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Methodological system for the formation of meta-subject skills of primary school students in the context of STEM education

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The significance of this study lies in fostering skills among school students that enables them to process information from several academic subjects, utilize science and technology at the same time, create new innovative projects, think critically and creatively, achieve meta-subject and personal outcomes, apply their abilities and knowledge to solve real-life problems, and make decisions based on current information utilizing available digital technologies. The main goal of this research is to propose a methodological system for the formation of meta-subject skills in primary school students in the context of STEM education. This framework encompasses several essential stages: a conceptual foundation for the formation of meta-subject skills of primary school students; methods of teaching through STEM; and interdisciplinary, meta-subject tasks and integrated projects aimed at fostering meta-subject skills. Moreover, the study describes an elective course program called "Secret of the World." This course is intended for second grade learners and serves as a practical implementation of the proposed methodology. This course focuses on the promotion of integrated learning based on common topics, application of scientific and technical knowledge, enhancement of critical thinking and problem solving, stimulation of curiosity in science and technical subjects, and utilization of creative and innovative approaches to projects.

KEYWORDS

meta-subject, STEM, interdisciplinary communication, methodological system, common topic, integrated project, research, technology

1 Introduction

Over time, today's primary school students will become integral members of society and pursue unknown professions. Therefore, it becomes essential for teachers to identify a child's interest from an early age and navigate their development in those areas. In today's digital world, the amount of information flow is very large. Therefore, students need to acquire the requisite knowledge, skills, and develop their innovative and creative thinking abilities. Teaching through STEM will enhance the student's interest in scientific research, enable them to take the first steps as a researcher or as a scientist, help them get acquainted with the laws of various fields of science, and develop in them an ability to make predictions and analyze data and obtained results during practice. At this point, the issue of teaching in the context of STEM education is one of the most relevant and demanding areas of research interest.

Therefore, for nurturing mathematical and technological literacy among students, education in science, technology, engineering, and mathematics has to be enhanced to global standards. The emphasis on STEM education is initiated in primary school, underlining the importance of generating interest in learning science, engineering, and mathematics within the STEM education framework (Lane et al., 2022).

STEM is an integrated approach to learning where academic concepts in science and technology are explored in a real-life context. The goal of this approach is to establish strong connections between school, society, work, and the real world that contribute to the development of STEM literacy and competitiveness in the global economy (Yesnazar, 2023). Thus, the central idea of STEM education concentrates on integration, whereby STEM facilitates the purposeful integration of diverse disciplines to solve specific problems (Sanders, 2009; Labov et al., 2017). According to the scientists, we observed that teaching in the STEM environment contributes to the emergence of a new form of teaching through the integration of science fields.

In STEM education, an essential learning achievement is the integration of knowledge across different fields of science. It is implemented by combining interdisciplinary knowledge to cultivate new combinations of integrated knowledge. Therefore, through the integration of scientific fields of mathematics, natural sciences, computer science, and engineering, STEM education fosters technological literacy among students while providing them with meta-subject skills necessary for the 21st century. This teaching strategy not only helps primary school students to acquire knowledge of mathematics and natural sciences but also aids in the development of critical thinking skills and fosters a desire to master science and technology.

In general, teaching STEM in primary school arouses students' curiosity in science, mathematics, and technical subjects, awakens their enthusiasm for new things, and enables them to master science and technology so that they can understand the construction of airplanes, submarines, and buildings and also study the world of plants. Working in pairs, teamwork, and integrated projects are key to this approach, allowing students to learn to use techniques and technology, physical laws, and the concepts of biological science.

1.1 Teaching issues in STEM education

Moreover, the STEM educational environment plays an important role in the development of mathematical literacy of primary school students. It enhances logical thinking, proficiency of natural and technological sciences, and fosters communication skills. These facets necessitate positioning of STEM education as an essential component in the modernization of the primary education system (Rotova, 2023).

In general, as a result of education that includes STEM, it is possible to strengthen the research abilities of students and foster their innovative and creative thinking and communication skills in group work (Kusainova et al., 2023). This interdisciplinary nature of STEM education enhances communication, establishing links between "school–society–world," thereby fostering STEM literacy among students.

Key benefits of STEM education:

- enhances problem-solving skills;
- develops creative engineering potential of individuals using their basic knowledge and skills;
- contributes to the development of logical thinking;
- builds confidence;
- encourages to explain and understand the secret of nature (Yildirim and Altun, 2015).

A model is developed on the basis of the "Early STEM Integration" program aimed at enhancing the interest of primary school students in STEM (Ibrayeva and Shaushekova, 2023). This model, aimed at developing research capabilities in primary school students, encompasses topics such as *Lego Duplo, Lego Mindstorm, Laser cutting, Basic circuitry, I create the world, I am an inventor, I am a scientist*, etc. We suggest that by teaching these proposed topics, students will become passionate about scientific and technical activity, develop an ability to solve tasks, use innovate thinking to invent new things, gain confidence in solving real problems, acquire interdisciplinary knowledge, and develop universal logical skills. We intend to apply these ideas in our research.

Ha et al. (2023) identified seven activities in the STEM context to improve student learning outcomes: educational robots, educational games, inquiry-based learning and engineering design, drawing and discussions about engineering, role-playing games, and group membership.

Vega et al. (2019) conducted an experiment involving primary school students to determine the effectiveness of STEM methodology in the educational process. The study comprised two groups: one utilized the STEM methodology and the other followed a traditional approach without applying the STEM methodology. The findings showed that the frequent application of STEM methodology in teaching primary school students enhances students' integral skills such as critical thinking, communication, cooperation, creativity, and research activities.

In order to enhance the competitiveness of prospective primary school teachers, domestic scientists suggest ways to introduce "education in primary school" and "STEAM (stem, technology, engineering, art, mathematics) is the approach in primary school" as an additional minor subject in the educational programs of universities. These initiatives stem from arousing the interest of primary school students in activities such as design, modeling, and robotics (Ageyeva and Agranovich, 2023). Therefore, this method is considered as an integrated experience-oriented teaching approach, underscoring their relevance in the educational programs and activities in the schools within the country.

Kudaybergenova (2023) considers the importance of incorporating the STEM educational method in schools. The author recommends enhancing school teacher education by providing methodological assistance and introducing STEM-related subjects into the educational programs of universities. Her other research suggests diverse actions such as introducing STEM education from primary school, creating educational centers focused on STEM, organizing training sessions and seminars, and developing STEM educational programs.

Current research demonstrates a concentration on STEM education within the education system, highlighting the utilization of interdisciplinary and applied approaches through the integration of sciences (Breiner et al., 2012; Costa and Domingos, 2018; Matos et al., 2019; Leung, 2020; Yesnazar, 2022). Furthermore, development of meta-subject skills among primary school is enabled through interdisciplinary integration, scientific creative work, and integrated projects. Therefore, teaching in the STEM direction facilitates primary school students'

acquisition of necessary knowledge, skills, and abilities. Thus, in the process of carrying out their project, the students are encouraged to apply their subject knowledge in several directions and gain a holistic comprehension of the world and a natural view of natural science.

The formation of meta-subject skills in primary school students in the context of STEM education is considered a relevant issue in the education system and requires research. In this context, the new paradigm of education highlights the formation of a unified worldview in students, underscoring the comprehensive acquisition of subject knowledge, skills, and abilities. The learners are encouraged to organize their learning activities independently, apply knowledge and skills according to the changing environment, and manage and learn independently (Jumabaeva, 2021). This entails the development of students who can process information from several academic subjects, utilize science and technology at the same time, create new innovative projects, think critically and creatively, and master meta-subject skills. These students possess the skills to differentiate, process, and apply knowledge of various academic subjects.

Consequently, considering the rapid development of the issue of teaching through STEM, one of the most remarkable achievements of teaching in the context of STEM education embraces the implementation of knowledge through collaboration involving different fields of science. Specifically, integrated knowledge is enriched and expanded by integrating knowledge from other disciplines to form new combinations (Salcedo et al., 2024). However, a still unrealized goal of STEM education is to develop a methodological system for students and teachers in order to make the educational process conducive for teaching in the context of STEM education.

From this perspective, our proposed scheme is particularly relevant for developing a methodological system for the formation of meta-subject skills in primary school students in the context of STEM education. This necessitates creating an environment that enables primary school students to learn various fields of science in the "research-do-learn-know" way, to develop non-standard solutions, enhance creative thinking, independently analyze information, and design a project. The relevance of this issue arises from the need to ensure the development of a methodological system through STEM in the educational landscape. We assume that these recommendations will facilitate the creation of a quality educational environment, enabling the cultivation of students' technological competencies, the enhancement of intellectual thinking abilities, universal learning activities, subject basic abilities, critical thinking skills, and research activities.

2 Meta-subject skills of primary school students

In the context of STEM education, the meta-subject skills of primary school students are realized through interdisciplinary, cognitive, research, and other actions. These actions encompass.

- logical operations (identification of important features of objects; analysis of laws in facts and data; drawing deductive, inductive, and similarity conclusions) (Ibashova et al., 2017);
- research (independent analysis of data; validate predictions and opinions through judgment; experimenting according to a plan; conducting research to determine the interdependence of objects; evaluating the validity and correctness of information obtained during research; independently drawing conclusions based on the research results; predicting the development of events);
- information analysis and processing (application of different methods in the selection of different data; finding similar evidence from different information sources; illustrating information using a simple scheme, diagram, graph; evaluation of the reliability of information; effectively memorizing and organizing information);
- communication (students express their points of view; recognize non-verbal means of communication; propose problem-solving ideas; compare their judgments; present research findings in public).

Therefore, meta-subject skills are realized through engaging primary school students in universal learning activities comprising cognitive, communicative, regulatory (regulative), and personal universal learning activities (Asmolov et al., 2011).

3 Possibilities for the formation of meta-subject skills in primary school students in the context of STEM education

In this section, it is natural to pose the question, "What are the possibilities for the formation of meta-subject skills in primary school students in the context of STEM education?" In order to determine the response to this question, we analyzed the primary school textbooks on "Natural Science" (Bigazina et al., 2019), "Mathematics" (Aqpaeva et al., 2019), and "Digital Literacy" (Kadirkulov et al., 2022). This analysis allowed us to identify several possibilities for the formation of meta-subject skills in primary school students in the context of STEM education.

The first possibility encompasses the organization and implementation of educational activities aimed at the development of meta-subject skills in the planning of the educational process.

The second possibility facilitates the development of creative thinking among primary school students by connecting the contents of general subjects with life, enabling them to develop creative abilities through teaching in the STEM educational environment. Integrated teaching of scientific, natural science, social studies, and humanities allows students to develop a holistic worldview. Such classes are distinguished by their accuracy, capacity, comprehensiveness, logical interrelationship of the learning material at each stage of the lesson, informational ability, and focus on cultivating students' thinking skills.

The third possibility is aimed at promoting logical actions such as determining important features of objects; analyzing laws in terms of facts and data; drawing conclusions based on similarity and conducting planned experiments; assessing the validity and correctness of the information obtained during the research; drawing independent conclusions based on research results, finding similar evidence from different sources of information; illustrating information using diagrams, schemes, graphs, aimed at using specific methods that facilitate the development of meta-subject skills.

A fourth possibility is focused on implementing integrated projects that allow students to foster research skills in a STEM setting. Therefore, students are given different ideas to implement STEM projects, such as designing airplanes, bridges, etc.

The fifth possibility considers the incorporation of the elective course program "Secrets of the World" for primary school students as an additional material into the learning process.

These initiatives provide the possibility to form meta-subject skills of primary school students in a STEM setting.

4 Methodological system

4.1 Conceptual foundation of our methodological system

In order to implement the above-mentioned possibilities, it is imperative to develop a methodological system for the formation of meta-subject skills of primary school students in the context of STEM education. This methodological system focuses on the stimulation of primary school students' interest in learning science and technology, inculcation of research capabilities, enhancement of critical thinking, and development of skills and abilities for analyzing the sources of information.

The development of the methodological system is based on the subjects of natural science, mathematics, and digital literacy. It is very important to take advantage of these subjects. By its essence, the methodological system is aimed at effective management of the process of formation of meta-subject skills in primary school students, paying special attention to the goals and objectives of STEM education. In fact, in the context of STEM education, the methodological system for the formation of meta-subject skills of primary school students can be presented as a model comprising various components: purpose, content, teaching methods and tools, forms, and expected outcomes (as depicted in Figure 1).

4.2 Aim and objectives of the methodological system

Let us examine the components of the proposed methodological system in depth.

The aim of the methodical system is aimed at the formation of meta-subject skills in primary school students in the context of STEM education, incorporated into the educational system of the school. This aim leads to several specific objectives that guide the design and implementation of the methodological system:

1. organization of educational activities aimed at the development of meta-subject skills in the planning of the educational system;
2. cultivation of analytical, systematical, and meta-subject skills related to modern methods and technologies of teaching in STEM education;
3. implementation of integrated projects that allow students to develop their research skills in a STEM environment.

4.3 Ways to form meta-subject skills in primary school students in the context of STEM education

In the context of STEM education, we propose two ways to foster meta-subject skills of primary school students.

The first way is to focus on interdisciplinary and meta-subject assignments aimed at the cultivation of meta-subject skills. These assignments facilitate the development of cognitive, regulatory, communicative, and personal universal learning activities such as conducting theoretical research, drawing, diagramming; analysis and processing of information; implementation of modeling; proving opinions; self-control and mutual control; expressing opinions through group and pair work; creative assignments, etc. In this direction, we will offer meta-subject and interdisciplinary assignments.

The second way comprises the implementation of integrated projects. Through these projects, students show independence, responsibility, collaboration, and effective communication. Moreover, students will be able to enhance their comprehension of the laws of nature, the laws of physics, and the properties of materials by watching, observing, and analyzing the changes in nature and through physical laws. The utilization of STEM facilitates the acquisition of knowledge in school subjects and their understanding, the study of the environment in all aspects of the world: from building technology to rescue services, from physical phenomena to the animal world on earth.

To effectively implement these approaches, primary school teachers should create a consistent system of research-oriented teaching from the first grade, taking into account the knowledge of computer science, mathematics, physics, and natural sciences.

Encouraging students to research and then create structures surrounding us in our daily life using their working principles is crucial to motivating and stimulating their interest in learning about those technologies. To foster a deeper understanding of the techniques, it is necessary to give collective work to students. Teamwork enhances communication skills and creates cohesive and effective communication in small groups. The skills and knowledge acquired in the future will undoubtedly increase the demand for today's students in the labor market and applying them based on the knowledge acquired in school will help them quickly transition to adulthood.

4.4 Methods, tools, and forms of teaching

The next component of the methodical system for the formation of meta-subject skills of primary school students in the context of STEM education comprises traditional and innovative methods. We highlight the specific methods to facilitate the cultivation of meta-subject skills among primary school students such as "mind mapping" technology (Le et al., 2023), task-based learning (Willis, 2021), cooperative learning (Erbil and Kocabaş, 2018), project-based learning technologies (Supriyanti, 2022), design technology (Reiser and Dempsey, 2012), STEAM technology (Sanz-Camarero et al., 2023), etc.

The teaching tools encompass ViHart, Make:Workshop, Tinker Lab, Crash Course Kids, and Kids Animal Channel, It'sOkaytoBeSmart, Smarter Every Day, National Geographic, BrainCraft, Smithsonian Science Education Center, and more digital resources. We propose the following forms of teaching: interdisciplinary projects, game projects, research projects, informational projects, creative projects, interdisciplinary exercises, etc. The utilization of these approaches enables primary school students to develop meta-subject skills in the context of STEM education.

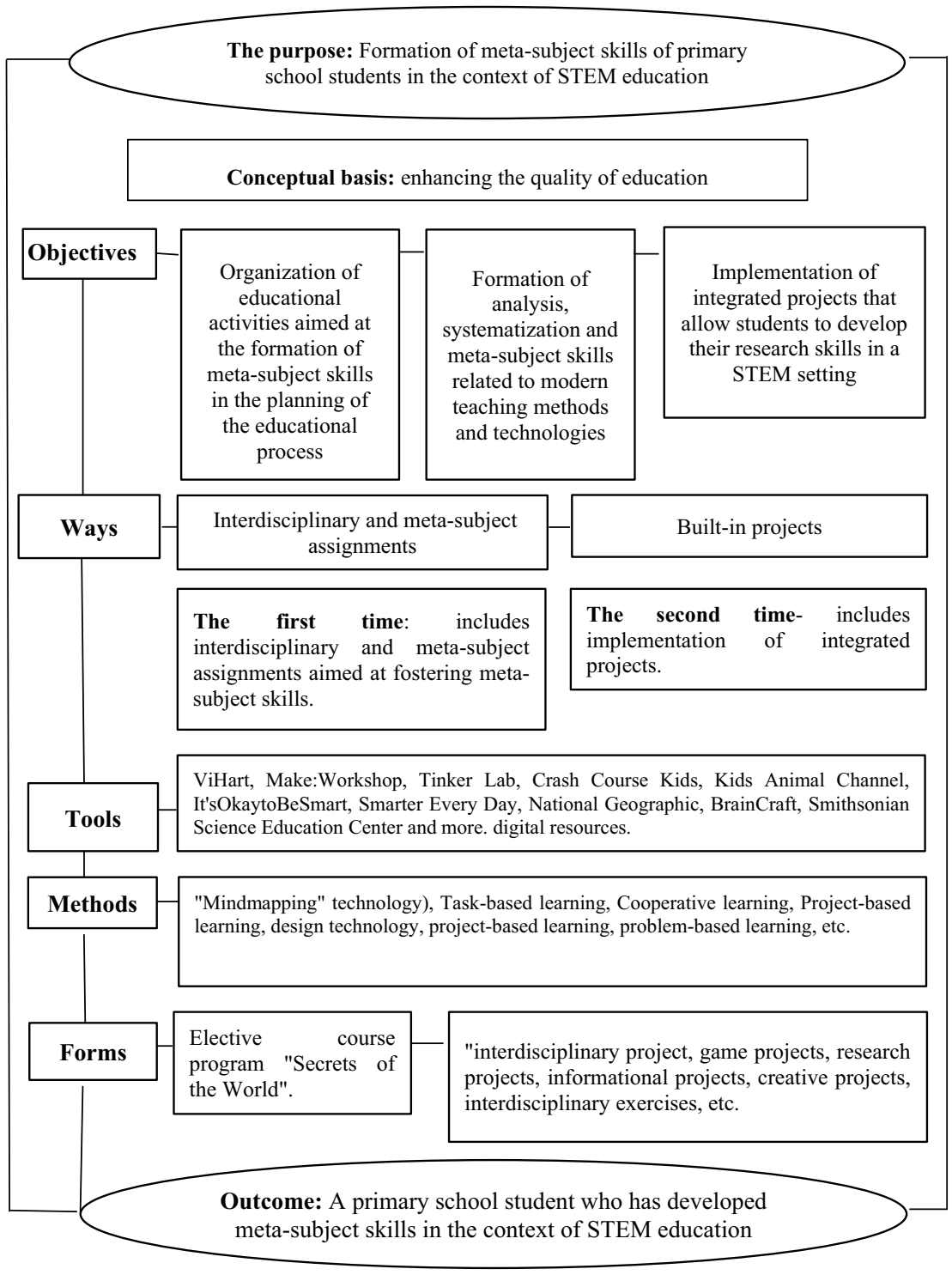

FIGURE 1
Methodological system of the formation of meta-subject knowledge in primary school students in the context of STEM education.

4.5 The elective course content

In order to implement the work in this direction, we developed an elective course titled "Secrets of the World" for primary school students (Table 1). This course aims to cultivate meta-subject skills among primary school students in the context of STEM education. The content and structure of the program are designed in accordance with the educational objectives, highlighting interdisciplinary linkage through common topics, and considering the achievement of the student's capabilities and cognitive needs with individual, paired, group, and sources, characterized by the presence of types of work.

TABLE 1 Thematic and calendar plan of the optional course "Secrets of the World."

No.	Topic	Product of knowledge	Hour
1	2	3	4
	Introductory lesson	Introduction of the purpose and content of the course	–
PART I. SURROUNDING WORLD (9 h)			
Common topic: About myself			
1	I am a researcher	Determines the conditions and personality traits of the researcher necessary for the study of the phenomena, processes, and objects of the surrounding world	1
2	A trip to the world of plants	Describes and studies the growth possibilities of plants, seasonal changes	2
3	Project: "I am a botanist"	Knows how to take care of a plant, compare ways of adaptation, analyze and process information	3
Common theme: My family and friends			
4	3D model of fish	Describes ways of adaptation of animals to their habitat	1
5	Reserve	Collects and analyzes information from sources	2
PART II. ELEMENTS OF PHYSICS (7 h)			
Common theme: My school			
1	Grace and beauty	Understands the importance of maintaining a healthy body shape	2
2	Hygiene science	Defines the role of personal hygiene in healthcare	1
Common theme: My native land			
1	Atmosphere	Knows the importance of air for the planet	1
2	I create the world	Develops the basics of creative imagination, shows non-standard, original, innovation	1
3	Properties of water	Understands the meaning of physical laws; determines the relationship between subjects; can observe, observe, and analyze changes in physical laws	2
PART III: WORLD AND SPACE (11 h)			
Common theme: A healthy soul means a healthy body			
1	Natural resources	Determines the use of natural resources	1
2	I am an inventor	Develops interest in inventing new things, innovation, solving real problems, knows how to use different materials	1
Common theme: Traditions and oral literature			
1	Journey to the land of astronomy	Gets acquainted with the elements of astronomy	2
2	Can we stop time?	Separates basic time units	2
3	Space world	Understands the features of distance and time in space	2
4	Resilient power	Studies the forces that create movement, illustrates information using a simple scheme, diagram, graph	1
5	Rocket launch	Uses interdisciplinary knowledge, uses elements of physics, learns to make predictions, draws conclusions using deductive, inductive, and analogical conclusions	1
6	How do we measure mass?	Knows measuring tools and can convert time measurements, evaluates validity and correctness of information obtained during research	1
PART IV. ENGINEERING AND STEM TECHNOLOGY (7 h)			
Environment, Travel			
1	Young scientist	Arousing interest in scientific and technical activities, developing the ability to set and solve tasks	3
2	I am an engineer	An understanding of the physical space in which scientists, engineers, and inventors work develops	3
3	The secret of the magnet	Conducts monitoring according to the plan and draws conclusions	1
Total:			34

This course is intended to introduce new concepts and understandings given in the textbook within the framework of interdisciplinary topics. The feature of this program is to expand the worldview of primary school students within the framework of common interdisciplinary concepts to foster their thinking skills through the utilization of methods such as analysis, compilation, comparison, and integrated projects.

The purpose of the course is the formation of meta-subject skills of primary school students in the context of STEM education. The objectives of the course comprise implementation of science,

technology, engineering, and mathematics concepts in interdisciplinary communication; cultivation of interdisciplinary, educational, research, and other skills; and implementation of integrated projects. The expected outcomes encompass establishing integration between common topics, utilizing interdisciplinary communication; applying PhET (teaching and learning physics, chemistry, math, and other sciences) stimulations to STEM education; and designing models of products through the application of scientific and technical knowledge. The topics proposed in the course allow students to master integrated knowledge through interdisciplinary communication in the context of STEM education, to connect theoretical knowledge with real-life experience and apply it in different contexts, and to work in a cooperative relationship in solving problems as a team.

5 Conclusion

The article presents a methodological system aimed at forming meta-subject skills in primary school students in the context of STEM education. This system encompasses various components such as purpose, content, teaching methods and tools, forms, and expected outcomes. The proposed methodological system is characterized as an innovative methodology, enabling primary school students to develop a new level of meta-subject skills. The utilization of this methodological system in the process of primary education empowers students to develop personalities to foster practical skills, to implement creative ideas and make new decisions independently, to think critically, to develop project products using available materials, to discover new things in the world around us, and to invent completely new things.

The analysis of mathematics, natural science, and digital literacy textbooks allows to identify the possibilities of the formation of meta-subject skills in primary school students in the context of STEM education. This comprises (i) organization and implementation of educational activities; (ii) development of creative thinking; and (iii) the possibilities focused on the promotion of logical actions. The elective course program called "Secrets of the World" contributed to the implementation of these possibilities. In this regard, in order to determine the effectiveness of the proposed elective course program "Secrets of the World," we intend to test it in a primary education environment in the future.

6 Suggestions for research

We suggest that it would be appropriate to implement our research program in primary education. Future research should aim at helping primary school students learn engineering and technology, math, and science. For instance, further study of teaching in the context of STEM education would enable the evaluation of the effectiveness of the formation of meta-subject skills in primary school students. Moreover, this investigation responds to questions concerning students' capability to apply scientific knowledge in practice.

Therefore, in order to further expand and continue the findings obtained in this research study, we propose the following steps:

- assessment of interdisciplinary knowledge, based on the cultivation of meta-subject skills in the context of STEM education;
- assessment of the long-term impact of the proposed methodological system in enhancing the scientific knowledge of primary school students;
- assessment of the impact of the proposed methodological system on the harmonious development of primary school students and its practical importance in the learning process;
- evaluation of the effectiveness of the content of the proposed elective course "Secrets of the World" and methods of implementation through the feedback of students and teachers in the educational process of primary school;
- dissemination of the results of scientific research at scientific conferences, scientific projects, and methodical seminars.

Finally, we recommend constantly enhancing the methods, forms, and tools presented in this methodological system. Based on these recommendations, this investigation facilitates further refinement of the educational programs and enhancement of the quality of teaching in the context of STEM education.

It is not possible to assume that all challenges have been fully resolved in our research study. Therefore, the content of the collected theoretical and practical materials requires constant improvement and clarification.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

AY: Writing – review & editing, Investigation, Writing – original draft. AZ: Resources, Writing – original draft. AK: Writing – original draft, Validation. BZ: Writing – original draft, Formal Analysis. SA: Writing – review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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