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Nataliia Soroko
PhD of Pedagogical Sciences, Leading Researcher
Comparative Studies Department for Information and Education Innovations
Institute for Digitalisation of Education of the NAES of Ukraine,
Kyiv, Ukraine
ORCID ID 0000-0002-9189-6564
nvsoroko@gmail.com

MONITORING MODEL OF STEAM-ORIENTED EDUCATIONAL ENVIRONMENT OF A GENERAL SECONDARY EDUCATION INSTITUTION

Abstract. The article is devoted to the problem and features of building a model for monitoring a STEAM-oriented educational environment of a general secondary education institution. It is aimed at studying the features of conducting monitoring procedures for a STEAM-oriented educational environment of a general secondary education institution. To achieve the goal of our research, as well as to clarify the problem of determining the features of models, we analyzed scientific articles on the problems of assessing the state and development of a STEAM-oriented educational environment. Methods of systematic and comparative analysis of pedagogical, methodological, and special literature were used; analysis of the pedagogical experience of domestic and foreign scientists in determining the stages, criteria, and indicators of assessing a STEAM-oriented educational environment. The model we formed includes six blocks: target, organizational and content, technological, diagnostic and analytical, prognostic, control, and correction. The result of the monitoring model is the development and implementation of measures to improve the STEAM-oriented educational environment of a general secondary education institution. A plan for implementing model for STEAM-oriented educational environment monitoring in secondary education institutions is proposed, which includes a preparatory stage, the formation of an expert group for data collection and analysis, a diagnostic stage, which may include collecting information on key criteria such as infrastructure, human resources, teacher readiness, student participation, the availability of projects, and the development of recommendations and proposals, which may include the formation of recommendations for school administration and methodological associations, planning internal professional development, and initiating participation in national projects.

Keywords: STEAM education; monitoring; quality of education; general secondary education institution; educational project; digital technologies.

1. INTRODUCTION

STEAM (Science, Technology, Engineering, Arts, and Mathematics) is one of the world's leading educational approaches to time. Its main goal is to develop creative thinking in young people, form innovative skills, and integrate interdisciplinary methods into the educational process. Regularly monitoring the state of the STEAM educational environment allows you to identify problems on time, objectively assess the quality of education, and make informed management decisions.

The problem statement. It is worth noting that over the past 15 years, there has been a gradual evolutionary transition from the STEM model to STEAM, and later to STEAME (Science, Technology, Engineering, Arts, Mathematics and Entrepreneurship) [1]. This approach is a key driver in preparing future specialists and innovators in STEAME fields through integrated educational projects. Subject teachers already working in the general education system and future teachers undergoing professional training at the university level play a significant role in implementing this concept.

To effectively implement the STEAM approach, creating an appropriate computer environment and carrying out its systematic monitoring is necessary. The monitoring model

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can contribute to effectively assessing the situation from various aspects of its implementation. In particular, it will allow the building of algorithms to evaluate the effectiveness of the use of digital technologies in the educational process, ensure the adaptability of the environment to the needs of students and teachers, and identify possible areas for improving the interdisciplinary approach to the educational process in secondary education institutions.

Analysis of recent studies and publications. The study of the problem of evaluating a STEAM-oriented educational environment is devoted to the works by Alcaraz-Dominguez Silvia, Molas-Castells Núria [1], Alkai S. et al. [2], Mang H.M.A., & Chu HE., & Martin S.N. et al. [3], Ovcharuk O. & Soroko N. [4], the issue of analyzing and improving teachers' digital competence for the development of a STEAM educational environment is devoted to the works by Pérez Torres M., & Couso Lagarón D. et al. [5], Dubek Michelle, DeLuca Christopher, Rickey Nathan [6], Blanc S. et al. [7], Wu X. et al. [8], Boice K. L., Jackson J. R. et al. [9], Deák C., Kumar B. [10], etc.

Alkai S. et al. substantiate a model for engaging students in environmental sustainability programs through a STEAM approach based on solving real-world societal problems [2]. The study was conducted using a mixed-method approach with the participation of 346 elementary school students to evaluate the effectiveness of this model. Scientists build the model in such stages as:

- problem identification, in which students should investigate challenges in their regions;
- formation of an interdisciplinary approach, during which students analyze the problem through the prism of different STEM disciplines;
- application of active learning methods when students independently create solutions to real-world problems;
- development and testing of solutions by students, that is, students at this stage construct, test, and improve their solutions;
- assessment and reflection on an educational project, during which students present their projects and receive feedback from experts and teachers.

The model is based on the following approaches:

- practice-oriented approach: Emphasise solving real problems, which increases student motivation.
- collaborative learning: students work in groups, which develops teamwork and critical thinking skills.
- use modern technologies like digital tools, simulations, and virtual laboratories.

The experience presented in the article Alkai S. et al. [2] can be used to develop a model for monitoring STEAM education in schools, such as:

- assessing the level of interdisciplinary integration - analyzing how effectively science, technology, engineering, art, and mathematics are combined in the educational process;
- monitoring students' active participation- tracking their interest and involvement in solving practical tasks;
- analyzing the effectiveness of learning - studying how creating a STEAM-oriented educational environment affects students' academic success and critical thinking skills.

It is worth noting the study by Alcaraz-Dominguez, & Silvia & Molas-Castells, Núria “STEAME projects in basic education: validating a competence framework for educators”, where a competency model for teachers was developed and tested, which includes [1]:

- pedagogical skills of teachers to integrate the STEAME approach into the learning process;
- digital competence of teachers and students;
- skills of teachers to develop interdisciplinary curricula;
- teachers' ability to assess STEAME learning's impact on students' acquisition of key competencies.

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Scientists conducted an analysis that shows that the following should be taken into account in the monitoring model of a STEAM-oriented educational environment:

- criteria for assessing the effectiveness of STEAME projects integrated into the school curriculum;
- indicators for determining the impact of STEAME methodologies on the formation of key competencies of students;
- methods for identifying gaps in teacher training and developing programs to improve their qualifications;
- development and implementation of courses and training based on the STEAME competency model;
- introduction of surveys and methods for assessing pedagogical competence to analyze the effectiveness of the STEAME environment in general education institutions;
- analytical platforms are used to collect and analyze data on teacher competence.

Pérez Torres M., & Couso Lagarón D., & Marquez Bargalló C. analyze STEAM projects implemented in five Spanish secondary schools from the perspective of STEM practices [5]. The researchers found an imbalance in the complexity of the projects concerning criteria related to scientific and technological disciplines, as well as meta-disciplinary criteria, that is:

- uneven inclusion of scientific disciplines, namely, some STEAM projects did not cover scientific research methods in sufficient depth (for example, students performed tasks related to natural sciences but without using an experimental approach or data analysis); most projects focused on practical aspects (creating models, prototypes), but students did not sufficiently develop a conceptual understanding of scientific laws;
- simplification of the technological aspect, i.e., students' use of technology in STEAM projects was usually limited to basic tools (e.g., standard software or simple constructors); in some cases, there was no integration of modern digital technologies such as programming, modeling, or data analysis;
- it was found that in some projects, the emphasis on engineering skills is insufficient or focused only on mechanical design without a deep analysis of the design and testing process, and students often work with pre-defined models instead of developing their solutions based on critical thinking;
- in many STEAM projects, the artistic component is reduced to visual aesthetics or design rather than being used to develop creativity and interdisciplinary thinking.

Given this study, it is worth noting that when creating a model for monitoring a STEAM-oriented educational environment, the level of integration of all STEAM components should be taken into account to avoid a one-sided emphasis on one discipline; analyze not only the presence of individual STEAM components but also how they interact with each other (for example, whether engineering solutions are used in artistic design, whether technological design is based on scientific data, etc.). In addition, the monitoring model should include tools for assessing students' level of critical thinking and reflection on their educational achievements.

It is worth paying attention to Dubek DeLuca, and Rickey's research. In their work "Unlocking the Potential of STEAM Education: How Exemplary Teachers Navigate Assessment Challenges", scientists analyze key aspects of assessment in STEAM education [6]. They emphasize that one of the main challenges is the development of effective assessment methods that correspond to the STEAM approach's interdisciplinary nature. The study examines experienced teachers' strategies to ensure high-quality assessment of student learning achievements, including project-based learning, authentic assessment, and adaptive digital tools.

The results of this study are essential for building a model for monitoring STEAM-oriented educational environments, as they indicate the need to integrate flexible assessment mechanisms that allow for the consideration of both academic achievements and the development of student's creative and critical thinking. In this context, it is proposed to include in the monitoring model such indicators as the level of use of formative assessment, the presence of competency-based tasks in curricula, and the level of student engagement in self-assessment of their progress.

Mang H.M.A., & Chu HE., & Martin S.N. et al. developed and tested a method for planning and evaluating STEAM programs based on socially significant issues (SSI) [3]. They argued that integrating STEAM into the curriculum through SSI is suitable for developing students' critical thinking, reasoned decision-making, and interdisciplinary learning. The authors propose several key criteria for evaluating STEAM programs. Based on them, it is possible to form key indicators to measure the effectiveness of a STEAM-oriented educational environment (Table 1).

Table 1

Criteria according to Mang H.M.A., & Chu HE., & Martin S.N. et al. and their possible indicators for monitoring STEAM-oriented educational environment

Criteria according to Mang H.M.A., & Chu HE., & Martin S.N. et al.	**Possible indicators for monitoring a STEAM-oriented educational environment**
Scientific validity	- share of educational projects containing scientific concepts; - share of experimental methods in educational activities
Interdisciplinary integration	- share of projects covering two or more STEAM disciplines; - number of hours of interdisciplinary learning per year
Social significance	- number of projects with actual practical application; - participation of students in local environmental or technological initiatives
Practical skills	- percentage of students who successfully use STEAM tools in projects; - number of hours of work with digital labs
Assessment and Reflection	- number of assessment formats (self-reflection, student feedback, peer review); - number of students maintaining electronic portfolios of STEAM projects

From this table, we can identify the key indicators to measure different aspects of STEAM education, particularly the STEAM-oriented computer education environment in a general secondary education institution.

- indicators of the quality of educational content, which may include the share of STEAM projects in the general curriculum (%), the share of educational tasks containing real research cases (%), the average level of scientific validity of STEAM tasks (for example, expert assessment on a 5-point scale);
- indicators of interdisciplinary integration, which may include the percentage of educational projects covering two or more STEAM disciplines, the share of teachers who collaborate across disciplines (%), the number of interdisciplinary educational activities (for example, the number of hours allocated to conducting an academic project);
- indicators of social significance, such as the percentage of projects aimed at solving real problems in society, the share of students participating in public STEAM initiatives (%), the percentage of school projects that have practical application in the community;

- indicators of the development of students' practical skills within STEAM disciplines, which may include the number of hours of students' work with digital technologies (STEM laboratories, robotics, etc.), the proportion of students who know how to use engineering tools and programming (%), the number of experimental works and laboratory classes in STEAM projects;
- indicators of assessment and reflection, such as the proportion of students who maintain electronic portfolios of STEAM projects (%), the percentage of STEAM tasks that include self-assessment and peer review (%), the proportion of teachers who use multi-criteria assessment (%).

At the same time, the criterion "scientific validity" can be studied by determining the proportion of educational projects that contain scientific concepts, that is, what part of educational projects implemented in an educational institution is based on fundamental scientific principles and concepts from natural sciences (physics, chemistry, biology), technology, engineering, and mathematics:

- projects that use scientific models (for example, research on electromagnetic waves in physics, analysis of chemical reactions, etc.);
- tasks where students apply the scientific method (formulating a hypothesis, conducting an experiment, analyzing data, and drawing conclusions);
- using accurate scientific data in learning (for example, analyzing climate change, environmental research, etc.).

This indicator can be calculated using the formula:

$$P_n = \frac{N_s}{N_t} \times 100\%,$$

where:

- P_n – share of educational projects containing scientific concepts, in percentage;
- N_s – number of projects involving scientific concepts;
- N_t – total number of training projects.

In addition, scientific validity should take into account the share of experimental methods in educational activities, which reflects how widely experimental methods based on research, observations, and practical tasks are used in the educational process, namely the use of laboratory work in natural sciences, practical experiments using physical or chemical processes, work with real or virtual laboratories (for example, simulations of chemical reactions, physical phenomena). In these research tasks, students independently analyze problems and propose solutions.

This indicator can be calculated using the formula:

$$P_e = \frac{N_e}{N_t} \times 100\%,$$

where:

- P_e – share of classes that include experimental methods, in percentage;
- N_e – кількість занять, що містять експериментальні методи;
- N_t – загальна кількість навчальних занять.

The criterion of "interdisciplinary integration" is a key aspect of STEAM education, as it involves combining knowledge and skills from different disciplines (science, technology, engineering, arts, and mathematics) to solve complex problems [7], [8]. This criterion assesses the interconnectedness of subjects in educational projects and how effectively students can apply knowledge from different fields in practical tasks.

The following indicators can be used to assess this criterion:

- the share of educational projects that integrate several subject areas, which is defined as the ratio of the number of interdisciplinary projects to the total number of educational projects in the STEAM educational environment;

- the number of subjects involved in the project, which is measured by the average number of disciplines that are integrated within one educational project (the more subjects covered, the higher the level of interdisciplinarity);
- the share of educational classes with projects that contain real problems, which is defined as the ratio of the number of classes where students work on solving real problems involving knowledge from different subjects to the total number of classes;
- the presence of common educational modules between subjects (modules that contain elements of several disciplines, for example, mathematics + physics + programming);
- the level of involvement of teachers from different subject areas, which is assessed using a questionnaire or the number of jointly developed lessons by teachers of different STEAM disciplines.

Social relevance is one of the key criteria for the effectiveness of a STEAM-oriented educational environment. It reflects how educational projects and tasks contribute to solving current social, environmental, and economic problems and developing students' civic responsibility, environmental awareness, and teamwork skills.

The main ways to assess the criterion of social significance of a STEAM-oriented educational environment can be focused on:

- analysis of curricula and projects, i.e., determination of the number of tasks that contain a social component;
- questionnaire survey of students and teachers, based on a study of the importance of social issues in the educational process;
- content analysis of project reports, which includes an assessment of the extent to which projects address socially important issues;
- assessment of the effectiveness of students' application of knowledge in actual conditions.

The criterion “practical skills” reflects the ability of students to apply the acquired knowledge in practice, solve real-world problems, and use modern technologies in the educational process [7]. Within the framework of this criterion, the following is investigated:

- how often experiments, modeling, and laboratory work are used during training;
- how many STEAM projects include the creation of physical or digital products (for example, mockups, prototypes, computer programs, models, etc.);
- the level of student's mastery of specific tools (3D printing, Arduino, robotics, programming, use of laboratory equipment, etc.);
- analysis of finished products developed by students according to quality, innovation and manufacturability criteria.

Developing practical skills in students within STEAM education allows them to more effectively integrate into scientific and technical fields, apply the knowledge gained to solve real problems, and successfully realize themselves in professional activities.

The criterion of “assessment and reflection” plays an important role in STEAM education, as it allows not only the monitoring of academic achievements but also the forming of students’ independence, critical thinking, and ability to improve. The introduction of a comprehensive assessment system contributes to the improvement of the educational process and the increase of students’ motivation to learn.

It is worth noting the article Boice K. L., Jackson J. R., Alemdar M., Rao A. E., Grossman S., & Usselman M. “Supporting teachers on their STEAM journey”, where the authors consider the issue of ongoing support for teachers in the process of implementing STEAM methodologies in the educational process, analyze the effectiveness of teacher training programs in the use of STEAM approaches and the development of their digital competence [9].

Based on this study, the following criteria for assessing teacher support can be identified: the level of training and professional development of teachers in STEAM education, the availability and effectiveness of mentoring programs, the integration of STEAM methods into everyday pedagogical practice, the formation of indicators for monitoring a STEAM-oriented educational environment. Accordingly, the monitoring model may include an analysis of formative assessment, portfolios, and self-assessment in the educational process. The proposed criteria can be used to develop a system of school ratings based on the implementation level of the STEAM approach.

Deák C. and Kumar B. explore the relationships between STEAM education, the digital competencies of teachers and students, and sustainable innovation in academic institutions [10]. They analyze how integrating science, technology, engineering, art, and mathematics provides a comprehensive approach to developing participants' digital literacy in the educational process. Scientists have proposed the NOISE (Needs – Opportunities – Improvements – Strengths – Exceptions) methodology, which is a tool for analyzing and improving educational processes. It is widely used to evaluate the effectiveness of educational programs, including STEAM education.

In the context of monitoring a STEAM-oriented educational environment, this approach can help identify key needs of students and teachers, identify opportunities for improving the educational environment, identify areas for improving learning processes, highlight the positive aspects of STEAM education, and consider exceptional practices that can serve as models for implementation in other educational institutions.

In developing a model for monitoring a STEAM-oriented educational environment in general secondary education, it is necessary to consider both theoretical foundations and practical experience. Ukrainian research over the past three years (2021-2024) highlights the growing importance of digital pedagogy, innovative tools for monitoring and promoting STEAM education nationally. Numerous initiatives and studies provide essential information for assessing digital readiness, inclusiveness, and interdisciplinary approaches to learning.

The study by Ovcharuk O., & Soroko N. “Monitoring the Effectiveness of the STEAM-Oriented Environment in General Secondary Education Institutions: Approaches to Defining Criteria” examines approaches to monitoring the effectiveness of the STEAM-oriented educational environment in general secondary education institutions [4]. The main focus of the study is on determining the criteria for assessing the effectiveness of the development of this environment. Scientists identify the following criteria for assessing the STEAM-oriented educational environment: infrastructure criterion, i.e., provision of material and technical resources (STEM laboratories, access to digital platforms, etc.); pedagogical criterion, which covers the level of teacher training and their participation in professional activities; methodological criterion, as the integration of the STEAM approach into the educational process; academic criterion, which is based on determining the level of student learning outcomes and the level of readiness of teachers to use the STEAM approach and digital technologies in their pedagogical activities; a social criterion, which the level of student involvement in project activities and cooperation with the real sector should determine.

Shapovalov Y., Shapovalov B., Andruszkiewicz F. & Volkova N. conducted an SEO-based analysis (Search Engine Optimization) of the portal Virtual STEM Center of the Junior Academy of Sciences of Ukraine, which hosts over than 300 educational materials for students related to STEM projects [11]. They used the Google Trends service, which helps researchers compare the popularity of search queries, identify educational activity centers and regions with potential development, compare with other educational areas, etc. Using this analytical system, scientists were able to establish that the popular sections of the site are interactive lessons and STEM scenarios for high school, a STEM lesson builder that allows teachers to create their own integrated modules, and methodological recommendations for implementing STEM in school. Such data can help adapt content to the needs of teachers and serve as one of the tools for monitoring the development of STEM education.

It is worth noting the study of Buturlina O., Dovhal S., Hryhorov H., Lysokolenko T., Palahuta V. "STEM Education in Ukraine in the Context of Sustainable Development", during which an analysis of the state of STEM education in Ukraine for 2021 was carried out [12]. They focused on the regulatory and legal framework affecting the development of STEM education in Ukraine; institutional support, which covers the role of the Ministry of Education and Culture of Ukraine, research institutions, partner organizations and participation in international programs (for example, Erasmus+, Horizon Europe); teacher training levels; the material and technical base, such as the availability of STEM laboratories, robotics rooms, 3D printing, etc.; methodological support (development of integrated curricula, availability of modern teaching materials for STEM lessons, etc.). Their research can serve as a basis for developing monitoring models of the educational environment, as scientists analyze practical examples of implementing STEM approaches in Ukrainian schools and provide directions that can be developed for designing a monitoring model.

The research goal is to justify and create a monitoring model of a STEAM-oriented computer educational environment of a general secondary education institution, which will allow us to provide proposals for the effective development of a STEAM-oriented computer educational environment in a general secondary education institution.

2. THE RESULTS AND DISCUSSION

According to the Order of the Ministry of Education and Science of Ukraine No. 54 dated January 16, 2020, "On Approval of the Procedure for Conducting Monitoring of the Quality of Education", educational quality monitoring is the process of collecting, processing, and analyzing information about the state of the educational process and its results to identify and track trends in the development of education quality, determine the compliance of actual educational outcomes with declared goals, and assess the reasons for deviations from these goals [13].

In a STEAM-oriented educational environment, education quality monitoring involves systematic observation and evaluation of the effectiveness of implementing an integrated approach to education that combines science, technology, engineering, arts, and mathematics. This includes assessing material and technical resources, teacher training, integrating STEAM methodologies into the educational process, students' academic achievements, and their engagement in project-based activities.

Considering the above analysis of scientific publications and the definition of the concept of monitoring, we should note that the monitoring model of a STEAM-oriented educational environment of a general secondary education institution should include the following stages: preparatory stage, data collection, data processing and analysis, interpretation of results, correction stage [14].

The preparatory stage encompasses defining monitoring objectives and tasks, forming evaluation criteria and indicators, developing monitoring tools (questionnaires, tests, surveys, checklists), and determining the participant sample (students, teachers, administration).

It is important to create appropriate questionnaires for students, teachers, and other participants in the educational process, which could provide adequate answers to existing problems in the development of the educational environment. In our opinion, the test for teachers should cover the following blocks (appendix 1): general questions which relate to the respondent's age, his/her teaching experience, information about the academic disciplines he/she teach; STEAM integration which may cover issues such as "How often do you use STEAM methods in your classes?", "What STEAM tools do you use?", "How would you rate the level of integration of STEAM education in your institution?"; challenges in implementing STEAM, which may relate to the clarification of the problems faced by the respondents when implementing the STEAM approach in the educational process. For students, the questionnaire may cover the following blocks: general questions that relate to the respondent's age or grade, and whether respondents participated in STEAM activities; using STEAM in education, which may cover issues such as "What technologies or methods do you use in your classes?", "How often do you work on projects integrating several subjects (for example, physics + mathematics + technology)?"; evaluating the effectiveness of STEAM education, which may cover issues such as "Do STEAM lessons help you develop these skills?", "Do you think that STEAM education will help you in your future profession?", "What difficulties do you experience in learning using the STEAM approach?", "What would you like to improve in STEAM lessons?".

At the stage of defining the goals and objectives of monitoring, it is essential to determine the goals and expected results of monitoring the educational environment focused on STEAM. Defining the goal of monitoring may include assessing the level of STEAM integration, assessing the availability of resources, measuring student engagement, etc. Defining specific tasks by experts involves evaluating the effectiveness of STEAM-based teaching methods, analyzing the impact of STEAM education on students' academic achievements, assessing the readiness of teachers to implement STEAM methods, and identifying areas for improving the educational environment.

To ensure effective and measurable monitoring, it is essential to establish clear criteria and indicators that will reflect the success and challenges of implementing the STEAM approach. At the stage of forming criteria and indicators, it is worth considering such key aspects as material and technical resources (availability of STEAM laboratories, digital tools and educational platforms), integration of VR/AR, robotics and AI-based tools, teacher qualifications and their readiness to use digital tools and the STEAM approach in their pedagogical practice (percentage of teachers who have undergone special training on implementing the STEAM approach in the educational process, frequency of interdisciplinary teaching practices), student involvement in STEAM projects and their success (percentage of students involved in STEAM projects, level of students' problem-solving and critical thinking skills), integration of the STEAM curriculum (number of STEAM-related courses or extracurricular activities, implementation of project-based approaches to learning, etc.).

The main tasks of the preparatory stage: development of tools, which involves the creation of reliable and valid monitoring tools that are important for data collection; conducting testing, questionnaires, surveys, etc., which will help to maximally clarify the status of the implementation and development of a STEAM-oriented educational environment in general secondary education institutions [15]. The tools should be designed to collect both quantitative and qualitative information about the STEAM-oriented educational environment. Types of monitoring tools (appendix 1):

- questionnaires – structured surveys of students, teachers, and administrators to assess the perception and experience of STEAM learning;
- tests – assessment of the development of student competence in STEAM disciplines;
- surveys – collection of feedback on the effectiveness of teaching strategies and resources;
- checklists – standardized assessment sheets to assess classroom practice, lesson structure, and use of digital tools.

Participants need to be identified to ensure representative and robust results. Key participants include: students – participating in different classrooms to analyze the impact of STEAM on various age groups; teachers – involving teachers from other subject areas to understand interdisciplinary collaboration; school administration – gathering information on institutional support, policy implementation, and infrastructure development; external experts (optional) – invite experts from the STEAM industry or academia for additional assessment.

The preparatory stage ensures the accuracy and reliability of monitoring the STEAM-oriented educational environment. It lays the foundation for the monitoring process by defining clear objectives, measurable criteria, reliable tools, and a representative sample of participants. Proper planning at this stage ensures meaningful data collection and supports informed decision-making for improving STEAM education.

The data collection phase is critical in monitoring STEAM educational environments. This phase involves collecting quantitative and qualitative data using pre-developed tools to assess the effectiveness of STEAM education [2]. This ensures that the monitoring process captures accurate, real-time information about implementing the STEAM approach in schools.

Depending on the objectives and scope of the monitoring, different data collection methods can be used:

- surveys and questionnaires to assess the views of educational stakeholders on the integration and effectiveness of STEAM education (surveys can include Likert-scale, multiple-choice, and open-ended questions);
- observation, typically conducted in classrooms, laboratories, and workshops to monitor how teachers apply STEAM methodologies and how students engage in learning;
- document analysis, for example, reviewing lesson plans, student projects, teacher reports, and instructional materials to assess the inclusion of STEAM principles and the extent to which schools adhere to educational standards when implementing STEAM projects;
- standardized testing and assessment, which consists of conducting pre-and post-tests to measure student progress in STEM and interdisciplinary subjects to identify strengths and weaknesses in STEAM teaching approaches;
- focus groups and interviews were conducted with students, teachers, and school administrators to collect in-depth information and identify problems in implementing STEAM education and teachers' needs for further professional development.

Data collection should be carried out taking into account the following organizational aspects:

- defining time frames, for example, establishing an explicit schedule for conducting surveys, classroom observations, and assessments (data collection should be coordinated with academic schedules to minimize disruptions to data collection and teaching);
- allocating roles and responsibilities, namely, finding and assigning those who will collect data (for example, interested scientific and pedagogical workers, external experts, and other researchers);
- ensuring anonymity, confidentiality of data, compliance of the monitoring process with the principles of ethical research, obtaining consent from participants;
- selection of digital technologies to ensure convenient and effective data collection and analysis (for example, use of online survey platforms such as Google Forms, SurveyMonkey, Qualtrics, etc. for convenient and fast data collection; use of learning management systems such as Moodle, Google Classroom, etc. to track student participation and activity in STEAM projects; AI-based analytics tools to evaluate responses in real-time).

The data processing and analysis stage is critical to monitoring the STEAM-oriented educational environment. This phase transforms raw data collected during the monitoring process into meaningful insights. It consists of several key steps [16]: pre-processing the collected data, descriptive statistical analysis, and synthesis of analyzed data into practical conclusions.

Pre-processing the collected data includes:

- handling missing data – using techniques such as deletion or predictive modeling to address gaps in the data set;
- removing duplicates and inconsistencies – ensuring data integrity by eliminating errors during data entry;
- standardizing variables – normalizing data formats (for example, converting all test scores to a 100-point scale);
- categorizing qualitative responses – using thematic coding for open-ended survey responses.

After preprocessing the data, an initial descriptive analysis summarizes the main trends. Common methods include:

- frequency distribution – understanding how often certain responses or scores appear;
- measuring the main trend – calculating means, medians, and modes for key indicators (for example, student engagement levels, teacher readiness ratings);
- measures of variability – using standard deviation and variance to assess the spread of the data.

The final step in the data processing and analysis phase is to synthesize the analyzed data into practical conclusions, which includes comparing the results with predefined benchmarks (evaluating performance against national or institutional standards), identifying strengths and areas for improvement, i.e. determining which aspects of STEAM education are effective and which need adjustment, and providing recommendations in the form of proposing evidence-based strategies to improve the integration of STEAM into the educational process.

Interpretation of results is a further step in monitoring a STEAM-oriented educational environment. Its main tasks are to analyze the obtained statistical data, identify patterns and relationships between various indicators, assess the degree of compliance of fundamental indicators with expected results, compare results with established criteria, determine the compliance of indicators for assessing a STEAM-oriented educational environment with the criteria for its effectiveness for a general secondary education institution, assess the level of integration of interdisciplinary components (STEM+Arts), analyze the impact of digital technologies on the quality of the educational environment, etc.

The final stage of monitoring a STEAM-oriented Educational Environment is corrective, which includes analyzing the results obtained and developing and implementing measures to improve this environment.

The main tasks of the stage are:

- interpretation of data, which includes such actions as comparing the obtained results with the planned indicators, identifying the strengths and weaknesses of the educational environment, and assessing the impact of the STEAM approach on students and teachers;
- development of recommendations for identifying areas for improving STEAM approaches and providing proposals for corrective measures;
- adaptation of curricula taking into account new technologies (for example, VR, AR, 3D modeling) and students' needs;
- assessment of the effectiveness of changes through re-testing or questionnaires, analysis of results after implementing corrective measures, generalization of conclusions, and formation of a strategy for further development.

This stage ensures a STEAM-oriented educational environment's continuous development and improvement.

According to the analysis of scientific research and the stages we have identified, we can distinguish the main blocks of the model of monitoring STEAM-oriented educational environment: target, organizational-content, technological, diagnostic-analytical, prognostic, and control-corrective (fig. 1).

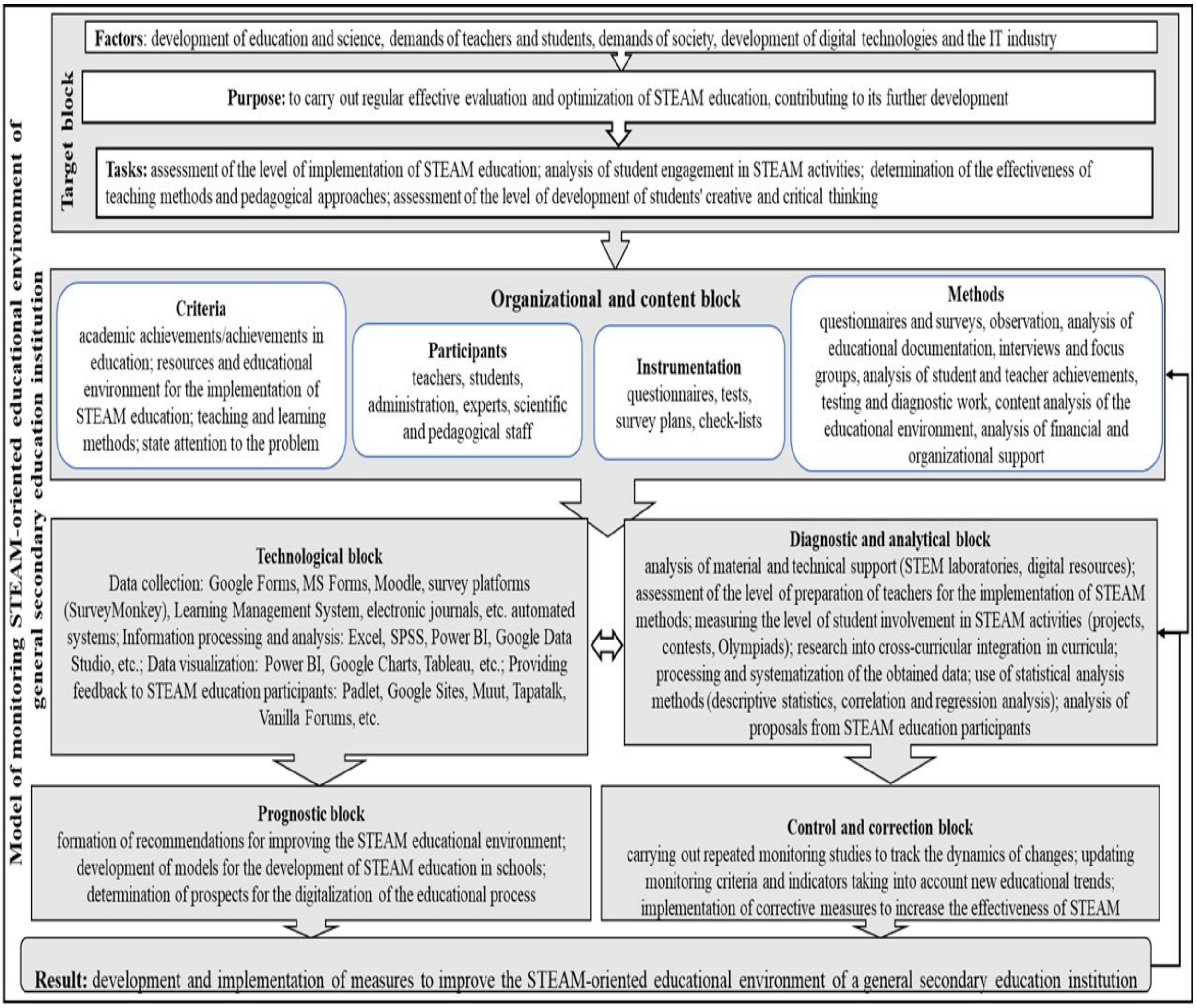

Fig. 1. Model of monitoring STEAM-oriented educational environment (author's vision that was created according to the analyzed sources [1], [2], [3], [4], [5], [7], [8], [9], [10], [11], [12], [14], [15])

The target block of the STEAM-oriented educational environment monitoring model is formed depending on the main factors that influence the monitoring process. Among them, attention should be paid to the development of education and science, the demands of teachers and students, the needs of society, the development of digital technologies, and the IT industry. The category of factors is variable, as it depends on globalization processes in education and the world, and it directly affects such blocks of the model as technological and organizational content.

Important elements of this block are the purpose and tasks of monitoring, which influence the further course of the process and use its main result, namely:

- Purpose: to carry out regular effective evaluation and optimization of STEAM education, contributing to its further development;
- Tasks: assessment of the level of implementation of STEAM education; analysis of student engagement in STEAM activities; determination of the effectiveness of teaching methods and pedagogical approaches; assessment of the level of development of students' creative and critical thinking.

The organizational and content block covers the identified main criteria and corresponding indicators, which will later be the basis for creating questionnaires and analyzing the collected data; monitoring participants who will participate in monitoring studies; instrumentation, for example, questionnaires, tests, survey plans, check-lists; methods such as questionnaires and surveys, observation, analysis of educational documentation, interviews and focus groups, analysis of student and teacher achievements, testing and diagnostic work, content analysis of the educational environment, analysis of financial and organizational support.

We have identified the following main monitoring criteria and corresponding indicators that can improve the analysis and diagnosis of STEAM-oriented educational environment development:

- Academic achievements/Academic success, which may include such indicators: percentage of teachers who have completed STEAM education courses and received relevant certificates; percentage of teachers who participate in scientific and practical events (conferences, seminars, trainings) related to STEAM education; analysis of articles, theses and scientific reports on STEAM education (number of publications in international and national journals); number of research projects completed by students under the guidance of teachers; level of knowledge in STEAM disciplines (based on the results of tests, assessments, experimental tasks); results of standardized tests and exams in STEAM disciplines; grades for laboratory work and practical tasks; percentage of students who received high scores in scientific olympiads and competitions;
- Resources and educational environment for the implementation of STEAM education, which may include such indicators: number of websites dedicated to STEAM education created in the educational institution; number of methodological recommendations for the implementation of STEAM projects; level of provision of classrooms for laboratory work and distance learning; percentage of lessons using STEAM laboratories, digital platforms and virtual environments; level of satisfaction of teachers with material and technical support; Level of satisfaction of students with material and technical support; percentage of students who have access to the necessary equipment for conducting STEAM experiments;
- Innovative teaching and learning methods, which may include such indicators: frequency of use of interactive platforms for conducting lessons (Kahoot!, Quizlet, Nearpod, etc.); percentage of lessons using interactive whiteboards or other innovative teaching tools; number of integrated STEAM courses in the school curriculum; percentage of lessons using the project-based learning method; percentage of students involved in interdisciplinary STEAM projects; percentage of students working in teams on the implementation of STEAM projects;
- State attention to the problem, which may include such indicators: availability of state orders and other regulatory documents on the implementation of STEAM education in educational institutions; percentage of STEAM education funding from the general education budget; number of grants and programs supporting STEAM initiatives in schools; level of implementation of state standards for STEAM education in educational institutions; number of organized STEAM education olympiads and competitions for students; number of participants in STEAM olympiads and competitions; level of student satisfaction with participation in such events (based on survey results).

The technological block is an element of the monitoring model that contains tools and methods of their use:

- data collection: Google Forms, MS Forms, Moodle, survey platforms (for example, SurveyMonkey), Learning Management Systems, electronic journals (for example,

Single School Electronic Database, "New Knowledge", "My School"), etc. automated systems;
- information processing and analysis: Excel, SPSS, Power BI, Google Data Studio, etc.;
- data visualization: Power BI, Google Charts, Tableau, etc.;
- providing feedback to STEAM education participants: Padlet, Google Sites, Muut, Tapatalk, Vanilla Forums, etc.

The diagnostic and analytical block includes an analysis of material and technical support (STEM laboratories, digital resources); assessment of the level of preparation of teachers for the implementation of STEAM methodology and the level of their digital competence; measurement of the level of student involvement in STEAM activities (projects, competitions, olympiads); research into cross-curricular integration in curricula; processing and systematization of the obtained data; use of statistical analysis methods (descriptive statistics, correlation and regression analysis), etc.; analysis of proposals from STEAM education participants. We also believe that when monitoring, it is necessary to take into account the participation of Ukrainian educational institutions in international projects on the problem of STEAM education, for example, Developing a STEAM Roadmap for Science Education (Road-STEAMer) within the Horizon Europe program [17], CRED4TEACH [18] and e-STEAMSEL [19] within the Erasmus+ program.

The prognostic block is a crucial element of the STEAM educational environment monitoring model, aimed at forecasting trends, identifying areas for improvement, and developing strategic recommendations. This block ensures continuous development and adaptation of STEAM education to the evolving demands of science, technology, and society. This block covers developing recommendations for improving the STEAM educational environment, developing models for STEAM education in schools, and determining prospects for digitalizing the educational process.

The control and correction block ensures the continuous refinement and enhancement of STEAM education by systematically tracking changes, updating evaluation criteria, and implementing targeted corrective actions. This block plays a crucial role in maintaining the effectiveness of STEAM education in response to evolving educational trends, technological advancements, and student needs.

The monitoring model results in the development and implementation of measures to improve the STEAM-oriented educational environment of a general secondary education institution. This result should ensure further adjustment of curricula and teaching methods, organization of additional measures to increase teachers' competencies in the use of digital technologies and conducting STEAM projects, improvement of the material and technical base, development of partnerships with scientific and business structures, creation of new recommendations for the integration of STEAM components into the educational process.

It should be noted that in order to implement the monitoring model, it is worth developing a plan for its practical application in terms of monitoring the STEAM educational environment in certain institutions. For example, in the context of a general secondary education institution, we offer the following plan: preparatory stage, which should include familiarizing the teaching staff with the monitoring model, conducting an initial questionnaire for teachers (based on SWOT analysis tools), forming an expert group to collect and analyze data; a diagnostic stage, which may include collecting information according to key criteria such as infrastructure, human resources, teacher readiness, student participation, availability of projects, or using the proposed questionnaires (Appendix 1), using the STEMUA.science platform as a digital tool for monitoring activity; an analytical stage, which may include building a SWOT profile of the educational institution to identify problem areas and strengths, conducting focus groups with teachers and students on motivation, challenges, and needs; development of recommendations and proposals, which may include the formation of recommendations for school administration and methodological associations, planning internal professional development, and initiating participation in national projects.

This approach can contribute to the systematic monitoring and development of STEAM environments in educational institutions.

CONCLUSIONS AND PROSPECTS FOR FURTHER RESEARCH

The STEAM-oriented educational environment monitoring model provides a practical framework for improving the educational process, enhancing student competencies, and aligning teaching methodologies with modern requirements. Contemporary digital technologies, such as artificial intelligence-based analytics and real-time data tracking, provide more accurate and objective assessment results. By adhering to the stages we have defined (preparatory stage, data collection, data processing and analysis, interpretation of results, correction stage) and taking into account the blocks of the model (targeted, organizational and content, technological, diagnostic and analytical, prognostic and control and correction), it is possible to ensure an effective process of monitoring the educational environment. The blocks we have proposed for creating tests for students and teachers can be used to determine the level of integration of STEAM methods, the use of technologies, and the problems of implementing STEAM projects.

Prospects for further research include the implementation and testing of the developed model, which may provide opportunities to expand the systems of criteria and indicators for assessing STEAM education, analysis of the effectiveness of international STEAM programs and their adaptation to the national context, identification of best practices for integrating STEAM approaches into general secondary education institutions.

Expanding monitoring research will increase the effectiveness of educational strategies, promote greater involvement of students and teachers in STEAM activities, and improve the quality of education in digital transformation.

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МОДЕЛЬ МОНІТОРИНГУ STEAM ОРІЄНТОВАНОГО ОСВІТНЬОГО СЕРЕДОВИЩА ЗАКЛАДУ ЗАГАЛЬНОЇ СЕРЕДНЬОЇ ОСВІТИ

Наталія Сороко
кандидат педагогічних наук,
провідний співробітник відділу компаративістики інформаційно-освітніх інновацій
Інституту цифровізації освіти НАПН України,
м. Київ, Україна
ORCID ID 0000-0002-9189-6564
nvsoroko@gmail.com

Анотація. Стаття присвячена проблемі та особливостям побудови моделі моніторингу STEAM орієнтованого освітнього середовища закладу загальної середньої освіти. Вона спрямована на дослідження особливостей проведення процедур моніторингу STEAM орієнтованого освітнього середовища закладу загальної середньої освіти. Для досягнення мети нашого дослідження, а також з'ясування проблеми визначення особливостей моделей нами було проаналізовано наукові статті за проблемами оцінювання стану та розвитку STEAM орієнтованого освітнього середовища. Були використані методи системного та порівняльного аналізу педагогічної, методичної та спеціальної літератури; аналіз педагогічного досвіду вітчизняних та зарубіжних учених щодо визначення етапів, критеріїв та індикаторів оцінювання STEAM орієнтованого освітнього середовища. Сформована нами модель охоплює шість блоків: цільовий, організаційно-змістовий, технологічний, діагностично-аналіційний, прогностичний, контрольно-корекційний. Результатом моделі моніторингу є розробка та впровадження заходів щодо вдосконалення STEAM орієнтованого освітнього середовища закладу загальної середньої освіти. Запропоновано план реалізації моделі моніторингу STEAM орієнтованого освітнього середовища у закладах загальної середньої освіти, який охоплює підготовчий етап, формування експертної групи для збору та аналізу даних, діагностичний етап, який може передбачати збір інформації за ключовими критеріями, такими як інфраструктура, людські ресурси, готовність учителів, участь учнів, наявність проєктів та розробку рекомендацій та пропозицій, які містять формування рекомендацій для адміністрації школи та методичних об’єднань, планування внутрішнього професійного розвитку та ініціювання участі в національних проектах.

Ключові слова: STEAM-освіта; моніторинг; якість освіти; заклад загальної середньої освіти; навчальний проєкт; цифрові технології.

Appendix 1

Examples of questionnaires for analyzing the state of STEAM-oriented educational environment development.

1.1. Questionnaire for teachers

Purpose: To determine the level of integration of STEAM methods, the use of technologies, and implementation problems.

1. General questions

Your age:

☐ Under 30
☐ 31–40
☐ 41–50
☐ Over 50

Teaching experience:

☐ Under 5 years
☐ 6–10 years
☐ 11–20 years
☐ Over 20 years

What subjects do you teach? (you can choose more than one)

☐ Mathematics
☐ Physics
☐ Chemistry
☐ Biology
☐ Computer science
☐ Technology
☐ Other: ______

2. STEAM integration

How often do you use STEAM methods in your classes?

☐ Never
☐ Rarely (1-2 times per semester)
☐ Sometimes (once a month)
☐ Often (once a week or more)

What STEAM tools do you use?

☐ 3D modeling
☐ Robotics
☐ Virtual labs
☐ Coding and programming
☐ Project-based learning
☐ Other: ______

How would you rate the level of integration of STEAM education in your institution? (on a scale from 1 to 5)

☐ 1 - Very low
☐ 2 - Low
☐ 3 - Average
☐ 4 - High
☐ 5 - Very high

3. Challenges in implementing STEAM

What challenges do you face when using STEAM approaches? (select all that apply)

☐ Insufficient resources (equipment, software)
☐ Lack of time to prepare lessons
☐ Insufficient level of teacher training
☐ Lack of support from the administration
☐ Other: ______

What do you think needs to be improved to develop STEAM education in school?

1.2. Questionnaire for students

Purpose: to determine how involved students are in STEAM education and how they evaluate its effectiveness.

1. General questions

Your grade:

☐ Grades 5–7
☐ Grades 8–9

☐ Grades 10–11

Do you enjoy STEAM-related lessons?

☐ Yes, very much
☐ Yes, somewhat
☐ Neutral
☐ No

2. Using STEAM in education

What technologies or methods do you use in your classes?

☐ Programming
☐ Robotics
☐ Research projects
☐ 3D modeling
☐ Laboratory experiments
☐ Other: ______

How often do you work on projects integrating several subjects (for example, physics + mathematics + technology)?

☐ Never
☐ Rarely (1-2 times per semester)
☐ Sometimes (once a month)
☐ Often (once a week or more)

3. Evaluating the effectiveness of STEAM education

Do STEAM lessons help you develop these skills?

☐ Critical thinking
☐ Logical thinking
☐ Creative approach
☐ Teamwork skills
☐ Problem-solving skills

Do you think that STEAM education will help you in your future profession?

☐ Yes
☐ Don't know
☐ No

What difficulties do you experience in learning using the STEAM approach?

☐ Insufficient explanation of the material
☐ Lack of necessary equipment
☐ Difficult to work in a team
☐ Too difficult tasks

What would you like to improve in STEAM lessons?

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