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The Role of Innovative Techniques in Development of STEM-education in Ukraine

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Abstract

STEM-education has become an important phenomenon changing the paradigm of education system. Developing STEM-education, makes it possible to respond to the existing and future challenges. The aim of the research was to evaluate the role of innovative techniques in development of STEM-education and to present the effective organization of STEM-based curriculum within the Ukrainian educational institutions. To answer the research questions, we applied qualitative research methodology (face-to-face interviews, observations, close-ended survey, written reports analysis) and the experts' assessment to validate the quality and relevance of the findings. The results showed that a number of innovative techniques are applied, including project-based learning, inquiry-based learning, case-study, collaborative learning, peer learning, simulations, gamification, distance learning, blended learning, artificial intelligence supported teaching and Virtual Reality. Innovative techniques bring certain advantages for STEM-education and enhance the process of training of future STEM professionals. At the same time, it was found that the use of innovative techniques positively affects the development of STEM-education in Ukraine and helps to overcome the existing challenges such as improvement of STEM-based curriculum, reduction of costs and increasing the access to education, making the educational process more interactive, organization of professional development for instructors and prepare students to solve real-world tasks.

Keywords
Project-Based Learning, Simulation, Collaboration, Gamification, Artificial Intelligence.

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Introduction

STEM education, which focuses on Science, Technology, Engineering, and Mathematics, is regarded as a reaction to changes in the society driven by rapid advancements and changes of the landscape of economic development. The emerging technologies such as "Big Data" analytics, Artificial Intelligence (AI), robotics, Virtual Reality (VR), hypersonics, and biotechnology point to holistic educational environment that is directly related to the introduction of STEM-based curriculum (Iskakova et al., 2023). Since the society moves forward adapting a number of technologies and innovations, there is a growing demand for individuals with strong STEM skills to drive economic growth and solve complex problems creatively. Currently, STEM has applications in a wide range of industries, from healthcare (Sofilkanych et al., 2023; Tsekhmister, 2023b) to architecture (Aljad, 2023). Iastremska, O., Tryfonova, O., Mantaliuk, O., & Baranets, H. (2023) state that STEM disciplines are essential for innovations and economic performance worldwide. In addition to driving sustainable economic growth and formulating strategic decisions, digitalization and STEM-education ecosystem provide social and political development (Kryvoshein, 2023) or cultural transformations (Zinchenko et al., 2023). As a result, STEM-education has become an important educational construct and phenomenon changing the paradigm of education of the XXI century (Bushman, 2022) since it seeks to prepare students for this evolving environment by equipping them with the knowledge and skills and creating innovative work behavior needed to succeed in STEM-related fields. Additionally, STEM-education aims to foster critical thinking, creativity, adaptability, and collaboration, which are essential competencies in the rapidly changing world (Eustache et al., 2023; Tsekhmister et al., 2023). By developing STEM-education, the civilization is able to respond to the need for a highly skilled workforce and, accordingly, address the challenges and opportunities of the future (Vasylyuk-Zaitseva et al., 2023).

Essentially, STEM-education stands as an innovation-oriented education that refers to a teaching and learning methodology emphasizing the development of skills and knowledge necessary for innovation (Khushk et al., 2023). According to Han, J., Kelley, T. & Knowles, J.G. (2023), STEM-education refers to an integrated approach to teaching and learning that combines these four disciplines in a cohesive learning paradigm. In this context, STEM-based curriculum is applied to prepare students for future professional activities by fostering skills such as critical thinking, problem-solving, creativity, and

collaboration. Also, STEM-education is related to a holistic approach that brings interdisciplinary connections and real-world applications (Iskakova et al., 2023). It seeks to overcame barriers of traditional learning and develop students' STEM competencies including a range of cognitive, interpersonal, and practical skills that are essential for success in STEM-related roles (Kharitonenko, 2022; Zinchenko et al., 2023). And STEM-education is understood as a socio-educational movement aimed at promoting STEM literacy and awareness in the society. This interpretation addresses the growing need for skilled STEM employees by encouraging more students to pursue education and careers in STEM fields (Huang et al., 2022). Obviously, STEM-education as a socio-educational movement is closely connected with the concept of open university which offers flexible learning options and accessibility (Hladoshchuk et al., 2023).

STEM-education in Ukraine is a growing field that is gaining attention due to the increasing demand for skilled professionals in science, technology, engineering, and mathematics (Nikitina & Ishchenko, 2022). And the approval of the Concept of STEM-education in Ukraine by the Cabinet of Ministers in 2020 confirms the importance of STEM-education as an integral system for Ukrainian educational institutions and, at the same time, raises the issue of new requirements for high-quality training of competitive specialists, who will be able to form the country's own scientific and technical elite in the future (Verkhovna Rada, 2020). Additionally, the Ukrainian scholars outline that STEM-education is developed and implemented through the innovative teaching methods and educational programs and it is oriented towards formation of cognitive skills, skills of information processing, interpretation and data analysis, engineering thinking, research skills, algorithmic and critical thinking, digital literacy, creativity and technical skills among future professionals (Buturlina et al., 2021). Despite a number of STEM-oriented educational institutions in Ukraine and the legal framework formed for the development of STEM-education, there are also challenges which in most cases are related to the use of traditional teaching methods that may not effectively engage all students or develop their essential skills (Osadchyi et al., 2022). Crucially, Kharitonenko (2022) considers that the curriculum improvements and adoption of innovative pedagogical techniques can help to address this challenge and build an effective STEM-education ecosystem. Therefore, it is essential to investigate the role of innovative techniques in development of STEM-education in Ukraine to drive economic growth and technological advancement through the development of a skilled workforce that is able to work in rapidly changing digital environment and solve professional tasks successfully.

1. Literature review

STEM-education as a response to challenges of war

Fostering innovations and advancing STEM-education can significantly shape Ukraine's economic future (Buturlina et al., 2021). Firstly, innovations drive economic growth by enhancing productivity, efficiency, and competitiveness. Secondly, STEM-education is fundamental for developing a skilled workforce capable of driving innovation and technological advancement. Prioritizing STEM subjects at the primary and secondary levels of education when implementing the New Ukrainian School reform as well as within the universities, Ukraine can ensure that the employees are equipped with the essential knowledge and skills, and, therefore, address the societal challenges (Shapovalov et al., 2020). When investing in STEM-education, Ukraine can lay the foundation for a strong economic system that benefits its citizens and positions the country as a leader in the global economy.

During emergencies such as wars, pandemics and economic crises, the need for STEM-education becomes even more acute (Tkach et al., 2023). This often requires innovative approaches to problem solving, and STEM-education provides the students with all the necessary tools to develop such solutions and form readiness to act in difficult circumstances. Indeed, STEM-education plays an important role during war since STEM professionals maintain essential services and they may contribute to the post-war reconstruction and recovery efforts significantly. STEM-education fosters a culture of innovation that is essential for developing new technologies and strategies for defense during wartime (Raska, 2019). STEM workforce is equipped with all the necessary instruments to develop and implement advanced defense technologies, enhancing Ukraine's national security (Tkach et al., 2023). The emerging technologies related to STEM such as cybersecurity, drone technology, satellite communications, AI, Machine Learning, and advanced weapon systems are shaping the future of military operations improving decision-making, efficiency, and situational awareness (Chmyr & Bhinder, 2023). Also, STEM-based areas positively impact on enhancement of military capabilities and present new opportunities for the defense formations and law-enforcement agencies (Harcey et al., 2022). Additionally, STEM-education is crucial for development of professional competencies among military personnel (Chmyr & Bhinder, 2023). Simultaneously, it promotes to build resilience to future conflicts by developing

technologies and strategies to mitigate the impact of war and prevent future conflicts (AlAli et al., 2023).

The war causes the disruption of educational process that means interruptions of educational activities due to armed conflict. It can have profound and long-lasting effects on individuals, communities, and society (Greshta et al., 2023). In Ukraine the educational institutions are facing closure due to safety concerns or damage to infrastructure (Bondarenko, 2022). This definitely results in the loss of learning opportunities for students and the displacement of instructors. STEM-education is greatly enhanced by technologies and it is usually introduced with the use of information and communication technologies (ICT) (Tsekhmister et al., 2023). During war technology-enhanced environment ensures continued access to education and mitigating the impact of conflict on learning. Also, ICT provide access to information and resources, enable personalized learning and interactive activities, and facilitate the positive communication among students and instructor through online platforms when traditional learning in the classroom is impossible.

The techniques for implementation of STEM-education in the educational institutions

In the modern educational institutions, STEM-education is implemented through interdisciplinary curriculum design, emphasizing real-world learning experience, integration of technology, and innovative teaching techniques (Osadchyi et al., 2022). The educational institutions also focus on inclusivity and diversity in STEM-education (Palid et al., 2023), ensuring that all students have access to learning opportunities. A range of diverse teaching techniques aim to cultivate a holistic understanding of science, technology, engineering, and mathematics. Also, they are to encourage students to explore, experiment, and collaborate, fostering critical thinking and problem-solving skills (Nikiforos & Kolyvas, 2020). It was found that STEM-education bridges the gap between theoretical concepts and practical knowledge, preparing students for future challenges and opportunities of in STEM-related fields (Huang et al., 2022). The emphasis on creativity and innovation makes students think broadly and develop a deeper understanding for the interconnectedness between STEM disciplines and the industries reflecting their foundational role in modern society.

According to Zavalevskyi, Y., Khokhlina, O., Gorbenko, S., Fliarkovska, O., & Chupryna, O. (2023), project-based STEM activities are considered highly promising

educational technique that fosters the development of essential life competencies among students, such as multicultural, communication, and digital skills as well as critical thinking, problem-solving. In project-based learning (PBL) students work in groups to investigate and solve complex problems, applying STEM concepts and skills to create accurate integrated solutions (Han et al., 2023). Other teaching techniques that involve solving real-world problems or addressing complex issues are inquiry-based learning (Attard et al., 2021) and the case study (Korniichuk et al., 2021; Tsekhmister, 2023b). Since PBL typically involves a more extended and structured project, inquiry-based learning focuses on open-ended investigation. At the same time, the case-study uses specific scenarios to illustrate broader concepts or principles.

The recent findings draw a great attention towards collaborative learning when implementing STEM-education due to its potentials to engage students in group activities promoting teamwork, communication, and problem-solving skills (Nikiforos & Kolyvas, 2020). Group discussions are common in collaborative learning environments; students are encouraged to express their ideas, ask questions, and participate in constructive debates to deepen their understanding of STEM-related concepts (Rusk & Rønning, 2020). Peer learning, in contrast to collaborative learning involves horizontal interactions between students (Gong et al., 2023).

Other effective teaching technologies include simulation-based learning (Banda & Nzabahimana, 2023) and gamification (Wang et al., 2023). In the context of implementation of STEM-education simulation-based learning focuses on creating realistic simulations of real-world scenarios to help students learn and practice skills in a safe, controlled environment. Gamification, on the contrary, involves using game-based activities, such as quizzes, storytelling, or role-plays, to improve students' motivation.

STEM-education can be implemented through distance learning using a variety of online tools including virtual labs, interactive software programs, video lectures and demonstrations (Markandan et al., 2023). Online assessments can be used to evaluate students' understanding of STEM concepts. According to Varianytsia et al. (2023), cloud technologies have recently revolutionized assessment in distance education by providing efficient solutions for creating, delivering, and managing assessments. The findings show that distance learning in STEM-education can provide students with access to high-quality resources through engaging and interactive learning experiences (Tsekhmister et al., 2023). At the same time, it can be challenging to facilitate effective collaboration among students in a distance learning environment (Kostenko et al., 2023). Additionally,

the efficiency of distance learning is affected by students' clip thinking that leads to attention deficit, loss of desire of new knowledge, inability to be creative (Khrenova et al., 2023). Some researchers confirm that blended learning offers more interaction between students and instructors compared to distance learning, as it includes face-to-face classroom sessions; and it allows more flexibility incorporating a variety of learning activities and technologies (Tsekhmister, 2023a).

AI-supported teaching in STEM-education refers to the use of AI technologies to enhance the teaching and learning process. The findings show that AI brings a number of advantages when implementing STEM-education, in particular personalization of learning experiences and building customized learning paths for students based on their individual needs and progress (Chmyr & Bhinder, 2023). AI-powered systems provide real-time feedback and guidance to students, deliver assignments and organize automated assessments (Vasylyuk-Zaitseva et al., 2023). Currently, VR is increasingly being used in STEM-education to provide students with interactive and engaging environments. The findings show that VR allows students to conduct experiments and explore scientific concepts in virtual laboratories, provides interactive 3D models and visualizations of STEM concepts, take students on virtual field trips to explore STEM-related locations (Cromley et al., 2023). Also, VR is an effective instrument to train students in practical skills, such as surgery, engineering, or programming, through realistic simulations (A. Snoswell & Snoswell, 2019). Table 1 shows the analysis of teaching techniques for implementation of STEM-education.

Table 1. The analysis of teaching techniques for implementation of STEM-education

Teaching techniques	Features
PBL	engages students in real-world projects (Han et al., 2023); encourages to explore different approaches to a problem (Zavalevskyi et al., 2023).
Inquiry-based learning	encourages to ask questions and seek solutions through experiments (Attard et al., 2021).
Case-study	provides real-world examples illustrating the relevance of STEM concepts to professional practice (Korniichuk et al., 2021); integrates multiple disciplines (Tsekhmister, 2023b).
Collaborative learning	enables to work together effectively (Nikiforos & Kolyvas, 2020; Rusk & Rønning, 2020); engages to apply theoretical concepts to practical situations (Rusk & Rønning, 2020).
Peer learning	more experienced students provide academic and social support (Gong et al., 2023); occurs informally through interactions outside of classroom setting (Köseoğlu & Türkmen, 2023).

Simulation-based learning	creates the simulated environments or scenarios (Banda & Nzabahimana, 2023); allows students to practice skills and apply concepts in the controlled environment (Banda & Nzabahimana, 2023); Simulations can be adapted to meet different students' needs or to address specific learning objectives (Kiv et al., 2019).
Gamification	involves incorporating game elements into the educational process (Wang et al., 2023).
Distance learning	STEM courses are delivered primarily through online platforms (Markandan et al., 2023); offers flexible scheduling (Kostenko et al., 2023); includes online tools to facilitate communication (Kostenko et al., 2023; Markandan et al., 2023).
Blended learning	combines online learning activities with in-person instruction (Tsekhmister, 2023a); offers personalized learning (Zavalevskyi et al., 2023).
AI-supported teaching	generates effective educational content (Vasylyuk-Zaitseva et al., 2023); provides personalized learning (Chmyr & Bhinder, 2023); analyzes the data to predict students' performance and educational outcomes (Vasylyuk-Zaitseva et al., 2023).
VR	provides an immersive experience (Cromley et al., 2023; A. Snoswell & Snoswell, 2019).

Source: author's development

Considering the role of STEM-education in the contemporary society, it is important to outline the features of implementation of STEM-based curriculum within the educational institutions. Therefore, the *aim of the research* was to evaluate the role of innovative techniques in development of STEM-education and to present the effective organization of STEM-based curriculum within the Ukrainian educational institutions.

Accordingly, the article addresses the following *research questions*:

1. What are the innovative techniques used to deliver STEM-education?
2. What are their advantages and how these techniques shape STEM-education during war?
3. What challenges do Ukrainian educational institutions face while implementing STEM-education? How to overcome these challenges using innovative techniques?

2. Materials and methods

Context

The research was carried out among instructors and students of three educational institutions in Ukraine during the first semester of 2023-2024 academic year. Also, six experts were involved (two from each institution) to ensure the credibility and reliability

of the study. The experts' assessment involved obtaining feedback and evaluation to validate the quality, relevance, and appropriateness of research methods, findings, and conclusions. The selection criteria for experts in educational research included the following: relevant expertise (at least 5 years of expertise in the STEM related area of educational research); professional experience of working in the field of education, such as teaching or educational administration; record of scholarly publications concerning STEM-education; academic affiliation; diversity (experts should teach different academic disciplines to provide a range of perspectives into the research topic); and absence of conflict of interest. The data was collected in the classroom or through the analysis of participants' reports. When conducting the research, the four fundamental principles (informed consent, anonymity, equitable treatment, and avoiding harm) were followed. The researchers ensured that their work respects participants' rights and their main task is to outline the perspectives on improvement and effectiveness of STEM-education in Ukraine. The special attention was paid towards the functioning of STEM-education during war.

Participants

All of the participants (53 instructors and 79 students) were representative of three Ukrainian institutions of higher educations. The instructors taught STEM-related disciplines: medicine (4), nursing (1), pharmacology (2), ecology (2), chemistry (3), physics (4), agronomy (1), computer science (4), information technology (5), mechanical engineering technology (5), electrical engineering (3), civil engineering (2), mathematics (8), statistics (5), and econometrics (4). The students were undergoing the following educational programs: Medicine (12), Information systems and technologies (13), Automatization and computer-integrated systems (9), Applied mechanics (7), Construction and civil engineering (4), Electronics (6), Ecology (8), Biology and biotechnology (6), Economic analytics (7), Secondary education (Mathematics) (5), and Secondary education (Physics) (2). All of them were informed about the procedure of the research and the research objectives. The research was conducted according to the Code of Ethics policy and the results were assessed objectively and impartially. The experts assessed the validity and reliability of the findings to ensure that they accurately reflect the research objectives and are consistent and accurate.

Instruments

To answer the research questions, we applied qualitative research methodology (face-to-face interviews, classroom observations, close-ended survey responses, and analysis of written reports). This methodology allowed the researchers to collect rich and detailed data that helped understand the complexities of educational environment where STEM-education is implemented. At the same time, qualitative methods being flexible and adaptable, enabled to take a holistic perspective of the research problem and consider various factors and contexts of the STEM-based curriculum. Importantly, qualitative methods prioritized the perspectives of participants. This helped to ensure that the research findings are relevant to those directly involved in STEM-education. Besides, the experts' assessment was used to obtain effective feedback and evaluation from STEM professionals to validate the quality, relevance, and appropriateness of the research findings and, as a result, to elaborate reliable conclusions that can be used for the improvements of STEM-education in the Ukrainian educational institutions.

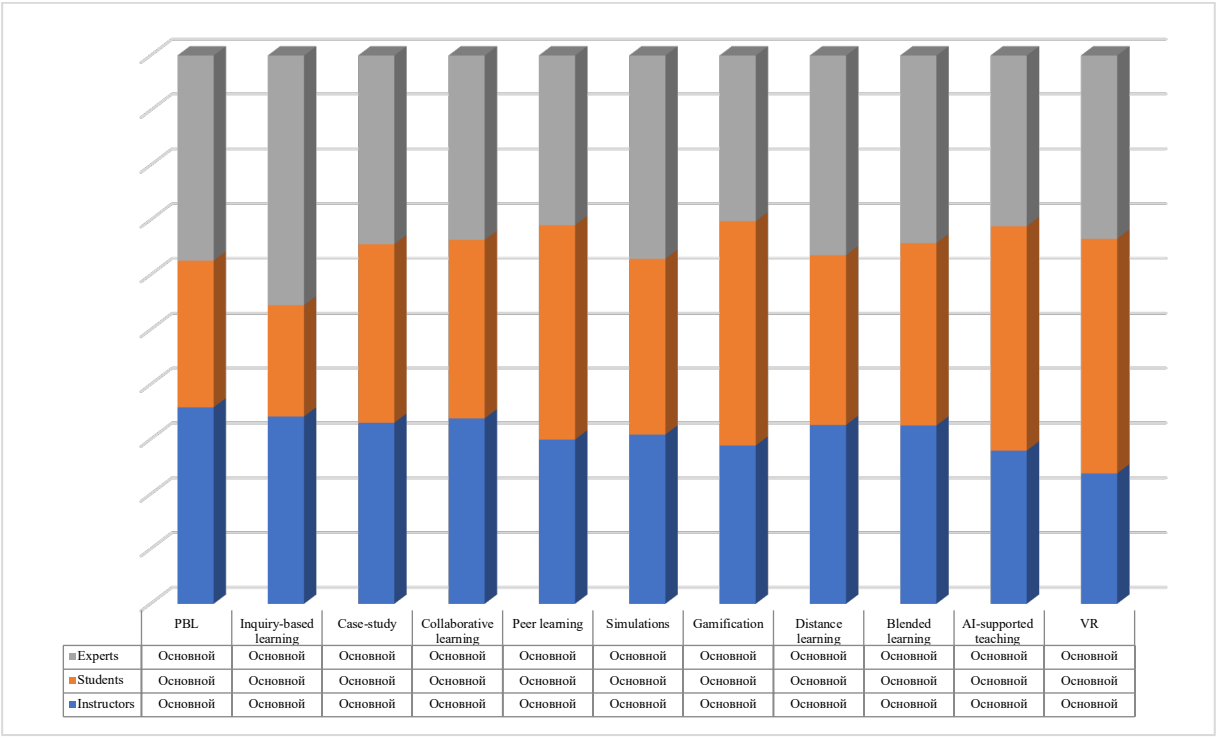
Data analysis

The data analysis involved synthesizing and interpreting the feedback of the participants. To make the accurate conclusions all the data was analyzed in four steps: (1) extraction of the relevant data collected using each instrument (face-to-face interviews, classroom observations, close-ended survey responses, or analysis of written reports); (2) organization of the extracted data into categories such as: types of innovative techniques in STEM-education, advantages of innovative techniques in STEM-education, and overcoming of the existing challenges through innovative techniques; (3) identification of key trends and patterns, or relationships to answer the research questions; (4) development of a comprehensive understanding of the role of innovative techniques in STEM-education and description of the efficient educational environment where STEM-education is implemented. The findings were evaluated by the experts to identify common patterns, and trends, and to draw the conclusions based on their feedback. Also, to overcome the challenges of STEM-education using innovative techniques the researchers conducted a comparative analysis of the feedback from participants and experts to identify differences in opinions. This helped provide a more comprehensive

understanding how innovative techniques may be introduced in STEM-education ecosystem.

3. Results

To identify the innovative techniques used to deliver STEM-education classroom observations, close-ended survey responses, and analysis of written reports were used. The findings showed that according to instructors collaborative learning (56,2 %), case-study (49,3 %), and PBL (47,7 %) are the most effective. According to students, gamification (54,6 %), collaborative learning (54,1 %), and case-study (48,6 %) can maximize the educational process. The experts' assessments show that collaborative learning (55,9 %), case-study (51,4 %), and PBL (49,8 %) when used effectively enhance the educational environment significantly and create the positive conditions for implementation of STEM-education. At the same time, the special attention must be paid towards the emerging technologies like AI and VR since they have considerable potentials for STEM-education but require specific preparation on instructor's side. Figure 1 shows the analysis of preferences on using innovative techniques in STEM-education according to instructors, students, and experts.



	PBL	Inquiry-based learning	Case-study	Collaborative learning	Peer learning	Simulations	Gamification	Distance learning	Blended learning	AI-supported teaching	VR
Experts	Основной	Основной	Основной	Основной	Основной	Основной	Основной	Основной	Основной	Основной	Основной
Students	Основной	Основной	Основной	Основной	Основной	Основной	Основной	Основной	Основной	Основной	Основной
Instructors	Основной	Основной	Основной	Основной	Основной	Основной	Основной	Основной	Основной	Основной	Основной

Figure 1. The preferences on using innovative techniques in STEM-education.
Source: author's development

To outline the advantages of innovative techniques and their role in shaping the contemporary STEM-education in the Ukrainian educational institutions detailed face-to-face interviews were conducted among instructors and students. Also, both the participants and the experts underwent close-ended survey to evaluate the advantages of using innovative techniques when implementing STEM-education. The findings showed that using innovative techniques bring a number of advantages for STEM-education and enhances the process of training of future STEM professionals. It was found that innovative teaching techniques, such as PBL, gamification, and VR, can increase students' engagement and makes learning more interactive. When students are engaged actively, it can improve retention of STEM knowledge and skills. Also, the use of innovative techniques within the educational process improves critical thinking, creativity, problem-solving, decision-making, collaboration and teamwork skills. According to the participants, innovative teaching techniques in STEM-education prepare students to succeed in the complex and technology-driven professional environment. Table 2 shows the collective results on advantages of innovative techniques used in STEM-education.

Table 2. Collective results on advantages of innovative techniques used in STEM-education

Teaching techniques	**Advantages for development of STEM-education**
PBL	promotes students' engagement; forms critical thinking and problem-solving skills; fosters creativity; develops project management skills; allows to assess students' understanding and skills in a real-world context.
Inquiry-based learning	engages students in active learning; promotes critical thinking skills; develops problem-solving skills to apply in real-world situations; leads to long-term learning outcomes.
Case-study	helps students see the practical applications of STEM concepts; promotes critical thinking skills and decision-making; integrates knowledge from multiple STEM disciplines; involves collaboration; provides the opportunities for students to reflect on their learning and evaluate their outcomes.
Collaborative learning	engages students actively; develops communication skills; fosters teamwork; builds students' confidence in their abilities to learn and apply STEM concepts; prepares students for real-world challenges in STEM fields.
Peer learning	develops communication skills; encourages teamwork; promotes diversity on problem perspectives; provides a supportive learning environment.
Simulation-based learning	provides students with real-world experience; provides a safe educational environment; simulates realistic scenarios; can be implemented remotely.

Gamification	makes learning more engaging and interactive; increases students' motivation; encourages students to think critically and solve problems creatively; introduces healthy competition among students.
Distance learning	makes STEM-education more accessible, especially during emergency; is more cost-effective than classroom-based education; gives students access to different resources; enables lifelong learning by providing opportunities for continuous professional development.
Blended learning	suits students' individual learning styles; enhances student engagement by incorporating interactive and multimedia elements into the educational process; simulates real-world scenarios; promotes collaborative learning through discussion forums, group projects, and virtual labs.
AI-supported teaching	provides personalized learning and adaptive educational paths; automates routine tasks; enhances accessibility; provides support to students outside of classroom; implements innovative teaching methods.
VR	helps students visualize and interact with abstract or complex STEM concepts; provides a safe environment to conduct experiments; increases students' engagement and motivation; helps students apply their knowledge and skills in practical contexts.

Source: author's development

To study the challenges the Ukrainian educational institutions, face while implementing STEM-education face-to-face interviews and classroom observations were conducted. The results showed that STEM-education in Ukraine experiences a number of difficulties. Firstly, it is political and economic instability in Ukraine and safety concerns that impact the whole education system, including STEM-education. As a result, STEM-education in Ukraine lacks adequate funding leading to a lack of resources, outdated equipment, and limited access to modern technology.

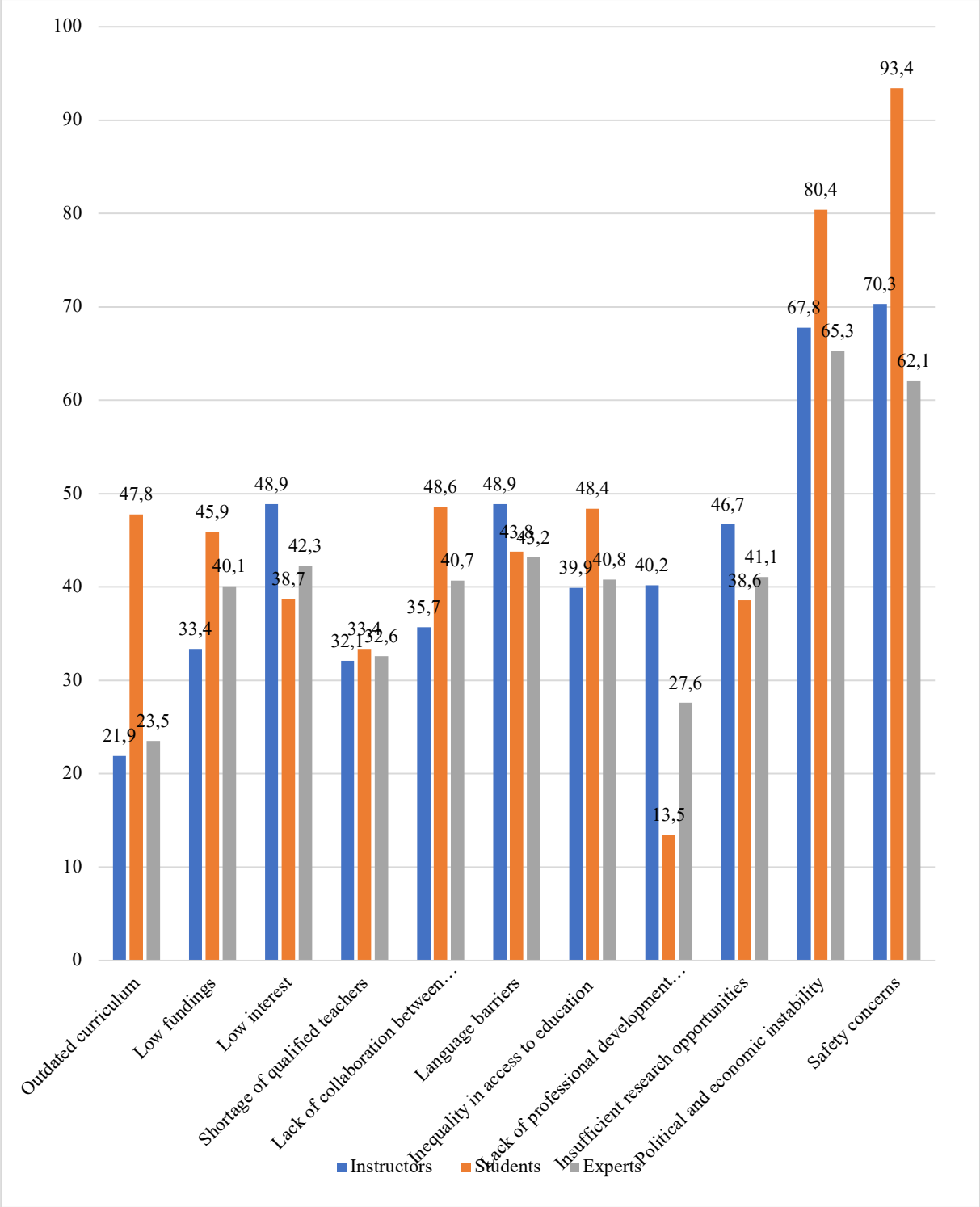


Figure 2. The challenges STEM-education faces in Ukraine.
Source: author's development

Secondly, the participants admit that the curriculum for STEM subjects in Ukraine is often outdated and does not reflect the latest advancements in science and technology. Other challenges are related to low level of interest among students in pursuing STEM subjects, shortage of qualified teachers in STEM since many professionals fled Ukraine

due to safety reasons. There is often a lack of collaboration between educational institutions and industries which can lead to prioritizing of theoretical knowledge in STEM-education. Thirdly, the instructors admit that they do not have many opportunities for professional development. Figure 2 shows the challenges STEM-education faces in Ukraine.

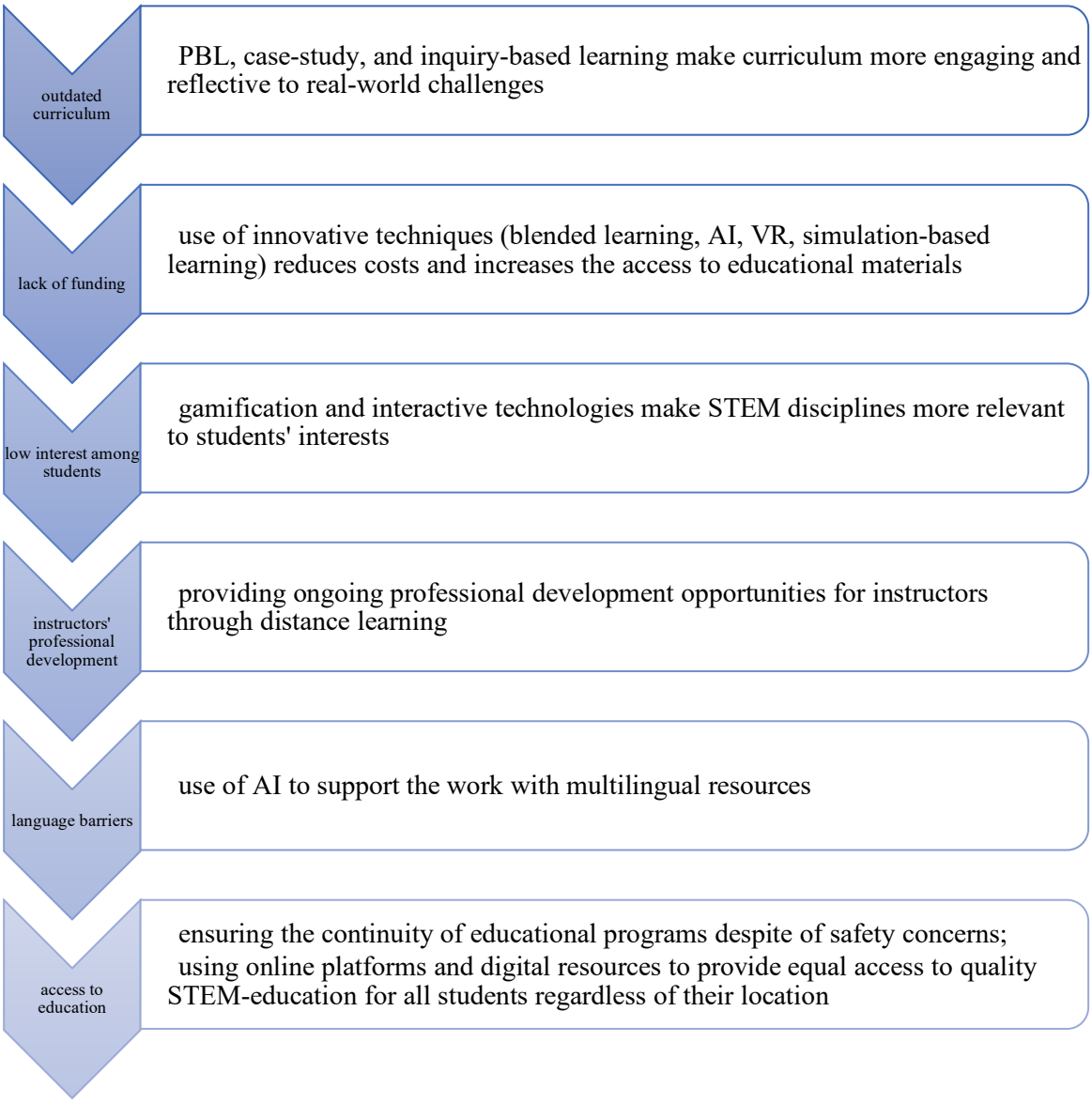


Figure 3. Overcoming of the existing challenges through innovative techniques.

Source: author's development

Overcoming the existing challenges in STEM -education in Ukraine can be facilitated by implementing innovative teaching techniques. The findings demonstrated that the use of innovative techniques can improve STEM-based curriculum, reduce costs

and increase the access to educational materials, make the educational process more interactive and interesting for students. Also, these techniques organize ongoing professional development for instructors and prepare students to solve real-world complicated tasks. At the same time, technology-enhanced environment ensures the continuity of educational process and provides the access to education to all students and, therefore, makes the education safe and flexible. Figure 3 shows how innovative techniques contribute to overcoming the existing challenges in STEM-education.

Further it is necessary to analyze the use of innovative techniques to optimize STEM-based educational process in Ukrainian educational institutions.

Discussion

The study results showed that the use of innovative techniques enhances the educational process and contributes to building of STEM-education ecosystem. The analysis of advantages of innovative techniques may help to form effective STEM-based curriculum and prepare students to work in the rapidly evolving digital environment. Also, the findings demonstrated that innovative technologies strengthen the education system in Ukraine during war and provide continuity of education, in particular STEM-education. According to the respondents' responses, some innovative techniques are more effective and provide long-term effect of STEM competency among students. This proves that the use of certain teaching techniques and strategies connects STEM concepts to real-world applications and integrates STEM knowledge from multiple disciplines. Also, effective STEM-education focuses on developing critical thinking and problem-solving skills, promotes collaboration and communication skills. The emerging technologies equip STEM-education with personalized learning approach encourage lifelong learning and adaptability as students are interested in new technologies, discoveries, and challenges. The findings showed that effective STEM-education requires using PBL, case-study, collaborative learning, simulation-based learning, gamification, blended learning, and AI-supported teaching.

PBL in STEM-education involves integrating concepts from multiple disciplines providing a holistic view of complex real-world problems (Iskakova et al., 2023; Zavalevskyi et al., 2023). Students actively engage in projects that promotes teamwork skills and learn from each other's strengths. Additionally, in the context of STEM-education, PBL focuses on multifaced assessment methods such as presentations,

demonstrations, or portfolios. PBL is a student-centered approach fostering critical thinking and problem-solving skills. In PBL the teacher acts as a facilitator guiding students through the learning and providing educational support.

Case-study is usually based on real-world situations, making them relevant for students. It was found that case-study requires students to analyze information, identify key issues, and develop solutions, promoting critical thinking and problem-solving skills (Korniichuk et al., 2021). The technique can be used as a collaborative learning tool, where students work in teams to analyze and solve the case. Also, case-study trains students to apply theoretical concepts in practical contexts. We found that case-study stimulates group discussions resulted in relevant decision-making (Tsekhmister, 2023b).

Collaborative learning in STEM-education focuses on teamwork, where students work together in groups to solve problems (Rusk & Rønning, 2020). At the same time, collaborative learning often involves experiential learning activities oriented towards preparation of students to future professional activities (Nikiforos & Kolyvas, 2020). It is worth mentioning that at present collaborative learning requires the use of technologies, such as online tools or VR simulations, to facilitate communication and enhance the educational process under varying conditions.

Simulation-based learning provides students with real-world learning experiences and allows them to apply theoretical knowledge to practical scenarios. According to our findings, simulations create a safe environment and provide immediate feedback through simple applications (Banda & Nzabahimana, 2023). This feedback reinforces the educational process and help instructors use the tasks of different levels of complexity. Moreover, simulations stimulate innovation and creativity among students and prepare them to make creative solutions.

Gamification in STEM-education makes the educational process more engaging by incorporating elements of games and motivate students to actively participate in learning activities. It was found that gamification can be personalized to suit students' individual learning styles and helps develop a range of skills, including problem-solving, critical thinking, and collaboration, which are essential for future STEM professionals (Wang et al., 2023). Game-based learning is also used as an assessment tool to evaluate students' understanding of STEM concepts. Importantly, games simulate real-world scenarios and teach students to use STEM concepts in the professional environment.

Blended learning combines traditional face-to-face instruction with online learning experiences and, therefore, it offers flexibility and creates individual educational paths

for students (Tsekhmister, 2023a). Blended learning also facilitates collaboration among students and allows for differentiated instruction where an instructor provides additional support to students based on their individual needs.

Using AI in STEM-education provides personalized learning and generates effective educational materials. AI tools analyze large amounts of data to provide the information on students' educational outcomes helping instructors make data-driven decisions about instructional strategies and curriculum development. At the same time, the implementation of AI in STEM-education requires integration with the existing education systems which may pose technical challenges and require specialized expertise (Vasylyuk-Zaitseva et al., 2023). Definitely, AI-supported teaching has the potential to reshape STEM-education making it more personalized, engaging, and effective for students.

The innovative techniques described cannot overcome all the challenges in STEM-education but they can contribute to its development significantly and improve the training of future STEM professionals in Ukrainian educational institutions, particularly under conditions of war.

Conclusion

STEM-education in Ukraine is a growing field that is gaining attention due to the increasing demand for skilled professionals in science, technology, engineering, and mathematics. The approval of the Concept of STEM-education in Ukraine by the Cabinet of Ministers in 2020 confirms the importance of STEM-education as an integral system for Ukrainian educational institutions and, at the same time, raises the issue of new requirements for high-quality training of competitive specialists. During emergencies the need for STEM-education becomes even more acute since it provides the students with all the necessary tools from readiness to action in difficult circumstances. Also, STEM-education fosters a culture of innovation that is essential for developing new technologies and strategies for defense during wartime. The war can have profound and long-lasting effects on individuals, communities, and society. In Ukraine the educational institutions are facing closure due to safety concerns or damage to infrastructure. As a result, technology-enhanced environment ensures continued access to education and mitigating the impact of conflict on learning.

Studying the teaching techniques for implementation of STEM-education, it was found that a number of innovative strategies are applied. They include PBL, inquiry-based learning, case-study, collaborative learning, peer learning, simulations, gamification, distance learning, blended learning, AI-supported teaching and VR. According to instructors collaborative learning, case-study, and PBL are the most effective. According to students, gamification, collaborative learning, and case-study can maximize the educational process. The experts' assessments show that collaborative learning, case-study, and PBL when used effectively enhance the educational environment significantly and create the positive conditions for implementation of STEM-education.

Using innovative techniques bring a number of advantages for STEM-education and enhances the process of training of future STEM professionals. It was found that innovative teaching techniques, such as PBL, gamification, and VR, can increase students' engagement and makes learning more interactive. When students are engaged actively, it can improve retention of STEM knowledge and skills. Also, the use of innovative techniques improves critical thinking, creativity, problem-solving, decision-making, collaboration and teamwork skills. According to the participants, innovative teaching techniques in STEM-education prepare students to succeed in the complex and technology-driven professional environment. Moreover, the use of innovative techniques helps overcome the existing challenges in STEM -education in Ukraine. The findings demonstrated that the use of innovative techniques can improve STEM-based curriculum, reduce costs and increase the access to educational materials, make the educational process more interactive and interesting for students. Also, these techniques organize ongoing professional development for instructors and prepare students to solve real-world complicated tasks. Most importantly, online tools ensure the continuity of educational process and provide the access to education to all students.

Study limitations

This research still concerns some limitations that should be addressed in future. Firstly, there is a lack of comprehensive research studies focusing on the impact of innovative techniques in STEM-education in Ukraine, making it challenging to draw definitive conclusions. Secondly, the effectiveness of innovative techniques in STEM-education can be influenced by a number of contextual factors and they may slightly differ for each educational institution. These limitations should be considered when interpreting the

findings on the role of innovative techniques in the development of STEM-education in Ukraine.

Suggestions for further research

In future, it will be valuable to assess the long-term impacts of specific innovative techniques on students' outcomes, while exploring the integration of emerging technologies and the potential benefits of interdisciplinary approaches may enhance the development of STEM-education in Ukraine, particularly when the education system has been affected by war in the country. Additionally, analysis of educational policies and drawing international comparisons will offer significant perspectives for educational reforms and the adoption of successful strategies in Ukrainian STEM-education.

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