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METHODOLOGY FOR FORMING SUBJECT KNOWLEDGE OF PRIMARY SCHOOL STUDENTS BASED ON STEM EDUCATION

Annotation

The conducted scientific research provides a methodology for forming subject knowledge in primary school students based on STEM education. This approach to STEM education focuses on developing key competencies such as research, information-seeking, experimentation, project management, and communication skills. The implementation system and structural model, which form the foundation of our research methodology, have been examined in detail in a broader study. This study focuses solely on the methodology of knowledge formation.

The goal of this method is to help primary school students learn better by using STEM education. It focuses on creating lessons, teaching methods, and strategies that allow students to use STEM knowledge in everyday life. To achieve this, the study will explore how STEM education helps develop important skills. A special test, including a questionnaire and tasks, will check how well students gain knowledge and skills. These skills will help students identify real-world problems, understand the importance of nature and society, and make independent decisions about STEM-related issues. STEM education provides opportunities for the development of subject-specific skills through research, exploration, experimentation, project work, and decision-making in linguistic and communicative contexts.

The study uses analysis, comparison, and teaching experiments to assess how well primary school students learn through STEM education. Based on the results, clear conclusions and recommendations will be made. These will help guide future research and further experiments.

Keywords: primary school student, STEM education, subject skills, STEM lesson, innovative approach, STEM class, interdisciplinary approach.

Introduction. In the special era of scientific and technological progress, when humanity begins mass practical realization of its accumulated treasury of science and education in the XXI century, the need for STEM education is growing daily. In the 21st century, it has become evident that the theoretical advancement of science alone is insufficient to support a nation's development. Consequently, the need to cultivate skills that enable individuals to apply knowledge as a practical tool from an early age has become increasingly critical over time.

Developing subject-specific skills through STEM education in primary grades establishes a foundation for integrating and expanding STEM education within Kazakhstan’s education system. This contributes to modernization and a more cohesive approach to science and practice. After all, STEM education is an opportunity to introduce a new system of forms and teaching methods in the primary education system, to form the content of education necessary for obtaining mathematics and engineering education for elementary school students.

The STEM educational process will be aimed at supporting the technical skills of primary school students and, scientific and technical creativity of students and will become a support for the formation of a full-fledged personality of students. It is known that fundamental training is necessary for the personality of junior schoolchildren to develop and evolve in engineering and technology.

In this regard, the actual problem is the formation of students' subject skills on the basis of the STEM education system with the use of natural, mathematical, computer, and humanitarian disciplines, if possible all disciplines in one direction.

STEM education is a science, technology, engineering, and mathematics program that is interdisciplinary and practical approach. Instead of teaching the four disciplines individually, STEM combines them into one model [1].

Many developed countries, such as the USA, China, Finland, Australia, UK, Israel, Korea, and Singapore, have government programs in the application of STEM education. However, the opinions

of modern researchers regarding STEM technology are ambiguous, and in educational systems around the world, this method is represented by different variants [2], [3]. These differences are influenced not only by the age-specific characteristics of learners but also by the unique educational policies and priorities of each country. In Kazakhstan, the adoption of STEM education is gaining momentum as part of broader efforts to modernize the national curriculum and enhance students' competencies in science, technology, engineering, and mathematics. However, its implementation faces challenges related to infrastructure, teacher training, and the integration of interdisciplinary approaches within existing pedagogical frameworks.

In recent years, many countries around the world have focused on improving the quality of STEM education. This approach allows us to support economic progress, innovate, and form the basis of True Prosperity in modern society [4].

In fact, compared to other fields, science, technology, and engineering are rapidly developing and making progress. According to the demand in each industry in the 21st century, creativity, critical thinking, collaboration, and communication skills are also developing together. For people with knowledge and skills in science, technology, engineering, and mathematics, additional regulations on new educational programs were also required [5].

Besides, STEM-education aims to explore and develop the four fields in an integrated way. Through this approach, various skills are developed, including: understanding of subject matter, creativity ability, independent analysis, teamwork, independent thinking, communication, and digital skills [6], [7].

Research indicates that STEM education emphasizes a project-based learning approach, which highlights the importance of applying knowledge in real-world contexts. This approach integrates theoretical and practical knowledge with technological applications, fostering a deeper understanding and hands-on problem-solving skills [8], [9].

Rodger W. Bybee, in his analysis of the STEM education program, highlights several key findings that contribute to its effectiveness. He emphasizes the importance of adopting more rigorous mathematics and science standards, along with improved assessment methods, to ensure higher educational outcomes. Additionally, the recruitment and retention of highly qualified teachers play a crucial role in enhancing the quality of STEM instruction. Bybee also underscores the need for comprehensive student preparation through well-trained educators who can effectively deliver STEM content. Furthermore, he advocates for the integration of informal learning opportunities to extend mathematics and science education beyond the traditional school curriculum, fostering a more engaging and applied learning experience. Continuous improvements in STEM education through curriculum development and pedagogical innovations are also essential for maintaining its relevance and effectiveness. Finally, he highlights the necessity of establishing clearer educational objectives at the post-secondary level to ensure a more seamless transition for students pursuing STEM-related fields [10].

It is clear from the research data that based on STEM education the possibility of formation of subject skills in junior schoolchildren is high, and the necessity of its realization at the primary level is obvious. In this regard, the purpose of our study is to develop an effective methodology for forming subject competencies of primary school students based on STEM education and to justify its integration into the educational process. It shows that the purpose and objectives of our study have a great contribution to the desired result.

Methods and materials. The study analyzed, compared, and organized information on how STEM education helps young students develop essential skills. Each piece of information was carefully structured and used as the foundation for the first stage of the teaching experiment. During the pedagogical experiment, diagnostic methods such as pedagogical observation, surveys, and task completion were used to assess the level of subject knowledge based on STEM education. The experimental study was conducted in three stages: the diagnostic stage, the formative stage, and the control stage.

The experiment was carried out at «Zhas Daryn» Primary School and «N1 Talant» Primary School in the city of Shymkent. In this study, during the diagnostic stage of the experiment, the

authors conducted a survey titled «Do you know how to apply your knowledge in real life?». The content of the survey was based on the results of theoretical research. It was designed in accordance with ethical requirements, and participants were asked to select and mark one of the provided answer choices for the following questions.

During the diagnostic experiment, a closed-ended questionnaire was used to assess STEM education's impact on subject-specific skills in elementary students. The students had to choose from predefined answers: «Yes», «No», «I don't know» and «I will think».

For the confirmatory experiment, 36 students from an experimental class (EC-36) and 38 students from a control class (CC-38) were selected from 3rd and 4th grades. Both groups completed a specially designed set of tasks, and the results were analyzed to determine their level of understanding.

The obtained results were described based on percentage distribution to represent the average indicator. The t-test (Student's t-test) was used to verify the reliability of the conducted survey. A specially designed set of tasks was carried out in both groups, and the results were processed and analyzed to formulate key conclusions based on the identified level.

This study focuses on primary school students, specifically those in grades 3 and 4, which may limit the generalizability of the findings to other age groups. Future research could examine the implementation of the proposed STEM methodologies across different educational levels to assess their broader applicability. The experimental lessons were conducted within specific educational settings, where variables such as teachers' qualifications, school infrastructure, and access to resources may have influenced their effectiveness. Consequently, the results may differ in institutions with varying pedagogical approaches and material conditions.

Furthermore, the study underscores the potential benefits of STEM lessons in developing critical thinking, scientific inquiry, and problem-solving skills. However, the successful implementation of STEM education largely depends on the expertise of teachers and their ability to effectively employ interdisciplinary and project-based teaching strategies. Additionally, this study does not account for individual differences among students, such as learning styles, motivation levels, and prior knowledge, which may impact their engagement and academic performance in STEM lessons. Future research should explore personalized instructional approaches that accommodate diverse student needs and enhance learning outcomes.

Results and discussion. As noted by G.H. Valeev in his research, the questionnaire for students in grades 3–4 originally contained four questions [11]. Given the integrative nature of STEM education, an additional question about robotics was added. The content of the questionnaire consists of 5 questions:

The first question aimed to assess how students relate mathematics to natural science and world studies.1. Do you think it is necessary to make independent reports about nature and life situations in «mathematics» lessons? Answers: A. «Yes»; B. «No»; C. «I don't know»; D. «I will think about it».

Through the second question of the questionnaire, it is necessary to determine the pupil's ability to independently investigate, search, design, and experiment. Therefore, the content of the question is designed as follows: 2. Do you want to experiment independently in the lessons" worldview 'and' science"? Answers: A. A. «Yes»; B. «No»; C. «I don't know»; D. «I will think about it».

The third question was asked to find out how well elementary school students can construct, including robotics: 3. Do you think it is appropriate to start learning how to construct robots at the age of 3? Answers: A. A. «Yes»; B. «No»; C. «I don't know»; D. «I will think about it».

It is known that most elementary school students are more or less familiar with the LEGO assembly method. To determine the extent to which a student realizes that these abilities are important to the learning and cognitive process: 4. Do you believe that assembling LEGO in the classroom can help you become more skillful, knowledgeable, and adaptable in life? Answers: A. «Yes»; B. «No»; C. «I don't know»; D. «I will think about it».

Then, to find out the opinion of elementary school pupils about the integration of knowledge in humanities subjects along with mathematics, and natural sciences, the following question was asked: 5. Do you want to write an artistic talk about nature, phenomena, and changes of the Earth in the

future at the lessons of “Kazakh language” and “literary reading”? Answers: A. A. «Yes»; B. «No»; C. «I don't know»; D. «I will think about it».

Questionnaire Results. 74 students of 3-4 grades (E-36, B-38) received for the pedagogical experiment participated in the questionnaire. Of them, For the first question, 56 students (75,6%) responded 'I don't know,' indicating uncertainty about preparing independent reports on nature during math lessons. For the second question, only 7 out of 74 students expressed a willingness to conduct independent experiments. And the number of answers “no” (30) and “don't know” (29) prevailed. In response to the third question, the majority of students were hesitant about starting robotics at the age of 3, with 32 students selecting 'No' and 30 choosing 'I don't know. The fourth question examined whether students saw LEGO assembly as a valuable skill. However, 35 students responded 'No,' and 30 were unsure. For the fifth question, it was necessary to determine the stages of teaching the integration of Kazakh language and literature with science. It was found that the majority of pupils also answered “no” (28) and “don't know” (32) to this question. The survey results are more detailed in Figure 1.

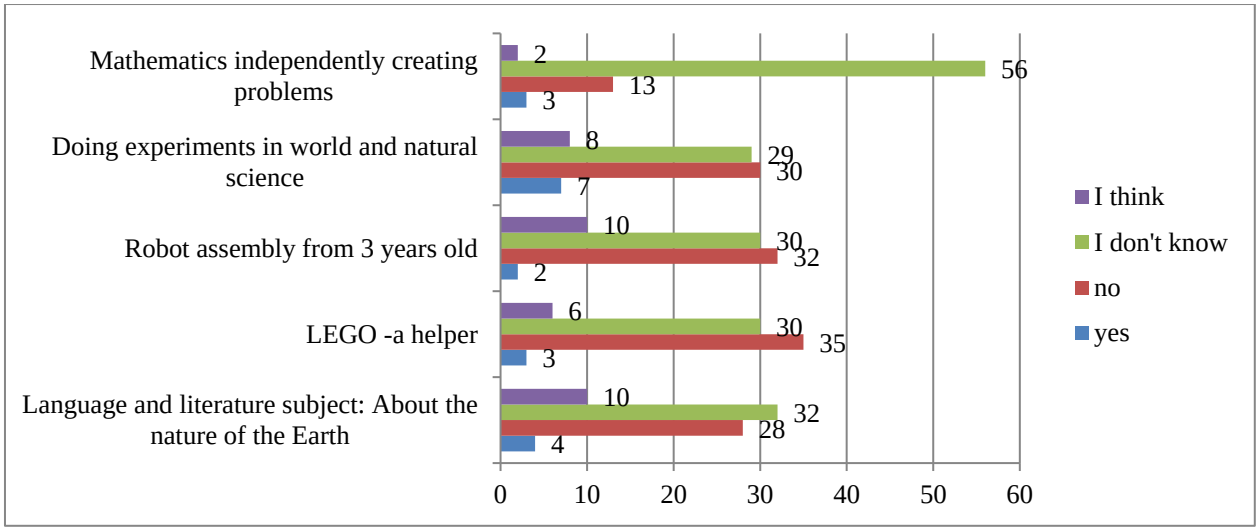

Figure 1. Results of questionnaire responses

Source: compiled by the author

As a result of the questionnaire, the current form and level of training of elementary school students in STEM education was determined, and the direction in which the additional questions to the materials used in the upcoming educational-formative stage should be included and incorporated was established.

In addition, it was necessary to perform individual tasks designed to determine the level of students' subject skills according to the determining level of our study. For this purpose, cut tasks were developed for studying, searching, designing, and practicing, Language and Communication skills, defined as components of subject skills. The tasks were conducted separately for the experimental group and separately for the control group.

By completing five STEM-based tasks, students demonstrated their initial abilities in research, problem-solving, experimentation, project work, language, and communication skills. Most students recognized the nature of the tasks but struggled to understand their connection to the textbook and specific topics. The teacher conducted explanatory work with the pupils and asked them to actively participate in performing the tasks. The results of cutting tasks are presented in the table below. The task structure is provided in Table 1. The results of task performance in the control and experimental groups were more clearly illustrated in Figures 2, 3, and 4.

Table 1. Results of Task Performance in the Control and Experimental Groups

	Criteria	**Research task**	**Inquiry task**	**Project task**	**Practical task**	**Linguistic-communicative task**
EXPERIMENT GROUP 36	*Task completed*	2 5,5 %	3 8,3%	4 11,11 %	2 5,5 %	4 11,11%
	Task was partially completed	13 36,1%	15 41,6%	17 47,2%	20 55,5%	23 63,8%
	Task not completed	21 58,3%	18 50%	16 44,4%	14 38,8%	9 25%
	Criteria	**Research task**	**Inquiry task**	**Project design task**	**Practical task**	**Linguistic-communicative task**
CONTROL GROUP 38	*Task completed*	2 5,2%	4 10,5%	5 13,15%	2 5,2%	4 10,5%
	Task was partially completed	12 31,5%	15 39,4%	20 52,6%	25 65,7%	22 55,2%
	Task not completed	24 63,15%	19 50%	13 34,2%	11 28,9%	12 28,9%

Source: compiled by the author

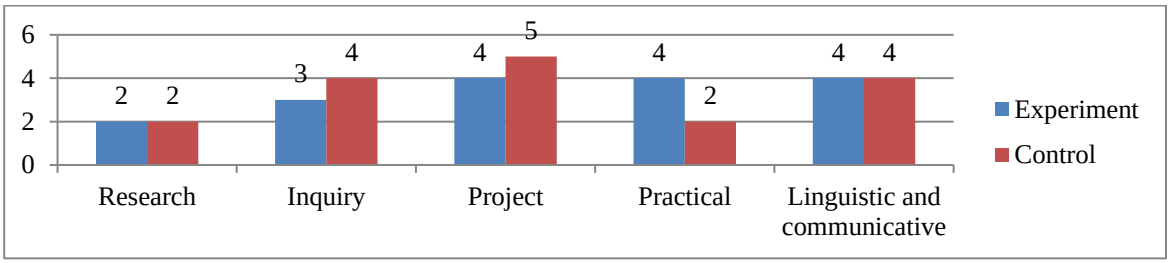

Figure 2. Number of those who completed the cutting tasks in full

Source: compiled by the author

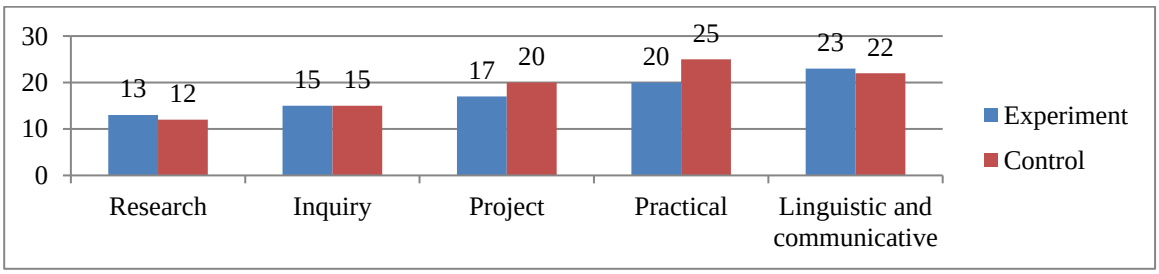

Figure 3. Number of those who partially completed the cutting tasks

Source: compiled by the author

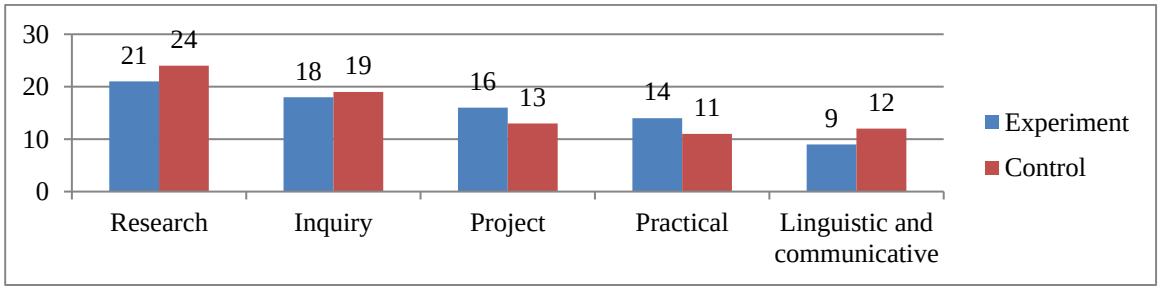

Figure 4. Number of those who did not complete the cutting tasks

Source: compiled by the author

The results of cutting tasks, which have their place in the diagnostics of the formation of subject skills of junior schoolchildren on the basis of STEM education, helped to identify the problems necessary for the upcoming educational stage.

The results showed that STEM education can help develop subject-specific skills in primary school students. However, this was only effective when a special program was designed and implemented, including integrative STEM lessons and a structured system of STEM tasks.

The next step is to analyze teaching aids and lessons needed for the learning process, based on the diagnostic results. The theoretical materials used in the STEM curriculum cover key topics in mathematics, science, world studies, information literacy, Kazakh language, and literary reading for 3rd-4th grades. The proposed exercises and tasks are specifically designed to develop research, problem-solving, practical, language, and communication skills. This system of exercises and tasks consists of three different levels:

- Integrated exercises and STEM tasks;
- Problem exercises and STEM tasks;
- Designing STEM exercises and tasks.

The development of this system of teaching and learning aids was carried out according to the following principles:

- First of all, according to the principle of systematicity, i.e. the formation of subject skills in junior schoolchildren based on STEM education was considered as a system;
- Secondly, based on STEM education, which was not imposed on one subject, but higher than the traditional one, because not only on one subject, but also based on integration of several / two subjects, the ability of junior schoolchildren to find new content in the teaching material was put in an important place, thus finding their way between knowledge and life experience;
- Thirdly, the cooperation of teacher and student was at the center of attention, as the creation of a new innovative system of STEM exercises and tasks is a complex work of new quality for the teacher, and the formation of elementary school students to perform innovative STEM tasks is a new level of complexity, as the teacher and student must work together with the principle of collaborative pedagogy.

The methodology of the formation of subject skills of elementary school students based on STEM education is a three-dimensional methodological system. We decided to name the layers that make up this three-dimensionality as follows:

1) Methodology of special STEM classes;
2) Methodology of interdisciplinary STEM lessons;
3) Methodology of face-to-face STEM classes.

Each of them has its own “themes” depending on the didactic goal, and each of them should be focused on the formation of a certain subject competence and use individual, paired, and collective forms of work. The logic of application of the proposed model is presented in the figure in the form of a model of “methodology of three-dimensional STEM education” Figure 5.

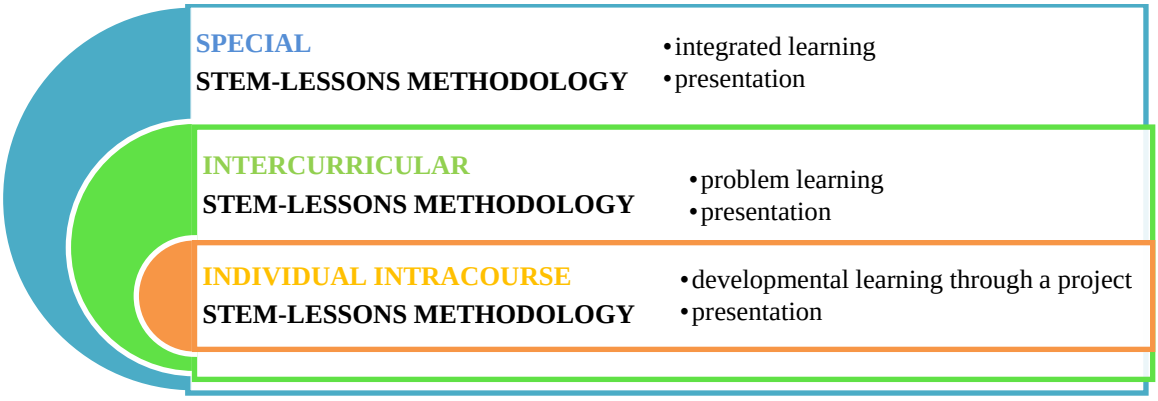

Figure 5. Three-dimensional STEM education methodology

Source: compiled by the author

The «Special STEM Lessons» for 3rd and 4th grades are considered separately for conducting general STEM-themed lessons. These lessons are organized based on integrative teaching technology. In these sessions, students are shown the real-life applications of scientific and technical knowledge through practical exercises. The lessons foster students' critical and scientific thinking, increase their confidence in their knowledge, and develop their adaptability to innovative changes in life. Although such special lessons may not be conducted frequently, their integrative nature must be clearly recognizable to students. This is essential for the development of integrative knowledge and experience as subject-specific competencies.

The «Interdisciplinary STEM Lessons» involve teaching STEM topics that are common to two or three subjects. These lessons adopt a problem-based approach, encouraging students' inquiry and exploration of interdisciplinary issues. The distinctive feature of interdisciplinary lessons is that they provide primary school students with the opportunity to consider the common challenges of STEM subjects within a unified framework and develop holistic solutions. In problem-based lessons, students' thinking skills are enhanced from critical, theoretical, and practical perspectives, helping them acquire the knowledge and competencies necessary for technological advancements. These lessons support the development of students' research and inquiry skills, strengthening their engineering thinking and practical abilities.

The «Intra-Subject STEM Lessons» focus on exploring common issues across multiple topics within a single subject, emphasizing the development of students' subject-specific competencies. These lessons are particularly effective for project-based learning. Projects can be completed individually, in groups, or as a collective effort. Through such activities, primary school students develop inquiry, experimentation, and creative thinking skills. Independent learning and project work allow students to recognize the real-world applications of their knowledge and establish meaningful connections between theoretical understanding and practical experience.

Integrative teaching methods were employed in the organization and delivery of STEM lessons. These included, but were not limited to:

- One STEM lesson can be taught by one fully trained teacher or two teachers (technology, personal computer teacher);
- When designing and delivering a STEM lesson, it is determined in advance whether it will be a theoretical, practical, or laboratory lesson;
- In a STEM class, you can do projects in one lesson or continue for several lessons;
- STEM projects can be pre-studied by the student independently, given search assignments, and listened to in class only as a systematic presentation and a good report.

STEM lessons, taken together, can have the following didactic advantages:

- Improves the quality of students' knowledge;
- Prove the didactic principle that movement from easy to hard;
- Creates opportunities for students to use authoring computer games (e.g., Scratch program);
- Research creative skills are constantly formed in each lesson.

The experimental curriculum, which implements the methodology of the model of formation of subject skills of junior schoolchildren based on STEM education, is built as follows.

The experimental curriculum for the 3rd grade is designed for 20 hours. Of these, 4 hours were allocated for special, 6 hours for interdisciplinary, and 10 hours for separate intra-subject topics. The type of subject skills, the formation of which is given priority about each topic, is outlined.

The experimental curriculum for 4th grade also showed three-dimensional STEM classes for 20 hours. New topics for special STEM lessons were added, while the rest of the topics were taken from the 4th-grade textbooks.

The content of education reflected in the experimental curriculum for grades 3-4 solves many educational, didactic tasks. Namely:

- elementary school students learn to conduct various experiments with their environment;
- using the acquired knowledge in mathematics about various geometric figures, and measuring time and space, it is possible to make sure that in all spheres of life, there is only measurability, consistency, accountability;
- learning to construct products by looking at different angles faces, and dimensions.

Conclusion. This research defines STEM-based education as an innovative approach to modern schooling. The main feature of STEM education is its interdisciplinary approach, i.e. integrated teaching of disciplines of certain processes, and phenomena within the framework of certain topics, and problems. Based on the STEM education of elementary school students many didactic tasks are solved, the process that can form subject knowledge necessary for the application of theoretical knowledge in life practice based on common topics of subjects of natural science, worldview, mathematics, digital, computer literacy, robotics, Kazakh language.

Based on the analysis and comparison of data from the formative experiment, a special methodology was introduced in the experimental group. This methodology aimed to develop subject-specific skills in elementary school students through STEM education.

After implementing this approach, the lessons conducted in the experimental group were classified as STEM classes, specifically designed to enhance subject-specific skills. The study focused on the methodology for skill formation, relying on the results of the ascertaining experiment.

We believe that the findings from the formative stage can serve as a foundation for future research, which extends beyond the scope of this study.

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STEM БІЛІМ БЕРУ НЕГІЗІНДЕ БАСТАУЫШ СЫНЫП ОҚУШЫЛАРЫНЫҢ ПӘНДІК БІЛІГІН ҚАЛЫПТАСТЫРУ ӘДІСТЕМЕСІ

Аңдатпа

Жүргізілген ғылыми зерттеуде STEM білім беру негізінде бастауыш сынып оқушыларының пәндік білігін қалыптастыру әдістемесі қарастырылған. Оның барысында жалпы STEM білім беру жүйесінің нақты зерттеу білігін, ізденім білігін, тәжірибе жасау білігін, жоба жүргізу білігін, тілдік-коммуникативтік білігін қалыптастыруға бағытталған. Зерттеуімізге сай әдістемеге негіз болатын модельдің жүзеге асырылу жүйесі мен құрылымы үлкен зерттеу барысында көрсетілген. Аталған зерттеу кезінде тек қалыптастыру әдістемесін ұсыну жоспарланған. Осы орайда, STEM білім беру негізінде бастауыш сынып оқушыларының пәндік білігін қалыптастыру әдістемесінің мақсаты – бастауыш сынып оқушыларын STEM білім беру барысында алған білімдерін өмірдегі қажеттіліктеріне сай қолдану біліктерін қалыптастыратын оқу мазмұнын, әдістер мен амал-тәсілдердің жүйесін жасақтау. Бұл мақсат аясында, зерттеу барысында келесі міндеттер өз шешімін табады: STEM білім берудің қажетті дағдыларды дамытудағы мүмкіндіктеріне талдау жүргізіледі, анықтау эксперименті негізінде арнайы сауалнама мен тапсырмалар арқылы күнделікті шынайы өмірдегі мәселелерді айқын танып, қоршаған табиғи орта мен әлеуметтік ортаның маңызды орнын түсінуіне, STEM мәселелері бойынша өзіндік шешімдер жасауына тірек болатын білім мазмұны мен пәндік біліктерін қалыптастыру мүмкіндігі анықталады; STEM білім беруде зерттеу, ізденім, тәжірибе, жобалау, тілдік-коммуникативтік шешім түріндегі пәндік біліктерін қалыптастырудың мүмкіндіктері көрсетіледі. Зерттеу кезінде талдау, саралау, салыстыру, педагогикалық эксперименттің алдында бастауыш сынып оқушыларының STEM білім алуы негізінде пәндік білігінің қаншалықты қалыптасқандығын анықтау әдістері пайдаланылды. Алынған теориялық және анықтау эксперименті бойынша нақты тұжырымдар мен болашақ қалыптастыру мен бақылау экспериментіне негіз болатын ұсынымдар берілді.

Түйінді сөздер: бастауыш сынып оқушысы, STEM – білім беру, пәндік білігі, STEM – сабақ, инновациялық тәсілдеме, STEM-сынып, пәнаралық тәсіл.

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МЕТОДИКА ФОРМИРОВАНИЯ ПРЕДМЕТНЫХ ЗНАНИЙ УЧАЩИХСЯ НАЧАЛЬНЫХ КЛАССОВ НА ОСНОВЕ STEM-ОБРАЗОВАНИЯ

Аннотация

Проведенное научное исследование представляет методику формирования предметных знаний у учащихся начальной школы на основе STEM-образования. В ходе этого процесса общая система образования STEM направлена на развитие конкретных исследовательских навыков, навыков поиска информации, экспериментальных навыков, навыков управления проектами, а также языковых и коммуникативных навыков. Система реализации и структура модели, составляющей основу методологии данного исследования, рассматривается более подробно в исследовательской деятельности. В настоящем исследовании рассматривается только методика формирования предметных знаний.

В связи с этим целью методики формирования предметных знаний учащихся начальной школы на основе STEM-образования является разработка системы образовательного содержания, методов и подходов, которые позволят сформировать у учащихся начальной школы умения применять полученные в ходе STEM-образования знания для удовлетворения потребностей своей жизни. В рамках поставленной цели в ходе исследования решены следующие задачи: проведен анализ возможностей STEM-образования в формировании необходимых навыков и на основе констатирующего эксперимента с использованием специальной анкеты и заданий определена возможность формирования содержания знаний и предметных навыков, которые поддерживают способность четко осознавать реальные проблемы повседневной жизни, понимать важную роль окружения и социальной среды, принимать самостоятельные решения по вопросам STEM. STEM-образование развивает предметные навыки, такие как исследование, изучение, экспериментирование, проектирование, а также принятие языковых и коммуникативных решений. В исследовании использовались методы анализа, дифференциации, сравнения и педагогического эксперимента для определения степени формирования предметных знаний учащихся начальной школы на основе STEM-образования. На основе полученных теоретических и экспериментальных данных в ходе исследования были сделаны конкретные выводы и рекомендации, которые послужат основой для будущих исследований, формирующего и контрольного эксперимента.

Ключевые слова: ученик начальных классов, STEM – образование, предметные навыки, STEM – урок, инновационный подход, STEM-класс, междисциплинарный подход.