fuentes Hurtado M and Gonzalez Martinez J 2017 *RED - Revista de Educación a Distancia* URL `https://doi.org/10.6018/red/54/8`
[15] Salleh M F M, Md Nasir N A and Ismail M H 2020 *Asian Journal of University Education* **16** 1–10 URL `https://doi.org/10.24191/ajue.v16i3.11091`

[16] Demir B K 2021 *Athens Journal of Education* **8** 401–416 URL https://doi.org/10.30958/aje.8-4-4
[17] Galadima U, Ismail Z and Ismail N 2019 *International Journal of Engineering and Advanced Technology* **8** 1272–1281 URL https://doi.org/10.35940/ijeat.E1181.0585C19
[18] Galadima U, Ismail Z and Ismail N 2019 *International Journal of Engineering and Advanced Technology* **8** 47–52 URL https://doi.org/10.35940/ijeat.E1006.0585C19
[19] Tumasheva O V, Shashkina M B, Shkerina L V and Valkova Y E 2020 *Journal of Physics: Conference Series* **1691** 012225 URL https://doi.org/10.1088/1742-6596/1691/1/012225
[20] Elías M, Pérez J, Cassot M D R, Carrasco E A, Tomljenovic M and Zúñiga E A 2022 *Frontiers in Education* **7** 932609 URL https://doi.org/10.3389/feduc.2022.932609
[21] Ortega-Torres E 2022 *Journal of Technology and Science Education* **12** 484–495 URL https://doi.org/10.3926/jotse.1319
[22] Domenici V 2022 *Education Sciences* **12** 30 URL https://doi.org/10.3390/educsci12010030
[23] Tillinghast R C, Petersen E A, Kroth W, Powers G, Holzer M, Osowski J and Mansouri M 2019 Bringing Geosciences to K-12 Classrooms: A Teacher Training Program Developed by the Sterling Hill Mining Museum *2019 9th IEEE Integrated STEM Education Conference, ISEC 2019* pp 69–75 URL https://doi.org/10.1109/ISECon.2019.8882052
[24] Lantau J M, Bracke M, Bock W and Capraro P 2020 *International Perspectives on the Teaching and Learning of Mathematical Modelling* 455–465 URL https://doi.org/10.1007/978-3-030-37673-4_39
[25] Dibarbora C 2021 *Journal of Physics: Conference Series* **1882** 012139 URL https://doi.org/10.1088/1742-6596/1882/1/012139
[26] Sundaram R 2015 TIES to STEM: University outreach model for teachers in K-12 STEM schools to be trained in engineering skills *2015 IEEE Frontiers in Education Conference (FIE)* pp 1–4 URL https://doi.org/10.1109/FIE.2015.7344244
[27] Yildirim B 2020 *Pamukkale Üniversitesi Eğitim Fakültesi Dergisi* 70–98 URL https://doi.org/10.9779/pauefd.586603
[28] Ferrando Palomares I, Hurtado Soler D and Beltran Meneu M J 2018 *ATTIC - Revista d Innovacio Educativa* 35–42 URL https://doi.org/10.7203/attic.20.10946
[29] Ezzeldin S M Y 2022 *International Journal of Online Pedagogy and Course Design* **12** URL https://doi.org/10.4018/IJOPCD.302085
[30] Tijani B, Madu N, Falade T and Dele-Ajayi O 2021 Teacher training during Covid-19: A case study of the virtual STEM project in Africa *IEEE Global Engineering Education Conference, EDUCON* vol 2021-April ed Klinger T, Kollmitzer C and Pester A (IEEE Computer Society) pp 226–234 URL https://doi.org/10.1109/EDUCON46332.2021.9453920
[31] Madahae S, Pisapak P and Thanyasirikul C 2021 *Journal of Physics: Conference Series* **1835** 012062 URL https://doi.org/10.1088/1742-6596/1835/1/012062
[32] Weiner S, Lande M and Jordan S S 2020 *International Journal of Engineering Education* **36** 702–711
[33] Barana A, Fissore C, Marchisio M and Pulvirenti M 2020 Teacher training for the development of computational thinking and problem posing & solving skills with technologies *eLearning and Software for Education Conference* ed Roceanu I (National Defence University - Carol I Printing House) pp 136–144 URL https://doi.org/10.12753/2066-026X-20-103
[34] Scaradozzi D, Screpanti L, Cesaretti L, Storti M and Mazzieri E 2019 *Technology, Knowledge and Learning* **24** 247–268 URL https://doi.org/10.1007/s10758-018-9356-1
[35] Wu B, Hu Y and Wang M 2019 *British Journal of Educational Technology* **50** 2271–2287 URL https://doi.org/10.1111/bjet.12873
[36] Martinez-Borreguero G, Mateos-Nunez M and Naranjo-Correa F L 2019 Levels of Teacher Self-Efficacy and Emotions Expressed by Teachers in Training STEM Areas *New Perspectives in Science Education, 8th edition* PIXEL (Bologna: Filodiritto Publisher) pp 586–591 ISBN 978-88-85813-56-4
[37] Punsrigate Khonjaroen K and Srikoon S 2021 *Journal of Physics: Conference Series* **1835** 012063 URL https://doi.org/10.1088/1742-6596/1835/1/012063
[38] Martinez-Borreguero G, Mateos-Nunez M and Naranjo-Correa F L 2018 Forces and their effects: Comparative analysis of the knowledge of teachers in training versus primary school students *11th Annual International Conference of Education, Research and Innovation (ICERI2018)* ICERI Proceedings ed Chova L G, Martinez A L and Torres I C (Valencia: IATED) pp 258–267 ISBN 978-84-09-05948-5
[39] Thomas S W, Campbell S W, Subramanyam M D and Ellerbrock C R 2019 Contemporary STEM issues: Engineering training of pre-service teachers for middle school stem curriculum development (evaluation) *American Society for Engineering Education Annual Conference and Exposition, Conference Proceedings*
[40] Castro-Rodríguez E and Montoro A B 2021 *Revista de Educacion* **2021** 353–378 URL https://doi.org/10.4438/1988-592X-RE-2021-393-497
[41] Mateos-Nunez M, Martinez-Borreguero G and Naranjo-Correa F L 2019 Emotional, attitudinal and

competency analysis in stem areas of secondary school students versus teachers in training *12th Annual International Conference of Education, Research and Innovation (ICERI 2019)* ICERI Proceedings ed Chova L, Martinez A and Torres I (Valencia: IATED) pp 559–568 ISBN 978-84-09-14755-7

[42] Martinez-Borreguero G, Naranjo-Correa F L, Perez-Rodriguez A L, Pardo-Fernandez P J and Suero-Lopez M I 2018 Validation of didactic simulations and STEM experiences to improve the teaching of content about light and colour with teachers in training *EDULEARN18: 10th International Conference on Education and New Learning Technologies* EDULEARN Proceedings ed Chova L G, Martinez A L and Torres I C (Valencia: IATED) pp 7594–7603 ISBN 978-84-09-02709-5

[43] Elisa E, Farhan A, Herliana F, Wahyuni A and Susanna S 2021 *Journal of Physics: Conference Series* **1882** 012030 URL `https://doi.org/10.1088/1742-6596/1882/1/012030`

[44] Acar D, Tertemiz N and Taşdemir A 2018 *International Electronic Journal of Elementary Education* **10** 505–513 URL `https://doi.org/10.26822/iejee.2018438141`

[45] Castro E, Cecchi F, Salvini P, Valente M, Buselli E, Menichetti L, Calvani A and Dario P 2018 *International Journal of Social Robotics* **10** 669–685 URL `https://doi.org/10.1007/s12369-018-0475-6`

[46] Kert S B 2019 *European Journal of Educational Research* **8** 477–489 URL `https://doi.org/10.12973/eu-jer.8.2.477`

[47] Rursch J A, Burkhardt B and Jacobson D 2009 Training non-IT teachers to advise and facilitate inquiry-based learning in IT: A pilot study *Proceedings - Frontiers in Education Conference, FIE* p 5350577 URL `https://doi.org/10.1109/FIE.2009.5350577`

[48] Dinh D H and Nguyen Q L 2020 *European Journal of Educational Research* **9** 363–373 URL `https://doi.org/10.12973/eu-jer.9.1.363`

[49] Fonseca D, Jurado E, García-Holgado A, Olivella R, García-Peñalvo F J, Sanchez-Sepulveda M, Amo D, Maffeo G, Yiğit Ö, Hofmann C, Quass K, Sevinç G and Keskin Y 2022 *Lecture Notes in Educational Technology* 29–50 URL `https://doi.org/10.1007/978-981-19-7431-1_3`

[50] Toldson I A and Lewis C W 2017 *Journal of Negro Education* **86** 83–93 URL `https://doi.org/10.7709/jnegroeducation.86.2.0083`

[51] Hodhod R, Khan S, Ray L and Kurt-Peker Y 2016 Training teachers to integrate computational thinking into K-12 teaching *SIGCSE 2016 - Proceedings of the 47th ACM Technical Symposium on Computing Science Education* pp 156–157 URL `https://doi.org/10.1145/2839509.2844675`

[52] Pewkam W and Chamrat S 2022 *Informatics in Education* **21** 311–329 URL `https://doi.org/10.15388/infedu.2022.09`

[53] Knie L, Standl B and Schwarzer S 2022 *Computer Applications in Engineering Education* **30** 1423–1439 URL `https://doi.org/10.1002/cae.22529`

[54] Tzafilkou K, Perifanou M and Economides A A 2022 *Education Sciences* **12** URL `https://doi.org/10.3390/educsci12110790`

[55] Chirico A, Serafini F, Pizzolante M, Malvezzi R, Gianotti E, Micucci C, Manduca E, Carvelli C, Vago F, Renda M, Cascio E and Gaggioli A 2022 *Annual Review of CyberTherapy and Telemedicine* **20** 31–35

[56] Lasica I E, Meletiou-Mavrotheris M, Katzis K, Dimopoulos C and Mavrotheris E 2018 Designing a teacher training program on the integration of augmented and mixed reality technologies within the educational process *12th International Technology, Education and Development Conference (INTED)* INTED Proceedings ed Chova L G, Martinez A L and Torres I C (Valencia: IATED) pp 8943–8953 ISBN 978-84-697-9480-7

Journal of Physics: Conference Series

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The issues of design of a Petri net-based software component for modelling holistic and coordinated curriculum for potential specialists' training

To cite this article: L I Bilousova and L E Gryzun 2023 *J. Phys.: Conf. Ser.* **2611** 012026

The issues of design of a Petri net-based software component for modelling holistic and coordinated curriculum for potential specialists' training

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Abstract. This paper proposes a Petri nets-based software component for automating the holistic and coordinated curriculum building process for pre-service IT specialists. The design of the software module is based on the holistic educational paradigm and the authors' approach to Petri nets-based curriculum modeling. The core components of the software module are identified and their requirements are formulated. The groups of software classes are specified and described. The benefits of the software module for pre-service IT specialists are highlighted. The prospects for further research include implementing the software module and testing it on specially prepared cases.

1. Introduction

Addressing the significance of our current research, it is imperative to underscore several pivotal factors. The process of preparing future specialists for successful careers in today's dynamic world presents a multifaceted challenge that demands adaptation to meet contemporary labor market demands [1–3]. Moreover, the urgency of revamping vocational training in various fields is compounded by unforeseen circumstances such as global pandemics and military conflicts, necessitating the development of innovative teaching and learning approaches. Thus, there is a pressing need to devise an updated model for university student training rooted in new paradigms. One of these paradigms appears to be holistic education, a concept emphasized in various normative documents, including the National Strategy for the Development of Education in Ukraine for 2012-2021, the Law of Ukraine "On Education" [4], the Concept of the New Ukrainian School [5], and the Law of Ukraine "On the Concept of National Education Information Programs," as well as Education for Sustainable Development Goals: Learning Objectives, among others.

In the realm of holistic education, research papers have defined it as a paradigm that provides educators with a framework of principles [6, 7]. Central to holistic education is the idea of comprehensive development of the learner's personality, encompassing both intellectual and emotional growth [6]. It is emphasized that this holistic progress should be facilitated through strong connections between students' personal experiences and real-world challenges.

However, an examination of current educational practices reveals that the productive concepts of the holistic paradigm are only partially implemented, often overlooking its potential benefits in fostering integrated educational content, effective methods of delivery, and practical application.

With these insights in mind, as we develop an updated model for vocational training, we aim to fully embrace the holistic approach in several dimensions: creating cohesive and coordinated educational content, identifying effective methods for presenting and mastering this content, and organizing professional educational activities for future specialists throughout their training. This approach is manifested in the university curriculum through an integrative approach to structuring module-based disciplines, the utilization of multiple formats for presenting content to stimulate students' cognitive processes, and the seamless integration of students' educational experiences with real-world challenges through project-driven learning. It is important to note that these aspects are interrelated and mutually reinforcing, contributing to a more comprehensive integration of the holistic concept into educational practice.

Therefore, the design of the university curriculum and its integrative elements play a pivotal role in realizing the holistic paradigm. Additionally, given the backdrop of globalization and ongoing transformations in scientific and technological fields, the development of mechanisms for building university curricula has become increasingly urgent. This has spurred our exploration and the creation of tools to preserve natural connections between disciplines, integrate newly emerging subjects into existing curricula, and coordinate their mastery. In this context, we have also developed a Petri nets-based approach to holistic curriculum modeling, aimed at investigating its coordinated implementation by future specialists, as detailed in our previous works [8].

2. Purpose of the study

Building upon the factors emphasized above, this study aims to delineate specific stages in the development of a Petri nets-based software component tailored for the creation of holistic and integrated curricula. Moreover, we seek to underscore the advantages of this approach for the training of prospective IT specialists during their vocational education.

3. Theoretical framework

Our research is underpinned by a comprehensive array of theoretical, modeling, and design techniques. At its core, the theoretical framework of this study is rooted in the holistic educational paradigm, as previously elucidated, coupled with our proprietary approach to modeling holistic and integrated curricula for specialist training using the Petri nets framework. This approach, extensively detailed in our earlier publications [8, 9], hinges on structuring module-based curriculum disciplines and the process of their mastery using the advantages offered by the frame-based model of knowledge representation and the mathematical apparatus of Petri nets.

In accordance with Petri nets theory [10,11], these nets are viewed as a formal simulation tool characterized by graphical visualization and a well-defined semantics and syntax. A Petri net is formally defined as a directed bipartite graph represented as $N =< P, T, R >$, where $P = p_i$ denotes the set of graph vertices (referred to as places) and $T = t_i$ signifies the set of vertices (referred to as transitions). The R component encapsulates the relationships between vertices, corresponding to the arcs.

In the graphical representation of a Petri net, places (P) are depicted as circles, while transitions (T) are represented by bars. In terms of simulating real processes, places serve to emulate various states or conditions within the process, while transitions simulate the events occurring within it.

Tokens, which are movable entities, can reside within places and navigate through the net via transitions. The disposition of tokens within places is determined by the marking set M, which assigns an integer value to each place: $M =< M(p_1), ..., M(p_k) >$, where k represents the total number of places in the net, and $M(p_k)$ signifies the number of tokens present in place p_k. Consequently, the quantity and arrangement of tokens across the net govern its execution [10]. Diverse markings of the Petri net represent different states of a dynamic process, with changes in state dynamics being simulated by the movement of tokens across the places within the net. The marking of the net can change as its transitions are triggered, and when a transition is activated, one token is removed from each input place and added to each output place.

In our approach to curriculum development, which leverages the frame-based model of knowledge representation and the mathematical framework of Petri nets, academic disciplines are structured through the use of frames (discipline modules). These frames serve as unifying structures for the learning elements (LEs) comprising the educational content. They are presented in charts that delineate the sequence and precedence relationships among the LEs. The frame-based model was opted for among other common AI models (semantic networks, productive rules, scripts etc.) due to its powerful built-in features in terms of educational content representation [12, 13]. According to the frames theory which also takes essential roots from psychology, the frame-based representation reflects conceptional basis of the human memory organization, enables flexibility and visualization [13–15]. Inheritance and hierarchy features deffer this model from others in terms of keeping and spreading the connections between the elements of knowledge. These features enable to group the elements of knowledge related to the objects of the same type, facilitating the processes of inference and consistency maintenance. Inheritance pointers (as a frame components) store the references to the other frames, which makes the frames implicitly associated with each other, and in such a way keeping the related knowledge clustered. New elements and relations can be easily added into the frame system, and hierarchy feature ensures that the associated procedures will propagate the values and references from the top level frames to the lower levels and to the newly introduces elements [8].

Consequently, the utilization of the frame-based model of knowledge representation has enabled the creation of a holistic curriculum. This is attributed to the inherent characteristics of frames, which facilitate the preservation and dissemination of connections among the learning elements (LEs) across various disciplines. As illustrated in figure 1, each frame possesses both inputs and outputs. Inputs can be viewed as the prerequisite LEs that a student must grasp before delving into the LEs encapsulated within the frame. Similarly, the outputs can be understood in the context of their relevance to other frames.

During the preparatory phase of Petri net-based modeling for the curriculum mastery process, we identified various types of precedence relations for the inputs, as outlined in [10]:

- *1 LE to 1 LE relation*: In this scenario, the sole prerequisite for mastering a particular Learning Element (LE) is the completion of learning one specific previous LE, whether it resides within the same frame or across different frames.
- *1 LE of K LEs from Frame N to 1 LE of Frame M relation*: In this case, a LE within Frame M requires the completion of mastery in one out of K LEs from the preceding Frame N. This signifies an OR-based precedence relation.
- *The entire set of K LEs to 1 relation*: Here, a LE in Frame M necessitates the successful completion of the entire set of K LEs from the previous Frame N, establishing an AND-based precedence relation.

For the outputs, we determined the following relations:

- *1 LE to 1 LE relation*: This signifies that the LE is a prerequisite for the learning of only one other LE, whether it is within the same frame or across different frames.
- *1 LE to K LEs relation*: In this context, the learning of a specific LE takes precedence over a set of K LEs' learning.

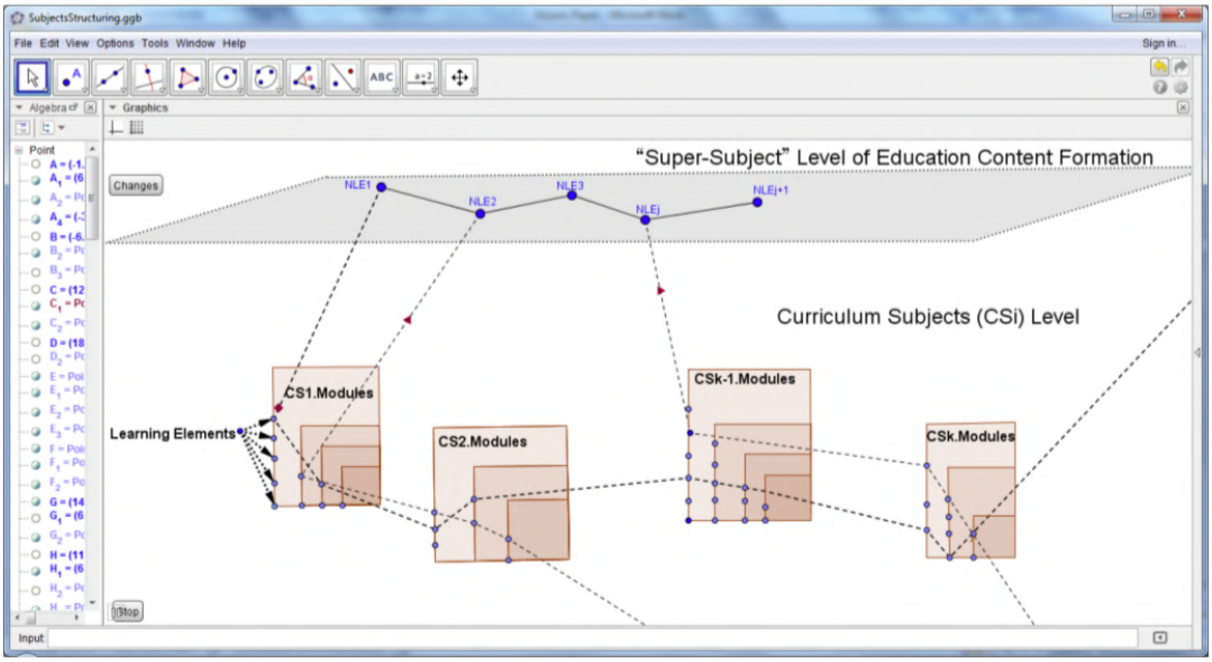

Figure 1. The result of the curriculum development, utilizing the frame-based model of knowledge representation, involves each frame serving as a curriculum discipline containing nested frames, also referred to as discipline modules.

By applying the established precedence relations, we were able to simulate the student's process of mastering Learning Elements (LEs), frames (comprising multiple LEs), and curriculum disciplines (comprising frames composed of LEs) using the capabilities of Petri nets.

In such a way, mastering of any LE can be represented with a common Petri net shown in the figure 2. It is also regarded as the fundamental component for constructing the model of how a student masters a discipline.

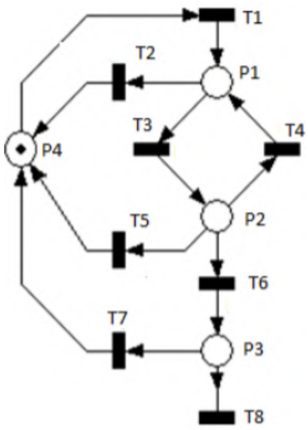

Figure 2. The Petri net that simulates the process of a student mastering a Learning Element (LE).

In this model, the places P1 to P4 within the Petri net represent the states of Learning Elements (LEs) with respect to their readiness for students to learn, considering their precedence relations. The transitions T1 to T8 correspond to various events:

(i) T1 and T2: Commencement of LE's learning.
(ii) T3 to T7: The learning process, accounting for academic time and the LE's availability based on its precedence relations.
(iii) T8: Completion of LE's mastery.

The net contains only one token, signifying that only one of the LE states is true at any given time. Consequently, only one place can be marked at a time, as exemplified by place P4 in the model depicted in figure 2.

In subsequent stages of modeling, Petri nets simulating the mastery of a single LE were employed to model the mastery of a frame (discipline module). This was achieved by connecting these LE mastery models based on their precedence relations. The composition of these models involved merging transitions T1 (representing the availability of an LE for student learning) from the dependent LE model and T8 (indicating that the LE is available for continuation) from the preceding LE mastery model. Using Petri nets modification operations (e.g., fusion) defined in [11] and the various types of LE connections (as determined earlier), we created a model for the mastery of a curriculum discipline module, and ultimately, for the mastery of an entire curriculum discipline. A few instances of this modeling process are illustrated in figure 3.

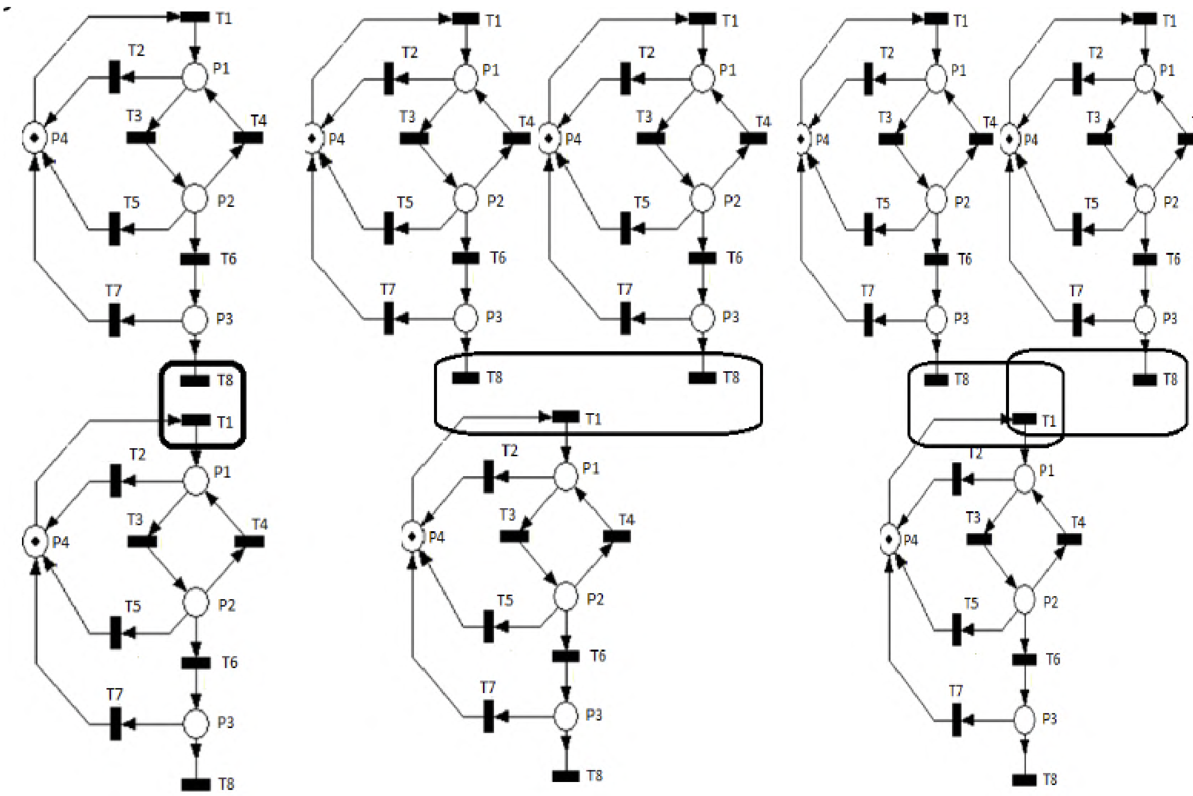

Figure 3. Instances of applying Petri nets modification operations.

The constructed Petri net models comprehensively simulate the progression of LEs mastery by students within curriculum courses. It's crucial to note that the output transitions of each Petri net model, representing the mastery of an LE, can trigger the subsequent LE's mastery only if the mastery of the preceding one (in accordance with the precedence relation) has been completed. This is ensured by the rules governing Petri net execution and modifications.

Overall, employing such simulations for the development of a coordinated curriculum for training prospective specialists offers several advantages:

(i) The Petri net models enable the simulation of the LE mastery process by students within curriculum course modules as well as between them.

(ii) Petri nets facilitate the grouping of LEs into modules, considering both the connections between them and the sequence in which a student should learn them.

(iii) The capabilities of the frame-based model of knowledge representation facilitate the propagation of links between LEs within a module and across modules from different curriculum disciplines, ensuring the holistic nature of the curriculum being constructed.

This theoretical framework serves as a foundation for the design of a Petri nets-based software component aimed at creating a holistic and coordinated curriculum, as well as modeling the process of its mastery.

4. Results and discussion

Based on the presented theoretical framework, the software module for the automatization of the coordinated curriculum modeling (SMPNCM) and its design features can be characterized as follows.

SMPNCM, based on Petri nets modeling, allows the dynamic execution of the simulated process of curriculum course mastery by a potential specialist, enabling educational staff and students to trace and learn this process.

The functionality of SMPNCM at the operational level focuses on:

1. Preliminarily and statically storing the Petri net execution graph, which specifies when each task related to a particular Learning Element (LE) mastery should be executed.
2. Successively and dynamically using Petri net properties to track tasks that have been executed (LEs that have been mastered) and obtaining a list of tasks ready for execution (LEs available for mastery by a trainee) by allowing the Petri net to evolve.

Two core components of SMPNCM are distinguished: the *Tasks Manager* and the *Coordinator*. In this context, a *Task* represents the mastery of a Learning Element (LE) by a student.

The *Tasks Manager* is responsible for:

1. Initiating the execution of each *Task* by notifying the *Coordinator*.
2. Detecting when a *Task* completes its execution and notifying the *Coordinator*.
3. Querying the *Coordinator* for the list of executable *Tasks*.

The *Coordinator* is responsible for:

1. Managing a data structure that implements the Petri net execution graph.
2. Receiving notifications of *Task* start (termination).
3. Evolving the status of the net graph accordingly.

Dynamically, at each step, the *Tasks Manager* and the *Coordinator* interact as follows:

1) The *Tasks Manager* queries the *Coordinator* for the list of executable *Tasks* (in fact, the list of LEs available for a student to master with respect to the defined precedence relationships in the theoretical part of the work).
2) The *Coordinator* checks the status of the net graph and provides the *Tasks Manager* with the list of executable *Tasks*.
3) If the list is empty and no other *Tasks* are available for execution, the process waits for new executable *Tasks* to become available.

4) If the list is empty but there are *Tasks* in execution, the process proceeds to step 7.
5) If the list is not empty, the *Tasks Manager* triggers the execution of each *Task* in the list and notifies the *Coordinator* of each execution.
6) Upon receiving a notification from the *Tasks Manager*, the *Coordinator* updates the status of the net execution graph.
7) The *Tasks Manager* waits for the completion of a *Task* and notifies the *Coordinator* about this event.

Thus, based on the described interaction of these two components, a set of design requirements has been formulated. Specifically, the *Coordinator* must:

- Build the Petri net execution graph by adding its nodes (a place, a transition, or an arc).
- Determine the executable *Tasks* (graph nodes).
- Update the graph by influencing its dynamics: execute a node, terminate a node, freeze (unfreeze) a node, and set an executable node.

These requirements can be met through a group of classes.

The *PetriNet* class provides all the basic methods for building, running, and managing a Petri net. This class utilizes fundamental classes *Place* and *Transitions*, which are described below.

The *Place* class manages tokens, inner and outer arcs.

The *Transitions* class controls the enabling or disabling of transitions, as well as the management of inner/outer arcs.

The *Coordinator* class offers methods for managing the built Petri net in terms of executable *Tasks*, using a private Petri net (PN) object. These class methods enable the addition of nodes (*Tasks*) to be executed and the formation of the list of executable *Tasks.* Thus, the Coordinator provides high-level methods for utilizing the Petri net execution graph.

The *TasksManager* class provides methods to manage the execution of specific *Tasks* that are available for execution.

The primary objective of SMPNCM, based on Petri nets modeling and designed according to the mentioned approaches, is to enable the dynamic execution of the simulated process of curriculum course mastery by potential specialists. In terms of discussing its practical benefits for training potential specialists, several points are worth noting. The functionality of SMPNCM allows both educational staff and students to:

- Trace and explore the curriculum mastery process.
- Visualize and analyze the position of each LE within modules and across the entire curriculum, considering their links and precedence relations.
- Monitor LEs that have been mastered and are required for the mastery of other sets of LEs.
- Create individualized study plans for students.
- Compare the equivalence of educational programs, among other capabilities.

The significance of SMPNCM, based on Petri nets modeling, is particularly evident in the training of pre-service IT specialists. The built and implemented model by SMPNCM enables the simulation of university curriculum mastery as a collection of disciplines sensitive to rapid changes in the volatile IT industry. It allows for the immediate integration of updated requirements for specialists across all modules while preserving the necessary links. Additionally, it facilitates the consideration of the evolution of disciplines and the inclusion of new ones in a flexible curriculum, eliminating unnecessary repetition and saving academic time. Thus, it supports individualized training for IT specialists and the development of their personalized educational paths.

Moreover, SMPNCM modeling can be used by educational staff in the design phase of the tutoring process to select relevant learning and project-driven activities, thereby creating a holistic system of knowledge and skills for students.

5. Conclusions

In pursuit of its objectives, this work has advanced several stages in the design of a Petri nets-based software component aimed at facilitating holistic and coordinated curriculum development. Drawing from a theoretical framework rooted in the holistic educational paradigm and an author-developed approach to modeling holistic and coordinated training using Petri nets, this section characterizes the software module designed for the automation of coordinated curriculum modeling (SMPNCM) and its key features.

The core components of the software module have been identified, and a set of design requirements has been articulated to align with their operational logic. The various software classes have been specified and described to provide a comprehensive overview of the module's architecture.

This section has also elucidated the functional aspects of the developed module, outlining its practical advantages for both students and educational staff engaged in training potential specialists. Special attention has been given to the module's relevance and benefits for pre-service IT specialists, considering the unique dynamics of the IT industry.

In terms of future research prospects, the plan involves the full implementation of SMPNCM based on the elaborated design stages and its testing on carefully prepared case scenarios.

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References

[1] Abuselidze G and Zoidze G 2023 *CTE Workshop Proceedings* **10** 366–379 URL https://doi.org/10.55056/cte.565
[2] Omelchuk L, Rusina N and Shyshatska O 2019 *CEUR Workshop Proceedings* **2387** 262–273 URL https://ceur-ws.org/Vol-2387/20190262.pdf
[3] Osadcha K, Osadchyi V, Semerikov S, Chemerys H and Chorna A 2020 *CEUR Workshop Proceedings* **2732** 547–558 URL https://ceur-ws.org/Vol-2732/20200547.pdf
[4] 2017 Law of Ukraine "On Education" URL https://zakon.rada.gov.ua/laws/show/2145-19?lang=en#Text
[5] Elkin O, Hrynevych L, kalashnikova S, Khobzey P, Kobernyk I, Kovtunets V, Makarenko O, Malakhova O, Nanayeva T, Shiyan R and Usatenko H 2017 *The New Ukrainian School: conceptual principles of secondry school reform* (Kyiv) URL https://mon.gov.ua/storage/app/media/zagalna%20serednya/Book-ENG.pdf
[6] Mahmoudi S, Jafari E, Nasrabadi H and Liaghatdar M 2012 *International Education Studies* **5**(3) 178–186 URL https://doi.org/10.5539/ies.v5n3p178
[7] Miller J P, Karsten S, Denton D, Orr D and Kates I C (eds) 2018 *Holistic Learning and Spirituality in Education: Breaking New Ground* (Albany, New York: State University of New York Press)
[8] Bilousova L and Gryzun L 2021 *CEUR Workshop Proceedings* **3083** 16–27 URL https://ceur-ws.org/Vol-3083/paper277.pdf
[9] Gryzun L 2018 *PEOPLE: International Journal of Social Sciences* **4**(2) 1446–1462 URL https://doi.org/10.20319/pijss.2018.42.14461462
[10] Barros J P and Gomes L 2003 Modifying Petri net models by means of crosscutting operations *Third International Conference on Application of Concurrency to System Design, 2003. Proceedings* pp 177–186 URL https://doi.org/10.1109/CSD.2003.1207712
[11] Rawson M and Rawson M G 2022 Petri nets for concurrent programming *2022 IEEE/ACM Fifth Annual Workshop on Emerging Parallel and Distributed Runtime Systems and Middleware (IPDRM)* pp 17–24 URL https://doi.org/10.1109/IPDRM56689.2022.00008

[12] Kumar R and Sharma S C 2023 *The Journal of Supercomputing* **79**(2) 2251–2280 ISSN 1573-0484 URL https://doi.org/10.1007/s11227-022-04708-9
[13] Moreno-López G, Giraldo L, Gómez-Bayona L, Valencia-Arias A and Patiño Vanegas J C 2022 *RISTI - Revista Iberica de Sistemas e Tecnologias de Informacao* (E50) 537–550 URL http://www.risti.xyz/issues/ristie50.pdf
[14] Kamala S P R and Justus S 2020 *European Journal of Molecular & Clinical Medicine* **7**(4) 2446–2452 URL https://ejmcm.com/uploads/paper/75982d5da1785f6cdcdf5a60b3b3dde9.pdf
[15] Bilousova L, Gryzun L and Zhytienova N 2021 *Educational Technology Quarterly* **2021**(3) 415–428 URL https://doi.org/10.55056/etq.34

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Substantiation of the sustainable education terms as one of the modern views on STEM education taking to account the European experience

To cite this article: Y B Shapovalov *et al* 2023 *J. Phys.: Conf. Ser.* **2611** 012027

Substantiation of the sustainable education terms as one of the modern views on STEM education taking to account the European experience

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Abstract. This paper examines the development of concepts related to education for sustainable development, such as sustainability education, sustainability and education, sustainable education, sustainable development education, sustainable didactics, and sustainable learning. The paper argues that these concepts are insufficient for designing educational processes that fully consider the factors of sustainable development. The paper proposes and justifies the need for new concepts: sustainable pedagogy, sustainable educational process, and didactics for a sustainable educational process. These concepts are based on the components of sustainable development: competence, health, and motivation and socialization. The paper discusses how to use these factors to assess the sustainability of educational approaches. It also provides a practical example of how to apply the "sustainability" methodology in the educational process using Google Lens in biology lessons.

1. Introduction

The integration of sustainable development principles into various aspects of life and activities has become a widely accepted norm. However, in many contexts, the term "sustainable development" lacks specific operationalization and may be perceived as mere rhetoric.

This issue becomes evident when examining the development of the terminology within the field of Education and Pedagogy. Notably, quality education ranks fourth among the United Nations' Sustainable Development Goals [1]. It is encapsulated by the established concept of "Education for Sustainable Development" (ESD), which has been prominently featured in scholarly research since 2015. UNESCO interprets Education for Sustainable Development as a response to the pressing global challenges facing our planet [2]. Furthermore, this concept advocates for an approach that fosters active and critical thinking among the younger generation, with a forward-looking orientation that encourages proactive problem-solving, question formulation, and thoughtful reflection at the level of actions and decisions, thus promoting the reevaluation and adjustment of activities [3]. Additionally, ESD emphasizes the cultivation of competencies necessary to effectively advance education for sustainable development [4].

Among the studies, there are synonymous terms that denote ESD, such as Teaching Sustainability [5], Sustainable and Education [6], Sustainable Education [7,8], and Sustainability

Education [9]. Among other things, the term "sustainable didactics" was used to describe innovative teaching methods in sports, which, according to the authors [10], outlines a new paradigm of learning and teaching. In the study [11], the term "sustainable teaching" was understood as the interaction of politicians and practitioners to ensure sustainable system reforms.

After the UN General Assembly's endorsement of the post-2015 development agenda, the theme of sustainability has gained prominence in reports related to STEM (Science, Technology, Engineering, and Mathematics) education [12, 13], indicating a direct link between the relevant pedagogical concepts: STEM education programmes are based on a transdisciplinary approach [14]. At the same time, the integration of disciplinary content and practical skills in the context of new technological opportunities create the conditions for applying the 21st century skills [15, 16] to address sustainable development issues through the development of more efficient, elegant, scientifically sound and technologically safe methods and innovative solutions [17].

The conducted research showed that the previously proposed concepts related to ESD mainly outline the direction of educational activity without considering specific practical approaches to education based on the requirements of sustainable development. Hence, this article seeks to emphasize the potential adaptation of the ideology, concepts, and their constituent elements commonly employed to delineate ESD within the context of specific pedagogical requirements.

2. Research methods

An analysis of the literature was carried out regarding the contexts of the use of the term ESD, "sustainable education", and their synonyms. The Venn diagram [18, 19] was used to display the sustainability components. Their impact on education was analyzed, adapted in the context of educational processes, and applied to justify the newly introduced terms "sustainable pedagogy" and "sustainable educational process".

3. Results

By its content, the approach based on sustainability should ensure the implementation of actions that would enable the existence of future generations in an environment not worse than it is now. The above can be implemented only based on a systematic combination in any field of activity, particularly in the project, economic, social, and environmental components of sustainability; their interaction is traditionally demonstrated using a Venn diagram (figure 1).

Significant practical and pedagogical experience underscores the appropriateness and necessity of introducing terminologies such as "sustainable pedagogy", "sustainable educational process", and "didactics for a sustainable educational process". In accordance with the Ukrainian Law on Education, the overarching aim of education in Ukraine is the comprehensive development of individuals, valuing their talents, intellectual, creative, and physical abilities, and instilling values and competencies essential for successful self-realization [20]. This education also seeks to nurture responsible citizens capable of making informed social choices and directing their efforts toward the betterment of society, thereby enriching Ukraine's intellectual, economic, creative, and cultural potential. Furthermore, raising the educational standards of citizens is integral to ensuring Ukraine's sustainable development and its alignment with European principles, as acknowledged in the Concept of the New Ukrainian School [21]. This approach has garnered commendation from the European Commission as a crucial step in Ukraine's educational integration into Europe [22].

The publication titled "Learning for the Future" establishes competencies within the realm of sustainable development [4]. Furthermore, numerous studies have delved into the cultivation of competencies within specialized fields, such as environmental proficiency among mining engineers [23], digital aptitude among physicists [24], and biologists [25].

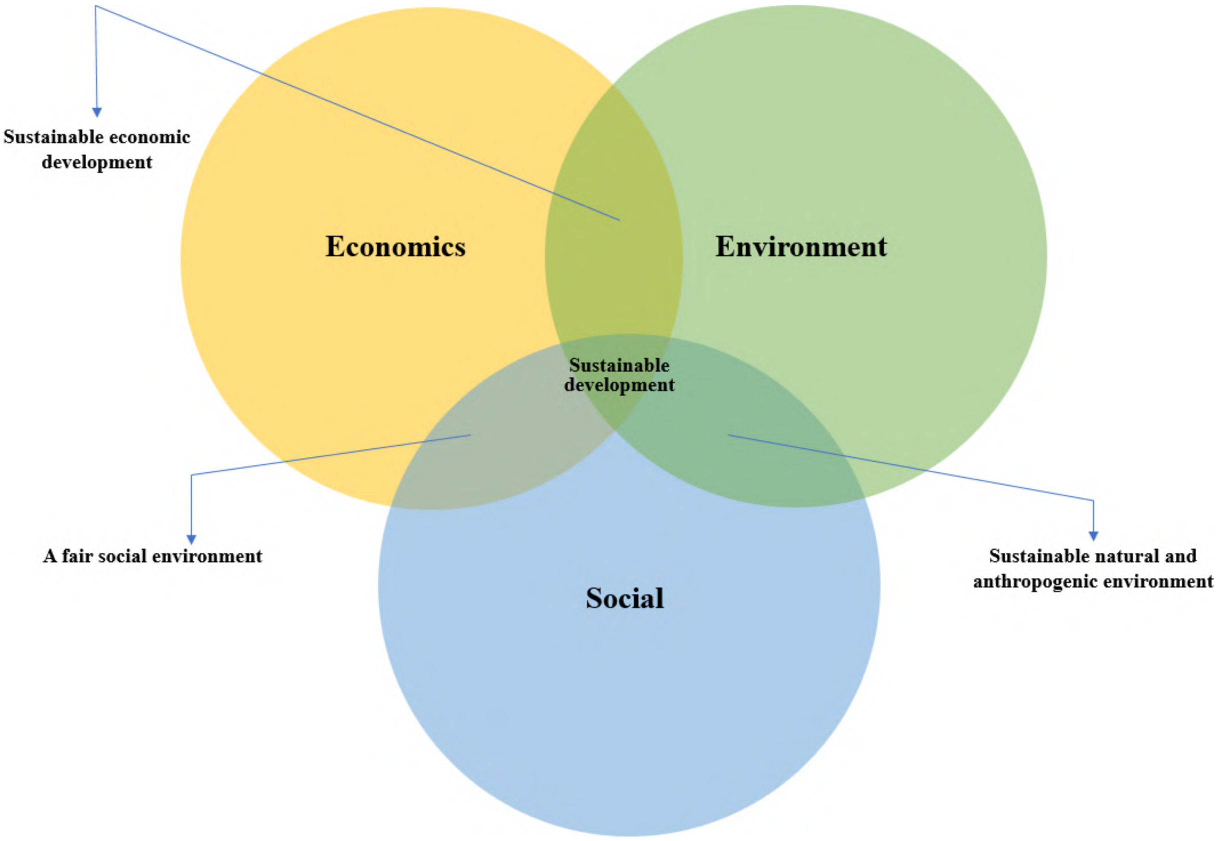

Figure 1. Traditional representation of project sustainability components.

The adoption of sustainable development values is facilitated by contemporary educational trends, including STEM education [26–30], scientific education [31], and technologies focused on fostering a positive approach to health [32], among others. Consequently, the presence of these educational domains and their constituents contributes to a favorable shift in the modern educational paradigm, encompassing not only knowledge and competence but also motivational factors [33, 34], socialization [35], psycho-emotional well-being, and health preservation [36, 37]. These factors collectively form the basis for delineating the following components of sustainable development within the realm of educational sciences (figure 2):

1. *Competence or Pragmatic Dimension*: This dimension directly influences an individual's ability and preparedness for future professional endeavors. It serves as the educational counterpart to the economic component of sustainability.
2. *Health-Preserving Dimension*: This dimension pertains to the preservation of the psychological and physical well-being of participants in the educational process. It corresponds to the environmental component of sustainability in the educational sphere.
3. *Motivational and Socialization Dimension*: This dimension serves as the educational equivalent of the social component of sustainability and comprises two subcomponents:
    - *Motivational Aspect*: This aspect involves enhancing students' interest, both situationally and in their motivation to engage in learning [33].
    - *Socialization Aspect*: This aspect is aimed at preparing students for assuming social roles that equip them for real-life responsibilities.

The Venn diagram allows visualizing the concepts of “sustainable pedagogy” and “sustainable educational process” (figure 2).

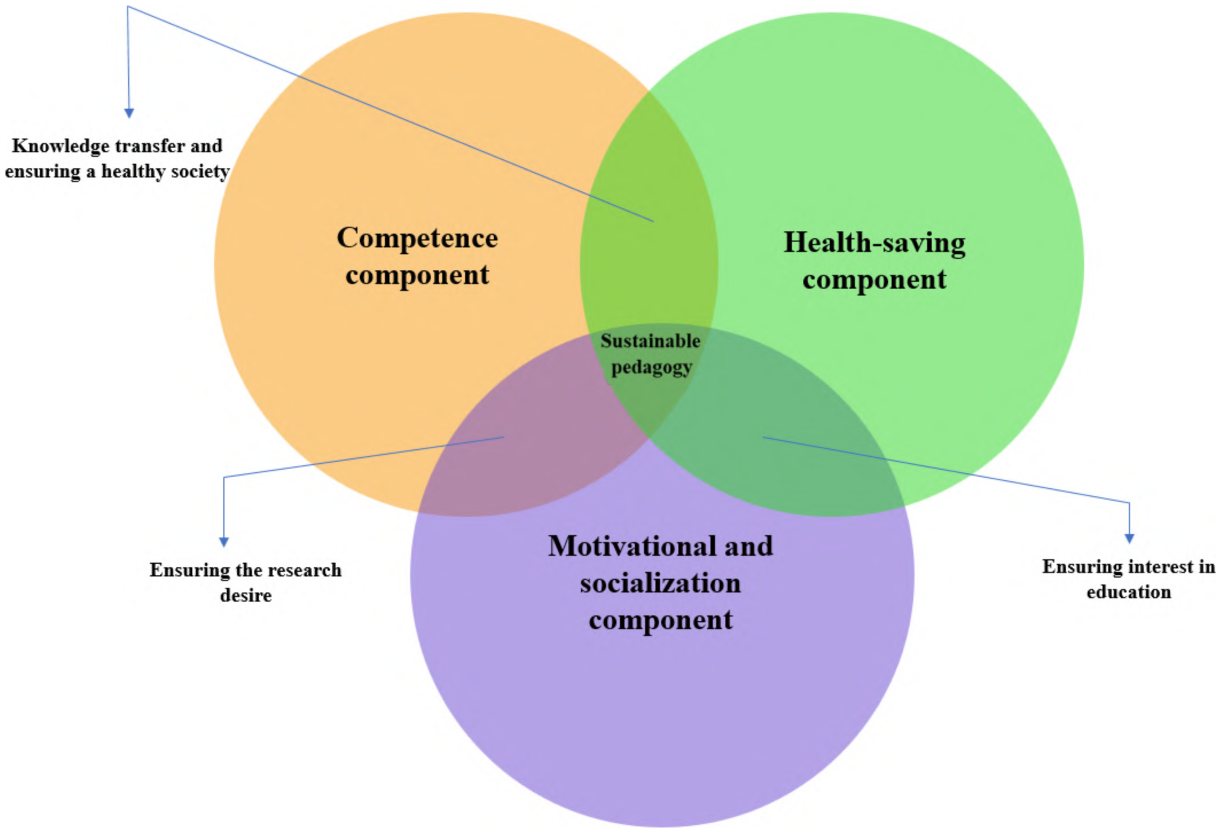

Figure 2. Projection of sustainable development components in the educational field.

Hence, the notion of “sustainable pedagogy” represents an approach within the pedagogical realm that encompasses all elements of educational practice, guided by the integration of sustainable development components. Conversely, the concept of a “sustainable educational process” entails the conscious incorporation of sustainable development components into the formal and informal learning and teaching processes within educational institutions.

Additionally, the term “didactics for a sustainable educational process” pertains to the creation and application of methodical and methodological didactic materials aimed at fostering the integration of sustainable development components within education.

4. Discussion

4.1. Practical applications

We believe that several approaches exemplify the effective integration of sustainable development principles in the field of education. These approaches include:

1. *STEM Education*: Various studies have emphasized the alignment of Science, Technology, Engineering, and Mathematics (STEM) education with sustainable development [13, 25, 27, 38, 39].
2. *Scientific Education in Specific Disciplines*: Tailoring scientific education to specific disciplines has been shown to enhance its relevance to sustainable development [31, 40].

3. *Immersive Technologies*: Technologies such as augmented reality and virtual reality have proven valuable in conveying sustainable development concepts in immersive and engaging ways [41–44].
4. *Personalized Smart Tools*: The utilization of personalized smart tools, particularly those focused on physiological aspects, can contribute to effective learning and align with sustainable development goals [38].
5. *Information Systems and Ontological Approaches*: The use of information systems, particularly those employing ontological frameworks as described in various works [45–47], aids in structuring and disseminating sustainable development knowledge.

These innovative teaching methods, when employed within the framework of "sustainable pedagogy", can be highly effective. However, their efficiency depends on various factors, with didactic approaches playing a pivotal role in determining their success.

Certainly, let's delve into the context of sustainability in pedagogy using the example of teaching biology, specifically botany, through the application of augmented reality (AR) with Google Lens, guided by the principles of scientific education (STEM) [25, 29]. Using this approach verifies theoretical knowledge in practice. Students are developing competencies in the use of digital technologies for plant identification. This, of course, obviously affects the competence component of the educational process that develops using phone apps to identify plants and develop students' thinking about how identification works. In addition, it was found that this approach has a positive effect on students' motivational, socialization, and psycho-emotional state (preservative health).

At the same time, using modern digital teaching methods and technologies is essential to consider digital well-being [47]. In particular, it is relevant to limit their use duration [49].

4.2. European dimensions
The European integration context now is extremely important. It is the way of growing of life level and economical development of Ukraine. The sustainability is highly used in the European sociality and legislation [50, 51]. A lot of reports are devoted to evaluate the state of sustainable development [52]. The European Union provide regular declaration of the sustainable development aims, for example in strategies Europe 2020 and Europe 2030 [53–55].

Some attraction also developed to science education and, particularly STEM [40], that involves the terms of motivation, critical thinking and socialization [56] as noted before. It's noteworthy that these terms and approaches are also integrated into the concept of the New Ukrainian School, as indicated by [57]. The New Ukrainian School initiative underscores the importance of aligning with best European practices and shares a similar orientation with European educational frameworks and documents.

Taking to account noted before, the proposed substantiation of the sustainable education terms as one of the modern views on STEM is relevant and important to take into account the European experience.

5. Conclusions
This article has explored the evolution of sustainable development concepts in education and pedagogy, arguing for the need for new concepts such as sustainable pedagogy, sustainable educational process, and didactics for a sustainable educational process. These concepts are based on the critical components of sustainable development: competence, health, and motivation and socialization.

The article also provided a practical example of how to apply sustainability methodologies in the educational domain using Google Lens in biology lessons. This case study demonstrated the practicality and effectiveness of integrating sustainability principles into everyday teaching practices.

Overall, the article has emphasized the importance of infusing the ethos of sustainability into the educational process to foster active and critical thinking among the younger generation. It has also called for a holistic approach to educational design that considers sustainable development factors. The introduction of innovative concepts such as sustainable pedagogy is essential for ensuring comprehensive personal development, elevating educational standards, and contributing to the sustainable advancement of society.

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References

[1] United Nations 2023 The 17 Goals | Sustainable Development URL https://sdgs.un.org/goals
[2] UNESCO 2023 Education for sustainable development URL https://www.unesco.org/en/education/sustainable-development
[3] The Australian Research Institute in Education for Sustainability 2009 Education for sustainability: The role of education in engaging and equipping people for change URL http://aries.mq.edu.au/publications/aries/efs_brochure/pdf/efs_brochure.pdf
[4] Sander R 1998 *Nursing Standard* **13**(4) 58–59 URL https://doi.org/10.7748/ns.13.4.58.s49
[5] Park H Y, Licon C V and Sleipness O R 2022 *Sustainability* **14**(15) 9485 ISSN 2071-1050 URL https://doi.org/10.3390/su14159485
[6] Michelsen G and Fischer D 2017 Sustainability and education *Sustainable Development Policy: A European Perspective* ed von Hauff M and Kuhnke C pp 135–158 ISBN 9781351978255 URL https://doi.org/10.4324/9781315269177
[7] Reynolds P and Cavanagh R 2009 Sustainable education: Principles and practices *Association for Research in Education Annual Conference, Canberra 2009* URL http://web.archive.org/web/20220617181906if_/https://www.aare.edu.au/data/publications/2009/rey091135.pdf
[8] Bussey M 2002 Sustainable Education: Imperatives for a Viable Future *Global Transformations and World Futures: Knowledge, Economy and Society: Encyclopedia of Life Support Systems* vol II ed Inayatullah S T (UNESCO Publishing) ISBN 9231038591 URL https://www.eolss.net/sample-chapters/c13/E1-24-03-08.pdf
[9] Boojh R and Ishwaran N (eds) 2022 *Sustainability Education for a Better World* (Newcastle upon Tyne: Cambridge Scholars Publishing) ISBN 978-1-5275-7723-7
[10] Borgogni A, Digennaro S, Manzo S and Vannini E 2010 *EQOL Journal* **2**(2) 43–49 URL https://www.eqoljournal.com/wp-content/uploads/2017/06/EQOL_2_2_e.pdf
[11] Farrell R and Sugrue C 2021 Sustainable Teaching in an Uncertain World: Pedagogical Continuities, Un-Precedented Challenges *Teacher Education in the 21st Century* ed Hernández-Serrano M J (Rijeka: IntechOpen) chap 7 URL https://doi.org/10.5772/intechopen.96078
[12] Khadri H O 2022 *PROSPECTS* **52**(3) 421–435 ISSN 1573-9090 URL https://doi.org/10.1007/s11125-021-09588-0
[13] Anderson J and Li Y 2020 Investigating the Potential of Integrated STEM Education from an International Perspective *Integrated Approaches to STEM Education: An International Perspective* ed Anderson J and Li Y (Cham: Springer International Publishing) pp 1–12 ISBN 978-3-030-52229-2 URL https://doi.org/10.1007/978-3-030-52229-2_1
[14] Soros P, Ponkham K and Ekkapim S 2018 *AIP Conference Proceedings* **1923**(1) 030045 ISSN 0094-243X URL https://doi.org/10.1063/1.5019536
[15] Huang B, Jong M S Y, King R B, Chai C S and Jiang M Y C 2022 *Frontiers in Psychology* **13** ISSN 1664-1078 URL https://doi.org/10.3389/fpsyg.2022.903252
[16] Villán-Vallejo A, Zitouni A, García-Llamas P, Fernández-Raga M, Suárez-Corona A and Baelo R 2022 *BHM Berg- und Hüttenmännische Monatshefte* **167**(10) 485–488 ISSN 1613-7531 URL https://doi.org/10.1007/s00501-022-01275-7
[17] Hebebci M T and Usta E 2022 *Participatory Educational Research* **9**(6) 358 – 379 ISSN 2148-6123 URL https://doi.org/10.17275/per.22.143.9.6

[18] Moir S and Carter K 2012 Diagrammatic Representations of Sustainability – a Review and Synthesis *Proceedings 28th Annual ARCOM Conference, 3-5 September 2012, Edinburgh, UK* ed Smith S D (Edinburgh: Association of Researchers in Construction Management) pp 1479–1489 URL http://www.arcom.ac.uk/-docs/proceedings/ar2012-1479-1489_Moir_Carter.pdf

[19] Gallopín G, Jiménez Herrero L M and Rocuts A 2014 *International Journal of Sustainable Development* **17**(3) 298–326 URL https://doi.org/10.1504/IJSD.2014.064183

[20] 2017 Law of Ukraine "On Education" URL https://zakon.rada.gov.ua/laws/show/2145-19?lang=en#Text

[21] Elkin O, Hrynevych L, kalashnikova S, Khobzey P, Kobernyk I, Kovtunets V, Makarenko O, Malakhova O, Nanayeva T, Shiyan R and Usatenko H 2017 *The New Ukrainian School: conceptual principles of secondry school reform* (Kyiv) URL https://mon.gov.ua/storage/app/media/zagalna%20serednya/Book-ENG.pdf

[22] 2022 Association Implementation Report on Ukraine Joint staff working document SWD(2022) 202 final European Commission Brussels URL https://www.eeas.europa.eu/sites/default/files/documents/Association%20Implementation%20Report%20on%20Ukraine%20-%20Joint%20staff%20working%20document.pdf

[23] Morkun V S, Semerikov S O, Morkun N V, Hryshchenko S M and Kiv A E 2018 *CEUR Workshop Proceedings* **2257** 198–203 URL https://ceur-ws.org/Vol-2257/paper19.pdf

[24] Slipukhina I, Kuzmenkov S, Kurilenko N, Mieniailov S and Sundenko H 2019 *CEUR Workshop Proceedings* **2387** 318–333 URL https://ceur-ws.org/Vol-2387/20190318.pdf

[25] Bilyk Z I, Shapovalov Y B, Shapovalov V B, Megalinska A P, Andruszkiewicz F and Dolhanczuk-Sródka A 2020 *CEUR Workshop Proceedings* **2731** 61–78 URL https://ceur-ws.org/Vol-2731/paper02.pdf

[26] Prykhodniuk V V and Stryzhak O Y 2017 *Matematychne modeliuvannia v ekonomitsi* (1-2) 47–61 URL http://nbuv.gov.ua/UJRN/mmve_2017_1-2_6

[27] Shapovalov Y B, Bilyk Z I, Usenko S A and Shapovalov V B 2022 *Journal of Physics: Conference Series* **2288**(1) 012032 URL https://doi.org/10.1088/1742-6596/2288/1/012032

[28] Shapovalov Y B, Bilyk Z I, Usenko S A, Shapovalov V B, Postova K H, Zhadan S O and Antonenko P D 2023 *Educational Technology Quarterly* **2023**(2) 210–232 URL https://doi.org/10.55056/etq.604

[29] Bilyk Z I, Shapovalov Y B, Shapovalov V B, Megalinska A P, Zhadan S O, Andruszkiewicz F, Dołhańczuk-Śródka A and Antonenko P D 2022 *Educational Technology Quarterly* **2022**(4) 328–346 URL https://doi.org/10.55056/etq.433

[30] Semerikov S O, Mintii M M and Mintii I S 2021 *CEUR Workshop Proceedings* **2898** 159–177 URL https://ceur-ws.org/Vol-2898/paper09.pdf

[31] Brock W H 1996 Science Education *Companion to the History of Modern Science* ed Olby R C, Cantor G N, Christie J R R and Hodge M J S (London: Routledge) pp 946–959 ISBN 9781003070818 URL https://doi.org/10.1201/9781003070818-70

[32] Klochko O V and Fedorets V M 2022 *Educational Technology Quarterly* **2022**(4) 276–306 URL https://doi.org/10.55056/etq.431

[33] Linnenbrink-Garcia L, Durik A M, Conley A M, Barron K E, Tauer J M, Karabenick S A and Harackiewicz J M 2010 *Educational and Psychological Measurement* **70**(4) 647–671 URL https://doi.org/10.1177/0013164409355699

[34] Rodríguez-Aflecht G, Jaakkola T, Pongsakdi N, Hannula-Sormunen M, Brezovszky B and Lehtinen E 2018 *Journal of Computer Assisted Learning* **34**(3) 259–268 URL https://doi.org/10.1111/jcal.12239

[35] Terziev V and Vasileva S 2022 The Role of Education in Socialization of an Individual *Abstracts & Proceedings of INTCESS 2022- 9th International Conference on Education and Education of Social Sciences, 17-18 January, 2022* ed Uslu F (Istanbul: International Organization Center of Academic Research) ISBN 978-605-06286-4-7 URL https://doi.org/10.51508/intcess.202272

[36] Goncharova G A, Lazurenko S B and Drobysheva M M 2022 *Probl Sotsialnoi Gig Zdravookhranenniiai Istor Med.* **30**(4) 673–678 URL https://doi.org/10.32687/0869-866X-2022-30-4-673-678

[37] Diachenko-Bohun M, Rybalko L, Grygus I and Zukow W 2019 *Journal of History Culture and Art Research* **8**(2) 93–101 URL https://doi.org/10.7596/taksad.v8i2.2075

[38] Shapovalov Y, Bilyk Z, Usenko S, Shapovalov V, Postova K, Zhadan S and Antonenko P 2022 Using Personal Smart Tools in STEM Education *Proceedings of the 1st Symposium on Advances in Educational Technology - Volume 2: AET* INSTICC (SciTePress) pp 192–207 ISBN 978-989-758-558-6 URL https://doi.org/10.5220/0010929900003364

[39] European Commission and Directorate-General for Research and Innovation 2015 *Science education for responsible citizenship : report to the European Commission of the expert group on science education* (Luxembourg: Publications Office of the European Union) URL https://doi.org/10.2777/12626

[40] European Commission 2019 Reflection Paper "Towards a Sustainable Europe by 2030" Tech. Rep. NAT/760

European Economic and Social Committee
[41] Dökme İ, Açıksöz A and Koyunlu Ünlü Z 2022 *International Journal of STEM Education* **9**(1) 8 ISSN 2196-7822 URL https://doi.org/10.1186/s40594-022-00326-2
[42] Mintii I S and Soloviev V N 2018 *CEUR Workshop Proceedings* **2257** 227–231 URL https://ceur-ws.org/Vol-2257/paper22.pdf
[43] Shepiliev D S, Semerikov S O, Yechkalo Y V, Tkachuk V V, Markova O M, Modlo Y O, Mintii I S, Mintii M M, Selivanova T V, Maksyshko N K, Vakaliuk T A, Osadchyi V V, Tarasenko R O, Amelina S M and Kiv A E 2021 *Journal of Physics: Conference Series* **1840** 012028 URL https://doi.org/10.1088/1742-6596/1840/1/012028
[44] Rashevska N V, Semerikov S O, Zinonos N O, Tkachuk V V and Shyshkina M P 2020 *CEUR Workshop Proceedings* **2731** 79–90 URL https://ceur-ws.org/Vol-2731/paper03.pdf
[45] Burov O Y and Pinchuk O P 2023 *Educational Technology Quarterly* **2023**(1) 58–68 URL https://doi.org/10.55056/etq.435
[46] Globa L S, Sulima S, Skulysh M A, Dovgyi S and Stryzhak O 2019 Architecture and Operation Algorithms of Mobile Core Network with Virtualization *Mobile Computing* ed Ortiz J H (Rijeka: IntechOpen) chap 6 URL https://doi.org/10.5772/intechopen.89608
[47] Stryzhak O, Horborukov V, Prychodniuk V, Franchuk O and Chepkov R 2021 *Journal of Physics: Conference Series* **1828**(1) 012007 URL https://doi.org/10.1088/1742-6596/1828/1/012007
[48] Semerikov S, Osadchyi V and Kuzminska O 2021 *Educational Technology Quarterly* **2021**(4) 429–604 URL https://doi.org/10.55056/etq.53
[49] Nadutenko M, Prykhodniuk V, Shyrokov V and Stryzhak O 2022 Ontology-Driven Lexicographic Systems *Advances in Information and Communication* (*Lecture Notes in Networks and Systems* vol 438) ed Arai K (Cham: Springer International Publishing) pp 204–215 URL https://doi.org/10.1007/978-3-030-98012-2_16
[50] Zantua L S O 2017 *Asia Pacific Journal of Multidisciplinary Research* **5**(2) 1–10 ISSN 2350-8442 URL http://www.apjmr.com/wp-content/uploads/2017/05/APJMR-2017.5.2.2.01.pdf
[51] European Commission 2023 Sustainable development URL https://policy.trade.ec.europa.eu/development-and-sustainability/sustainable-development_en
[52] European Commission 2023 Sustainable Development Goals URL https://commission.europa.eu/strategy-and-policy/sustainable-development-goals_en
[53] Sustainable Development Solutions Network and Institute for European Environmental Policy 2021 *Europe Sustainable Development Report 2021: Transforming the European Union to achieve the Sustainable Development Goals* URL https://www.sdgindex.org/reports/europe-sustainable-development-report-2021/
[54] Shapovalov Y B, Yakymenko I L, Salavor O M and Šebková K 2022 *IOP Conference Series: Earth and Environmental Science* **1049**(1) 012044 URL https://doi.org/10.1088/1755-1315/1049/1/012044
[55] European Commission 2010 Europe 2020: A strategy for smart, sustainable and inclusive growth Communication from the Commission COM(2010) 2020 final Brussels URL http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2010:2020:FIN:EN:PDF
[56] Shekhavtsova S, Koknova T and Shekhavtsov M 2021 *Educational Technology Quarterly* **2021**(2) 310–330 URL https://doi.org/10.55056/etq.28
[57] Zhorova I, Kokhanovska O, Khudenko O, Osypova N and Kuzminska O 2022 *Educational Technology Quarterly* **2022**(1) 56–72 URL https://doi.org/10.55056/etq.11

Journal of Physics: Conference Series

PAPER • OPEN ACCESS

Artificial intelligence in a modernizing science and technology education: a textual narrative synthesis in the COVID-19 era

To cite this article: F A A Pacala 2023 *J. Phys.: Conf. Ser.* **2611** 012028

Artificial intelligence in a modernizing science and technology education: a textual narrative synthesis in the COVID-19 era

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Abstract. The COVID-19 pandemic shifted the mode of learning to online. This gave the artificial intelligence (AI) developers the reason to increase its usage and production to every detail of the teaching learning process. This synthesis paper was intended to capture these new technologies in the last five years. Using the textual narrative analysis approach and course design triangle model, this paper looked into the AI integration in the field of science and technology education. A total of 15 studies were analyzed and synthesized coming from different journal hosting platforms such as Google Scholar, ERIC, Elsevier, etc. The results have shown that there is indeed a wider utilization of AI in various aspects of the teaching and learning process. These were seen in the learning activities, presentation translators, marking, feedbacking, predicting average score, and intelligent tutoring system. These AI technologies have proven to positively affect the learning of the students and helped the teachers along the process. Furthermore, there is a need to totally synthesize these AI systems which can be beneficial to a wider technical audience.

1. Introduction

The way teaching and learning process in science related subjects is managed in the classroom has been changing. From rote learning to active learning, it is a revolution in its own making. There was also a change in the platform where classes are undertaken. In the past, a physical classroom was the only way synchronous learning could happen; however today, a classroom can be considered virtual. Even assessment and evaluation can now be done online using different modern applications and software. Indeed, we are now living in a different world than the past.

The explosion of these myriad platforms for classroom meetings, activities, and assessments has become nonstop especially during the height of the COVID-19 pandemic. Hence, it is imperative to collect these literatures and form a synthesis paper about the AI integration in the science and technology most especially in the learning activities and assessment and evaluation in the post-COVID-19 era. During the COVID-19 pandemic, there were fewer ways for schools to operate and the main solution is doing online classes. Though the shift is a primacy, some schools were not ready. Hence, some schools faced closure. Most schools that shifted to online uses either Google Classroom, Moodle, Canvas, PowerSchool, or Edmodo to name a few as their Learning Management System (LMS). Instead of going to a real museum teachers opted to use virtual museum. Since it was impossible do conduct a physical experiment in the laboratories, many teachers used videos and simulations of the experiments. For instance, students can perform an experiment in sound waves using the PhET Sound Waves Simulation. Students in biology can execute a frog dissection utilizing an augmented reality software called The Digital Frog.

Artificial Intelligence (AI) is defined as a wide-ranging branch of computer science concerned with building smart machines capable of performing tasks that typically require human intelligence [1]. The impact of AI to the current educational arena has been a productive one so far [2, 3]. Despite the promising moments of AI in the classroom, there is still a need to debate the efficacy of the AI integration in the classroom and its effect on the resulting values and attitudes of the students [4]. Many educators are feeling the hype of AI without knowing if this technology has an effect on the holistic dimension of the students. Indeed, there is a wider room for debate. In the industry, many companies are currently using AI and robotic technology because it is cheaper than human labor [5]. Are we ready for this same change in the educator sector? Social interaction, an important value in education, might depart from the teaching and learning process when this happens.

The aims of this study are: 1) review the artificial intelligences, augmented reality, and other new technologies used in science teaching and learning during the COVID-19 pandemic; 2) provide guidance on how these new technologies can be better used in the classroom; and 3) use the course design triangle as basis for review of the new technologies used in science teaching and learning during the COVID-19 pandemic. This paper emphasized on the impact of AI integration in the science and technology classroom (e.g., role in the classroom, effectiveness, and dilemmas) in order for the entire academic community to be given a fair, legal, productive, and enjoyable educational process.

2. Methodology

This synthesis paper utilized textual narrative synthesis as its design as described by the guidelines of Popay et al [6]. They said that the purpose of a textual narrative synthesis is to condense or critique the results of previously published research articles in a scientific process. The effect of gathering the fruit of published articles in a narrative synthesis is to give the readers the new insights, in one article only, out of several researches [7]. Unlike narrative review, a textual narrative synthesis can provide comprehensive recommendations and implications for practice [8].

2.1. Data collection

This paper used electronic sources coming from different journal depository sites and platforms. These include ERIC, EBSCO, Emerald, Elsevier, and Google Scholar. From these sites, the main key words used are: AI in science education; AI in learning; and AI impact in education. The Boolean operators 'AND' and 'OR' were also used.

When the articles appeared, there were lots of articles. There were articles that do not concern science and technology education and AI integration, so these were not included. Articles that showed abstract only were excluded as well. Also, only articles within the two years were included since there has been a massive use of AI in education during the COVID-19 pandemic. Non-English language articles were eliminated as well. On the type of publication, only full original articles are included which can be quantitative, qualitative or both as an approach [9]. In total there were 11 original articles used in this synthesis. According to O'Donovan et al [10], at least 10 articles are required for a viable and comprehensive textual narrative synthesis.

2.2. Theoretical model

This synthesis paper followed the Course Design Triangle of Carnegie Mellon. This framework follows the alignment of learning objectives, activities, and assessment forming a closed triangle. The validity and quality assurance control are made possible through this framework [11].

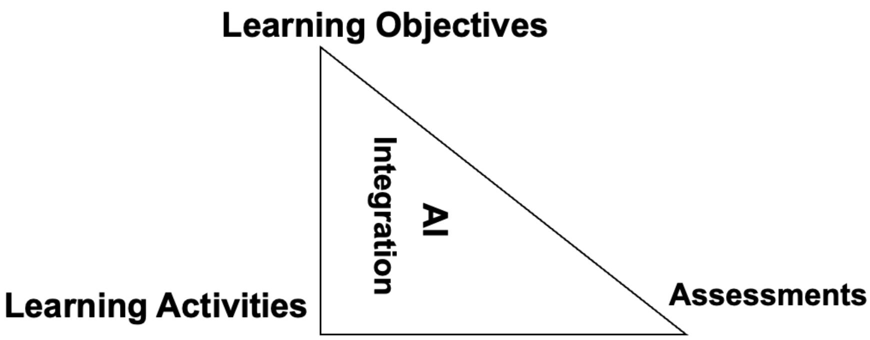

Figure 1. Theoretical model of the synthesis paper.

Table 1: Summary of articles included in this narrative review.

Author(s) and year	**Goals / Objectives**	**Data sources**	**Participants / Sample**	**Tools**	**Results**
Liu, B., Zhao, M., Niu, D., Lai, K., He, Y., Wei, H., & Xu, Y. (2019) [12]	Investigate the performance of Clue Guided Copy Network for Question Generation	Sentence or phase encoded by the users	2000 users	PyTorch 0.4.1, Tesla P40, and spaCy	Shown that Clue Guided Copy Network for Question Generation is effective in the question generation process on which words to generate and to copy. It also teaches the model to make decisions on what to copy and generate.
Noyes, K., McKay, R., Neumann, M., Haudek, K., & Melanie M. (2020) [13]	Investigate a computer-assisted analysis system to characterize students' explanation on London dispersion of forces.	Student coded responses from a test questionnaire	1730 students' responses	ML	Effectively characterize high level responses with critical thinking answers being highlighted
Subirats, L., Fort, S., Atrio, S. & Sacha, G.M. (2021) [14]	Create a methodology for students' grade classification system under a distance learning system.	students' self-evaluation tests using adaptive test platform	7490 self-evaluation tests	Programming code (Matlab in e-valUAM)	Developed a methodology to classify students as a function of their academic success. Helped students find an effective learning technique

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Continued from table 1

Author(s) and year	**Goals / Objectives**	**Data sources**	**Participants / Sample**	**Tools**	**Results**
Tarik, A., Aissa, A. & Yousef, Y. (2021) [15]	Compare systems that will predict the student's Baccalaureate average using AI	End of school year general average	averages of 72010 students	1. Linear regression 2. Regression-type decision tree 3. Regression-type random forest	Random forest algorithm provides the best predictions for the Baccalaureate Average of the students.
Kabir, A. I., Aktir, S. & Mitra, S. (2021) [16]	Develop and analyze a system for facial recognition of students and measure classroom engagement.	Pictures and videos of students from an online class.	15 students	1. R programming language 2. Machine Learning	Detected few faces and cannot detect different body positions. Needs AI enhancement.
Lu, A., Wong, C. S., Cheung, R. Y., & Im, T. S. (2021) [17]	Develop and investigate augmented reality and AI to simulate a person's daily life with chemistry.	Guided texts, videos, and human voices in an application	46 students	AR and AI	Students were positive on the use of AR and AI in simulating chemistry in daily life. However, students wanted more control and more content on the application.
Jescovitch, L.N., Scott, E.E., Cerchiara, J.A. et al (2021) [18]	Compare the performance of machine learning in using analytic and holistic coding approaches in students' constructed responses	Open-ended-constructed responses from the students	700 students' responses	Machine learning	Machine learning helped correctly score the students in both holistic and analytic rubrics. Even with a more different construct of students' response the AI had effectively scored the answer of the students and it had taken into account the scientific reasoning skill of the responder.

Continued on next page

Continued from table 1

Author(s) and year	**Goals / Objectives**	**Data sources**	**Participants / Sample**	**Tools**	**Results**
Neumann, A. T., Arndt, T., Köbis, L., Meissner, R., Martin, A., de Lange, P., Pengel, N., Klamma, R., & Wollersheim, H. W. (2021) [19]	Create and analyze a system of chatbots that provides a scale mentoring process to students of educational sciences.	Students' messages in the chatbots Feedbacks from the students scale mentoring scale	715 student users 19 students' feedbacks	FeedBot and LitBot	FeedBot and LitBot provide necessary guidance and instruction to the students. It was also providing mentoring mechanism whereby students are guided what to do in a task
Sarani, A. & Moud, S.G. (2022) [20]	Determine the effect of PowerPoint Designed Vocabulary Organizers to learning styles of pre-intermediate learners	Scores from vocabulary test using researcher-made instrument	340 students	Computer-Assisted Language Learning	Improves scores and positive students' attitude towards the tool
Singh, N., Gunjan, V. K., Mishra, A. K., Mishra, R. K. & Nawaz, N. (2022) [21]	Develop and investigate a system for intelligent tutoring system	Scores from prior knowledge test, learning style test, learner performance via quizzes and test, and feedback from students	60 students	intelligent tutoring system in this study is named SiesTutor	The ITS was sustainable and provided effective learning gain to the students. It analyzed students' behavior
Hooda, M., Rana, C., Dahiya, O., Rizwan, A., & Hossain, M. S. (2022) [22]	Compare and explore the effect of assessment and feedback systems to students' learning outcomes using AI.	Demographic profile, assessment information, and level of interaction with the online learning platforms.	32592 academic records of the students	Various AI and compared in Open University Learning Analytics (OULAD)	the Improved Fully Connected Network (I-FCN) maneuver to outperform the other compared AI technologies with 84 percent accuracy and 93 percent reliability in correctly providing appropriate feedback to the students.

3. Results and discussion

Using the course design triangle as the model, the results are divided into two sections: AI integration in course objectives and learning activities and AI integration in the course assessments. This kind of layout allowed this paper to holistically analyze the impact of AI in the entirety of the teaching and learning process in a classroom. Also, it made this section organized.

3.1. AI integration in the learning objectives and activities

Before the COVID-19 pandemic, most of the artificial intelligence educational products were related to simulations like those of PhET and some measuring tools like for intelligence quotient. As online education succeeds, there is even facial recognition and activity engagement tools produced and used by teachers. The study of Kabir et al [16] used such tools. Their research is one of a kind in this field by which they used R programming language to create the AI to measure student engagements in the classroom and facial recognition as well. This tool enabled the teacher to have reduced tasks because there is no more monitoring to the students as the learning activity is on-going. Plus, there is more attention given to the students as the AI can view the students at different angles and even at lower lighting and resolution quality. However, the authors cited that there is much more to enhance on the AI since there are many body positions and some faces that are undetectable.

One of the most common strategies during the pandemic was flipped classrooms. This strategy is done by allowing the students to read the course material before the class schedule [23]. Mostly this strategy was on an electronic basis during the pandemic. A study of Lu et al [17] used this strategy by integrating augmented reality and artificial intelligence. They developed an application for flipping the class in chemistry. The materials in the application contain cues with guiding texts, narration of the text and videos, and an augmented reality to simulate a real one. Students then should arrange some misplaced toxic chemicals and label them properly.

Moreover, there was a shortened teacher to student interaction during the pandemic and more schools are moving from half week synchronous classes and half week asynchronous classes. In the study of Fabriz et al [24] suggested that both synchronous and asynchronous classes may be futile to the learning of the students if there is no immediate feedback from the teacher. There were also studies citing that asynchronous classes were more effective than synchronous classes [25]. Whichever may hold true, immediate feedback to the students during the pandemic is vital in positively impacting the change in students' outcomes. The problem sometimes is the failure of some teachers to monitor the students. One of the solutions made was creating a live chatbots powered by AI in respect to the lesson of the students. The study of Neumann et al [19] was one of the most successful in recent years. They created two chatbots namely Feedbot and Litbot. These two chatbots provide necessary guidance and instruction to the students. It was also providing a mentoring mechanism whereby students are guided on what to do in a task, things they missed during the synchronous lessons, and additional guidance to formulate appropriate write up in science lessons.

Another important AI tool in the classroom during the pandemic was the Microsoft Office PowerPoint Presentation Translator. This was used to create translation in real time of whatever the teacher is saying. Students studying natural sciences in the English language who were not native speakers of English were generally the beneficiary of these AI. In the study of Sarani and Ghollasi Moud [20], this tool positively affected their students' learning towards learning different topics. Students were given an avenue to learn the lesson by grasping the meaning of some difficult topic vocabulary without interrupting the classroom activities.

In some countries, one issue of online learning during the pandemic was that students cannot cope up with the new platform of education as presented in the studies of Basar et al [26] and Li [27]. Students have difficulty catching up with the lesson and teachers were prone to use the same online technique that students were not learning in the first place. In light of this problem, many computer science experts created an Intelligent Tutoring System (ITS) to guide students on the lesson they missed. One of these ITSs is the SeisTutor in learning seismic data interpretation developed by Singh et al [21]. This ITS offers personalization and custom build

 2611 (2023) 012028 doi:10.1088/1742-6596/2611/1/012028

course material and a guided learning program from the system. The intelligent guidance of this ITS proved effective making advancement of those students have difficulty in regular lesson flow.

3.2. AI integration in the course assessment and evaluation

When classes shifted online, one of the big problems and issues is the validity of assessment. Also, if these assessment tasks can cater individual differences of learners and if these assessment tasks are suited for individual needs of the students. With the use of an AI called e-valUAM, Subirats et al [14] were able to analyze students' data and applied an adaptive test. This system gathered data from students who studied using a Learning Management System (LMS), either Google Classroom or Moodle can take a formative test from there. With this data, the AI can come up with adaptive tests which are suited to the student's skill and need. Meanwhile, the AI classified students who are about to fail and these allowed the teacher to conduct intervention activity to these students.

Moreover, the need to better assess the students during the online mode of learning was vital. It was difficult for a teacher to assess students without the physical output like those of performance tests during these times of online learning. Usually, a teacher will use a scoring rubric to assess students and can AI help in automating the scoring? The study of Jescovitch et al [18] managed to compare the performance of machine learning in assessing students constructed responses using holistic and analytic rubric. It was found out that machine learning can help correctly score the students in both holistic and analytic rubrics. Even with a more different construct of students' response the AI had effectively scored the answer of the students and it had taken into account the scientific reasoning skill of the responder. This promising development can help schools implement an AI-based scoring system over a wider population. However, the coding of machine learning must be carefully analyzed. This is supported by the Noyes et al [13] using Al of learning analytics for a large number of constructed responses in marking the topic London dispersion topic. It was also proved effective to a sample of 1730 constructed responses by which high level responses with critical thinking were characterized than the using human coders. In addition, a comparative analysis of various artificial intelligence tools that provides assessments and feedback was conducted by Hooda et al [22] using more than 35000 students' data from a certain university. They compared it using the Open University Learning Analytics Dataset (OULAD) and found that the Improved Fully Connected Network (I-FCN) maneuver to outperform the other compared AI technologies with 84 percent accuracy and 93 percent reliability in correctly providing appropriate feedback to the students.

Aside from using tools that mark a large sum of responses of students, artificial intelligence is also utilized in making valid and reliable test items for formative and summative tests. One example of this AI is the Cambridge Assessment International Education (CAEI) Support Hub Test Maker. This will allow a teacher to set a test from various topics of the CAEI test bank along with its marking scheme. The time consumption of the teacher in creating the test is now reduced. Also, the questions were reliable and valid since the questions underwent several testing and expert analysis [28]. Recent question generation techniques in artificial intelligence can be system guided and applied by clues just like the research of Liu et al [12]. They created a Clue Guided Copy Network for Question Generation in which a user can input a possible question or sentence to generate and the system will propose several questions and options for the encoded input by the user. The result of this research was effective in teaching the AI model to make its own better decision on possible questions to generate that are deemed correct and appropriate by the user. Moreover, the study of Jia et al [29] presented a most promising form of artificial intelligence integration in test questions making. The approaches utilized were: Examination-type Question Generation in generating exam like questions, a Rough Answer and Key Sentence Tagging scheme is utilized to extensively visualize the answers of the learners;

and an Answer-guided Graph Convolutional Network was applied in order to catch the textual underpinning meaning of the structured responses form by a test question.

Career guidance among students during the pandemic faced also a consequential dilemma since there were massive labor layoffs around the globe. It was troublesome for a guidance counselor to perform his/her job when students see that their future career is not sustainable all of a sudden [30]. More so the delivery of the guidance was another consideration and the knowledge of a counselor to use online platforms for career guidance. The career referral systems evaluated by Tarik et al [15] was essential to answer these gaps. The purpose of their research was to predict the baccalaureate average of the students using different AI prediction and machine learning systems. It was found out that random forest algorithm was best suited for the purpose. The implication of their research was that using this AI, counselors and students now have the ability to know which career path they will proceed by following their strength in their baccalaureate average. It was also effective in taking note which subject is the weakness of the students and with these an intervention program can be successfully implemented.

4. Limitations
This synthesis paper has casted a wider view of artificial intelligence in its integration in science and technology teaching and the education sector during the peak of the COVID-19 pandemic. This paper was balanced in its synthesis analysis providing as everything cannot seem perfect, this paper is not accepted. One limitation is that this paper did not dwell totally into how the AI system works for the various mentioned technologies since the focus of this paper is only to venture into the AI integration in the teaching and learning process. This is viewed as a synthesis for future consideration by this paper and the technical readers.

5. Conclusions
The COVID-19 pandemic has accelerated the adoption of technology in education, paving the way for the integration of Artificial Intelligence (AI) as a valuable tool for modernizing science and technology education. There is no doubt about the proliferation of AI in the science and technology teaching and the whole education field. The pandemic was its outlet and reasoning in order to propagate. The pandemic has shown the need for new ways of delivering education, and AI is at the forefront of this trend. It is clear that AI has the potential to transform the future of education in ways we cannot yet imagine, from adaptive learning to virtual reality classrooms. However, AI continues to face challenges such as data bias, privacy concerns, and ethical issues that need to be addressed.

Even a simple examination generation and test making or an easy marking can be effectively done using an AI. An intelligent tutor can now provide students with learning guidance in order to pass an exam. Evaluating students for their future career is now tied by an AI with their academic performance and predicting it. The textual narrative synthesis reveals that AI can enhance teaching and learning by providing personalized, adaptive, and interactive experiences for students. It also highlights the importance of incorporating ethical considerations and preparing teachers to effectively use AI in their classrooms. The volumetric number of research papers conducted from 2019 to 2022, the height of pandemic, has proven the thesis of this synthesis. This is now a holistic extension of what transpired in the last five years.

Moreover, AI has tremendous potential to transform science and technology education in the COVID-19 era and beyond. Educators must continue to prioritize research and development of AI applications that support student engagement, promote critical thinking and problem-solving skills, and offer equitable learning opportunities for all. As the technology continues to evolve, it will be essential to maintain a balance between innovation and ethical implications to ensure the responsible use of AI in education.

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References
[1] Schroer A 2023 What Is Artificial Intelligence? URL https://builtin.com/artificial-intelligence
[2] Hirschberg J and Manning C D 2015 *Science* **349**(6245) 261–266 URL https://doi.org/10.1126/science.aaa8685
[3] Heintz F and Roos T 2021 Elements of AI-teaching the basics of AI to everyone in Sweden *EDULEARN21 Proceedings* 13th International Conference on Education and New Learning Technologies (IATED) pp 2568–2572 ISBN 978-84-09-31267-2 ISSN 2340-1117 URL https://doi.org/10.21125/edulearn.2021.0559
[4] Chassignol M, Khoroshavin A, Klimova A and Bilyatdinova A 2018 *Procedia Computer Science* **136** 16–24 ISSN 1877-0509 7th International Young Scientists Conference on Computational Science, YSC2018, 02-06 July2018, Heraklion, Greece URL https://doi.org/10.1016/j.procs.2018.08.233
[5] Davenport T, Guha A, Grewal D and Bressgott T 2020 *Journal of the Academy of Marketing Science* **48**(1) 24–42 ISSN 1552-7824 URL https://doi.org/10.1007/s11747-019-00696-0
[6] Popay J, Roberts H, Sowden A, Petticrew M, Arai L, Rodgers M, Britten N, Roen K and Duffy S 2006 Guidance on the Conduct of Narrative Synthesis in Systematic Reviews: A Product from the ESRC Methods Programme URL https://www.lancaster.ac.uk/media/lancaster-university/content-assets/documents/fhm/dhr/chir/NSsynthesisguidanceVersion1-April2006.pdf
[7] Light R J and Pillemer D B 1984 *Summing Up: The Science of Reviewing Research* (Harvard University Press) ISBN 9780674854314 URL http://www.jstor.org/stable/j.ctvk12px9
[8] The Edanz team 2023 Systematic Review, Scoping Review, Narrative Review – What's the Difference? URL https://learning.edanz.com/systematic-scoping-narrative
[9] University of Melbourne 2022 Inclusion and Exclusion Criteria *Systematic Reviews for Health Sciences and Medicine: An introduction to systematic reviews, with examples from health sciences and medicine* chap 5 URL https://unimelb.libguides.com/sysrev/inclusion-exclusion-criteria
[10] O'Donovan M A, McCallion P, McCarron M, Lynch L, Mannan H and Byrne E 2019 *HRB Open Research* **2**(6) URL https://doi.org/10.12688/hrbopenres.12900.1
[11] Bier N, Lovett M and Seacord R 2011 An Online Learning Approach to Information Systems Security Education *Proceedings of the 15 th Colloquium for Information Systems Security Education. Fairborn, Ohio June 13-15, 2011* URL https://oli.cmu.edu/wp-content/uploads/2012/10/Bier_2011_Online_Approach_Information_Systems_Security_Education.pdf
[12] Liu B, Zhao M, Niu D, Lai K, He Y, Wei H and Xu Y 2019 Learning to Generate Questions by LearningWhat Not to Generate *The World Wide Web Conference* WWW '19 (New York, NY, USA: Association for Computing Machinery) p 1106–1118 ISBN 9781450366748 URL https://doi.org/10.1145/3308558.3313737
[13] Noyes K, McKay R L, Neumann M, Haudek K C and Cooper M M 2020 *Journal of Chemical Education* **97**(11) 3923–3936 URL https://doi.org/10.1021/acs.jchemed.0c00445
[14] Subirats L, Fort S, Atrio S and Sacha G M 2021 *Applied Sciences* **11**(21) 9923 ISSN 2076-3417 URL https://doi.org/10.3390/app11219923
[15] Tarik A, Aissa H and Yousef F 2021 *Procedia Computer Science* **184** 835–840 ISSN 1877-0509 The 12th International Conference on Ambient Systems, Networks and Technologies (ANT) / The 4th International Conference on Emerging Data and Industry 4.0 (EDI40) / Affiliated Workshops URL https://doi.org/10.1016/j.procs.2021.03.104
[16] Kabir A I, Akter S and Mitra S 2021 *Informatica Economică* **25**(3) 26–37 URL http://revistaie.ase.ro/content/99/03%20-%20kabir,%20akter,%20mitra.pdf
[17] Lu A, Wong C S K, Cheung R Y H and Im T S W 2021 *Frontiers in Education* **6** ISSN 2504-284X URL https://doi.org/10.3389/feduc.2021.623745
[18] Jescovitch L N, Scott E E, Cerchiara J A, Merrill J, Urban-Lurain M, Doherty J H and Haudek K C 2021 *Journal of Science Education and Technology* **30**(2) 150–167 ISSN 1573-1839 URL https://doi.org/10.1007/s10956-020-09858-0
[19] Neumann A T, Arndt T, Köbis L, Meissner R, Martin A, de Lange P, Pengel N, Klamma R and Wollersheim H W 2021 *Frontiers in Artificial Intelligence* **4** ISSN 2624-8212 URL https://doi.org/10.3389/frai.2021.668220
[20] Sarani A and Ghollasi Moud S 2022 *Teaching English Language* **16**(1) 311–329 ISSN 2538-5488 URL https://doi.org/10.22132/tel.2022.153486

[21] Singh N, Gunjan V K, Mishra A K, Mishra R K and Nawaz N 2022 *Sustainability* **14**(7) 4167 ISSN 2071-1050 URL https://doi.org/10.3390/su14074167

[22] Hooda M, Rana C, Dahiya O, Rizwan A and Hossain M S 2022 *Mathematical Problems in Engineering* **2022** 5215722 URL https://doi.org/10.1155/2022/5215722

[23] Arnold-Garza S 2014 *Communications in Information Literacy* **8**(1) 7–22 URL https://doi.org/10.15760/comminfolit.2014.8.1.161

[24] Fabriz S, Mendzheritskaya J and Stehle S 2021 *Frontiers in Psychology* **12** ISSN 1664-1078 URL https://doi.org/10.3389/fpsyg.2021.733554

[25] LeShea A V 2013 *The effects of synchronous class sessions on students' academic achievement and levels of satisfaction in an online introduction to computers course* Ph.D. thesis Liberty University Lynchburg VA URL https://digitalcommons.liberty.edu/cgi/viewcontent.cgi?article=1808&context=doctoral

[26] Basar Z M, Mansor A N, Jamaludin K A and Alias B S 2021 *Asian Journal of University Education* **17**(3) 119–129 ISSN 2600-9749 URL https://doi.org/10.24191/ajue.v17i3.14514

[27] Li D 2022 *The Electronic Journal of e-Learning* **20**(1) 1–18 URL https://doi.org/10.34190/ejel.20.1.2106

[28] Muhammad A 2018 *IDEAS: Journal on English Language Teaching and Learning, Linguistics and Literature* **6**(2) ISSN 2548-4192 URL https://doi.org/10.24256/ideas.v6i2.520

[29] Jia X, Zhou W, Sun X and Wu Y 2021 *Proceedings of the AAAI Conference on Artificial Intelligence* **35**(14) 13143–13151 URL https://doi.org/10.1609/aaai.v35i14.17553

[30] Šapale S, Iliško D and Badjanova J 3921 *Discourse and Communication for Sustainable Education* **12**(1) 140–150 URL https://doi.org/10.2478/dcse-2021-0010