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The implications of stem training on the development of younger students' research abilities: An exploration of practices

Maral Baimakhanbetova[1]
Asel Stambekova[2]
Aysegul Bayraktar[3]
Sveta Sikhimbayeva[4]
Ulbala Ibragimova[5]

(Corresponding Author)

[1,2]*Abai Kazakh National Pedagogical University, Almaty, Kazakhstan.*
[1]*Email: maral_abaikyzy@mail.ru*
[2]*Email: stambekova_81@mail.ru*
[3]*Ankara University, Ankara, Turkey.*
[3]*Email: aysegulfsu@yahoo.com*
[4,5]*M. Auezov South Kazakhstan University, Shymkent, Kazakhstan.*
[4]*Email: sveta060863@mail.ru*
[5]*Email: ulbala83@mail.ru*

Abstract

The purpose of this study is to investigate the impact of practice-based STEM instruction on the development of younger students' research abilities and the improvement of their analytical skills. Both quantitative and qualitative methods were used in this study. There were 72 participants in the 4th grade from the elementary school "Zhas Daryn-2" in Shymkent (South Kazakhstan). According to research findings, successful implementation of STEM practices requires an educational program that includes preparation, implementation and evaluation phases. Additionally, it was found that a STEM-focused educational program helps younger students increase their research abilities more effectively. The study's findings also show that STEM projects and research work help to identify, explore and solve problems through research activities leading to enhanced research and analytical skills. Despite this, STEM students often have difficulty staying focused on acquiring new knowledge and abilities, keeping up with recent technological advancements and comprehending the different difficulties that surround their significance. According to the research findings, teachers in primary school can use the outcomes of practice-based STEM training to support younger students' research abilities' manifestation and the improvement of their analytical skills.

Keywords: Development, Implications, Primary school students, Research abilities, STEM training.

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Contents

Contribution of this paper to the literature
This study analyzes whether the author's practice-based STEM training using technologies with STEM training methods that were not covered in previous studies contributes to the growth of younger students' research abilities and enhances their analytical skills which removes barriers to STEM learning in elementary schools.

1. Introduction

STEM education is very important in many countries. Teachers create an environment that encourages the manifestation and development of younger children's skills by incorporating STEM (science, technology, engineering and mathematics) (Martín-Páez, Aguilera, Perales-Palacios, & Vílchez-González, 2019; Wannapiroon & Pimdee, 2022; Wilson, 2021). The integrated method is ideal for STEM education since it encourages student collaboration and project work as well as the use of contemporary technology, the fusion of several sciences and disciplines, creativity and the support of innovative teachers (Shen, Roccosalvo, Zhang, Tian, & Yi, 2023; Tunc & Bagceci, 2021). STEM education is a digital learning platform based on science and techniques similar to the modern educational innovation process. (Parks, Hendryx, & Taylor, 2021). STEM education can be used at all levels of middle school education to ensure that the conceptual ideas of competence- and activity-based methods are effectively implemented (Hassan, Abdullah, Ismail, Suhud, & Hamzah, 2019). The STEM approach is an extension and modification of the integrated format in the context of the educational system's engineering and technological trends, i.e., the innovative component of the new paradigm for the development of this area (Dawson, 2019). The implementation of innovative projects and their effective management demonstrate that STEM education is the foundation for a qualitative transformation of the educational process (Barroso, 2020).

The technical creativity of young children has decreased in our country as a result of the system of circles for young technicians, modellers and designers dissolving. On the other hand, there are numerous regional and national projects in developed nations to encourage children to pursue scientific and technical creativity and to raise its attractiveness and status. Children in elementary school nowadays have access to a technical creative programme that takes into consideration the demands of the time. The construction of parks specializing in technology for children and adolescents has been supported. However, the problem's classification does not specify how technical inventiveness should develop in detail. More advanced competencies demand independence and responsibility in order to complete tasks that are beyond the scope of the traditional learning model. This question can only be answered by STEM technologies. Some schools are implementing STEM characterized mainly by the study of the initial foundations of "robotics," laboratory work in design and research methods. Since 2014, the annual Republic Robot Olympiad has been held among students in general education schools.

However, there is no single approach to implement the concept of STEM learning in Kazakhstan. The scientific basis for integrating educational content in disciplines such as natural and mathematical cycles, technology, robotics and computer science in the context of STEM approach requirements has not been studied. The natural sciences (physics, chemistry, biology, etc.) are introduced as a school subject in Western countries where the corresponding subject is commonly referred to as "science". In post-Soviet countries, including the Republic of Kazakhstan, natural sciences are taught as separate school subjects.

The main disadvantage of this approach in our country is its disregard for students' academic interests, emotional discomfiture, logically formalized and mechanical instructions.

1.1. Purpose of the Study

The use of STEM in our country is very important nowadays. The use of STEM strategies in teaching at all academic levels is the latest challenge to the classical education system.

Unfortunately, practice shows that there are barriers to STEM training in primary schools in our country. The first major issue with integrating STEM is that completely different technology needs to be introduced into the education system. Adopting STEM will necessitate a significant adjustment in curriculum due to the present classical education structure. The second focus is on teachers and their professional thinking and preparation. Teachers who are unprepared for STEM teaching or who are unwilling to quickly learn concepts or content may not be ready or able to support an integrated STEM approach to teaching.

Modern educational emphasis is mostly on passing exams in the form of tests. Students are “trained” to pass tests for a certain number of points by memorizing a great deal of theoretical data and facts in various disciplines. Many students do not see the immediate benefit of studying mathematics and do not understand the skills and knowledge they will gain (Nurgaliyeva et al., 2023). STEM education is extremely prevalent and continues to develop every year because the basic concepts of STEM are the integration of several fields of study into a single framework of human knowledge and the required application of this comprehensive knowledge in practice.

Unfortunately, the 2020–2025 National Programme for the Development of Education and Science in Kazakhstan only requires the creation of STEM classes. The reason that a government document on education only mentions classrooms and not teaching methods or teachers' STEM education and professional preparation raises questions in this situation.

Interviews with 4680 parents, 2937 teachers and 4788 children were conducted as part of the study. 70.7% of teachers have never participated in activities focused on STEM education. 57% have done it only occasionally and 22% have never come across the term STEM in their work. 62.8% of educators are unable to define STEM. 81.3% of parents are unaware of this idea. 63.5% of children have no idea what STEM education is, 21.4% have no idea what it means and 4.2% are aware of its meaning. According to the students, conventional methods are still used to teach courses in the natural scientific fields (Imangaliyev et al., 2020).

This raises a question for modern education: If a teacher does not have the technological knowledge needed to make it happen, how can he or she prepare schoolchildren for the future?

Therefore, issues such as the introduction of STEM education, staffing, teacher training and the creation of innovative educational programs are currently important topics.

There are very few strategies that rely on games and other activities that are suitable for children to ensure the development of engineering and natural science competencies in children, starting from primary school age despite the rapid growth in the number of children's robotic centres in Kazakhstan and the introduction of ICT technologies into education at all levels (Zhumash et al., 2021).

Therefore, this study makes an effort to provide more detail on STEM training techniques and curriculum to support the development of young students' research skills as well as their capacity for critical thought.

The following queries serve as research directions:

(1) How do students in lower grades view the value of STEM education?

(2) How successful are STEM training's methods and content in fostering the development of younger students' research aptitudes as well as their capacity for analytical and creative thought?

2. Literature Review

The foundation that leads to successful present education and growth in many fields of professional activity is created by STEM education through its effective and comprehensive application (Hatisaru et al., 2023; Vakil & Ayers, 2019). The goal of encouraging STEAM education in primary schools is to help students improve their capabilities, particularly their design and research abilities. The STEM method focuses more on thinking than it does on a particular manner of learning (Barak & Assal, 2018; García-Holgado, Verdugo-Castro, González, Sánchez-Gómez, & García-Peñalvo, 2020). With this mindset, children will grow up and be able to deal with global issues. They will have not only knowledge but also problem-solving skills. They will understand algorithms to overcome difficulties based on interdisciplinary knowledge and collaboration. STEM education emphasizes children's independence in learning new information, giving young children the chance to build their willpower, their creative ability and their teamwork skills. These are the skills required for a developed individual who is prepared and capable of resolving potential issues (Techakosit & Nilsook, 2018).

However, the traditional educational process management system deprives students of opportunities to take initiative. It is impossible to solve the problems of STEM education with this model of traditional education. According to STEM pedagogy, a student should be interested in learning, knowledge should be applied in practice and learning itself should be entertaining (Perignat & Katz-Buonincontro, 2019; Ugras, 2018). It is a practice that must connect disparate knowledge in the natural sciences. As a result, we must be aware of and examine the organizational concepts and methods used in other countries before introducing STEM education in our country. The development of pilot projects or experimental schools where new approaches are tested and recommendations and methods are developed for further distribution, animation, development and testing of new educational subjects working in an interdisciplinary approach (technology, science, etc.) are actions aimed at increasing support for the STEM approach. Develop STEM educational programs based on museums, libraries, galleries and other public spaces that are freely accessible to all interested parties. The inclusion of teachers in networks and communities that practice STEM education, programmes for the training of teaching staff and the development of programmes, methods, and methodological materials for staff members of educational institutions and initiatives are all examples of training and development activities for educators, school staff and school governing bodies. (Delahunty, Seery, & Lynch, 2020; Tan, Ong, Ng, & Tan, 2023).

The effectiveness of our research is supported by the findings of scientists from various countries that have adopted the STEAM education approach (Allina, 2018; Bakermans & Plotke, 2018; Bertrand & Namukasa, 2020; Conradty & Bogner, 2018; Harris & De Bruin, 2018).

3. Method

3.1. Data Collection and Research Procedure

The data was gathered through

(1) Pedagogical observation. This is a technique for directly observing and understanding the educational process under real-world circumstances. The planned research's directions can be clarified with the help of preliminary data obtained through pedagogical observation as a method of data gathering. This kind of monitoring broadens the perspective of the phenomena being examined and assists in identifying critical occasions. Second, the primary method for gathering more information is observation.

This method uses point scaling. The authors evaluated each indicator's level of performance in children on a 4-point scale.

The questionnaires were designed to identify and assess the general education skills and abilities of schoolchildren. The diagnosis's purpose is to determine the level of development of the student's general educational skills and abilities. Each questionnaire contained a list of characteristics of the students' learning activities. The teacher had to select the correct characteristic for each student.

(2) The researchers summed all the points obtained and divided them into three groups based on the total points: weak, medium and strong to determine the level of ability development.

(3) Survey of students. For diagnosis, schoolchildren are given a checklist of abilities in which they must demonstrate mastery: 0: I can't. 1: I can't do it more often. 2: Sometimes, I can and 3: I can.

(4) It is necessary to perform analytical processing of all the results obtained to determine the end of the experiment.

It is necessary to perform analytical processing of all the results obtained to determine the end of the experiment after diagnosing research abilities using various methods and techniques.

I. The following classifications of levels were taken as a basis to reduce all levels of research abilities to a common denominator: *Adaptive (low) level:* Younger students are not motivated to conduct research. Each stage of the study presents challenges. Students can only carry out research work by analogy with their teachers. Research abilities are not yet developed.

II. *Productive (average) level:* Among younger students, only extrinsic motivation to do research work was observed. They can conduct independent research only under the guidance of a teacher.

III. *Creative (high) level:* Lower-grade students have intrinsic motivation for research activities. Possess a set of skills required for independent research.

The first stage of research is to ascertain.

This stage allows for the determination of whether efforts are being made to develop research skills in elementary school children. It was carried out based on the selected criteria and indicators of the formation of research abilities: organizational (indicators: abilities that allow you to plan and effectively organize research work), search (indicators: abilities that provide an opportunity to find a research problem and select research methods that are adequate for solving it), informational (indicators: abilities that rely on working with literary or technical means of informing) and evaluative (indicators: skills that allow you to argue your opinion when evaluating your own and outside work).

The second phase of the experiment was exploratory. At this stage, we look for ways and means to develop research abilities in young students.

During this stage, we developed practice-based STEM training tasks aimed at the successful formation of research abilities.

3.2. Research Sample Formation

The study was conducted with 36 fourth-grade students as the experimental group and 36 fourth-grade students as the control group at the elementary school "Zhas Daryn-2" in the city of Shymkent (Southern Kazakhstan). Practice-based STEM training was used in the experimental group. Conventional training was provided to the control group. The same teacher conducted lessons in both the EG and the CG which ensured that the experiment's conditions were satisfied and that the educational process was successfully handled.

4. Results

Figure 1 shows the findings of the pedagogical observation.

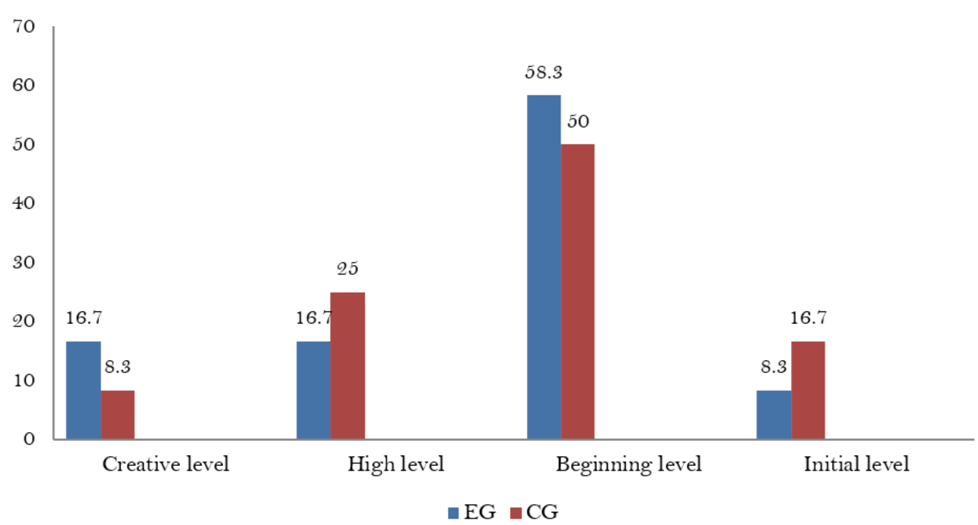

Figure 1. The results of the pedagogical observation.

The results are based on pedagogical observation. It can be argued that in the experimental group, one student (8.3%) demonstrated the initial level of development of research abilities, seven participants (58.3%) were at the beginning level and two students (16.7%) had developed their research abilities to a high level. In the CG, two participants (8.3%) demonstrated the initial level of development of research abilities, six participants (50%) were at the beginning level, three participants (25%) had developed their research abilities to a high level, and one student (8.3%) was at the creative level.

The results of the questionnaires are shown in Figure 2.

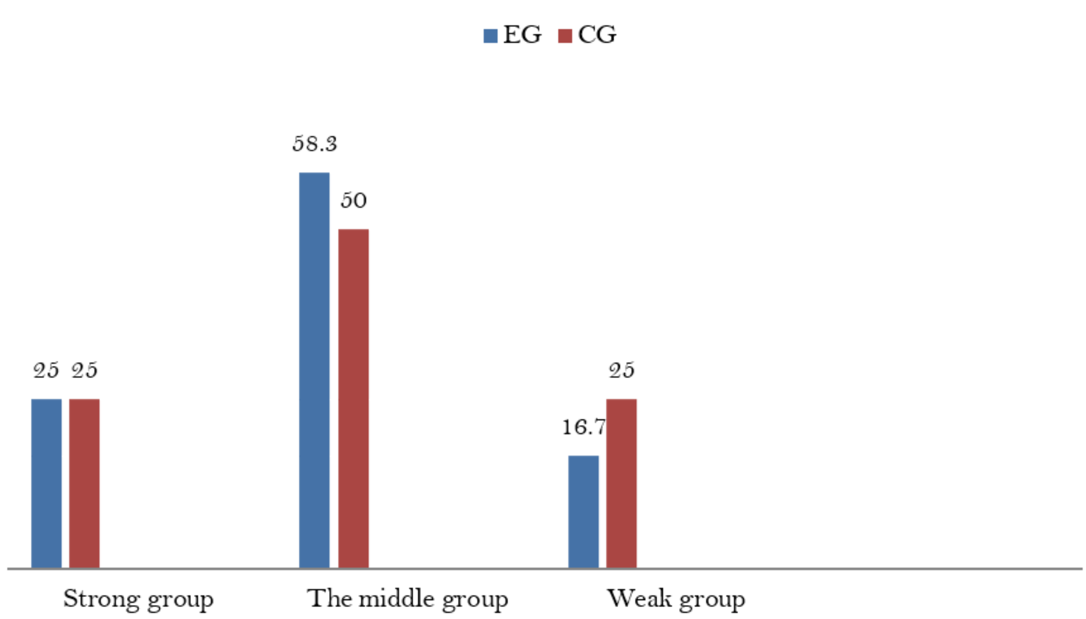

Figure 2. The results of the questionnaires.

According to the graph, in the EG, 2 participants (16.7%) were at a low research ability level, 7 students (58.3%) were at an average level and 3 students (25%) were at a high ability level. In the CG, 25% of students have a low or high level of ability development (3 students each) and six participants (50%) were at average research ability levels. According to the results, the research abilities of the participants in both groups are at an average level.

Figure 3 shows the results of a student survey.

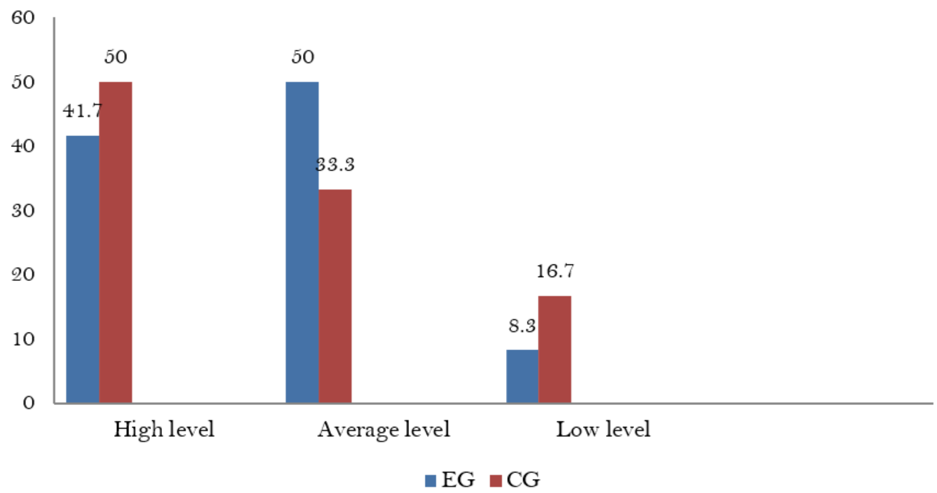

Figure 3. The results of a student survey on the development of research abilities.

The results of the questionnaire survey showed that 1 student (8.3%) in the EG group had a low level of research ability and 2 students (16.7%) in the control group had a low level of research ability. Six participants (50%) in the EG and four participants (33.3%) in the CG each developed their research skills to the average level. The capacity to establish hypotheses through observations and categories were among the research skills that students reported having effectively improved. In the EG, 5 participants (41.7%) identified a high level of development of research abilities. In the CG, six participants (50%) are at a high level. Most students in the control and experimental groups note a high or average level of research ability.

The analysis process to determine all the results obtained at the end of the experiment is shown in Figure 4.

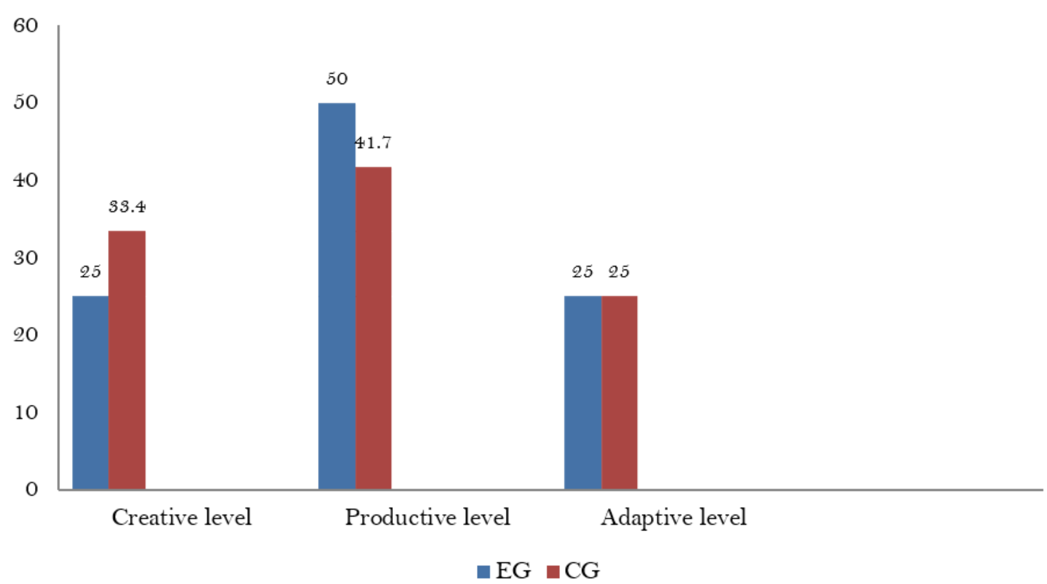

Figure 4. The analysis process to determines all the results.

According to the findings, junior students' research abilities need to be fostered. The second phase of work was carried out at the end.

Programme lessons and technologies with STEM training method content are developed and implemented into the educational process to support the development of younger students' research aptitudes as well as their ability for analytical and creative cognition. The authors introduced and tested the educational process of the research project "Robots of the Future" (see Table 1).

Table 1. Methodical designer of the author's research project "Robots of the future".

Stages of a STEM project	Teacher activity	Student activities
Knowledge update	Activates students' knowledge in the discipline "The World Around Us" (subject area "Natural Science").	Students acquire the necessary knowledge in the discipline "The World Around Us."
Instruction	Offers instructions for the implementation of the product including a list of necessary parts and fasteners and the algorithm for assembling the turtle robot.	Accept the proposed list of parts and fasteners. Understand the algorithm for assembling the turtle robot.
Practical work	Controls the progress of product design and helps in presenting the results of the assignment.	They assemble the robot and present the results of the completed task.

A technique similar to the ascertaining experiment is performed to determine the emergence and development of research talents. The final study's pedagogical observations of the students are in the form of a diagram shown in Figure 5.

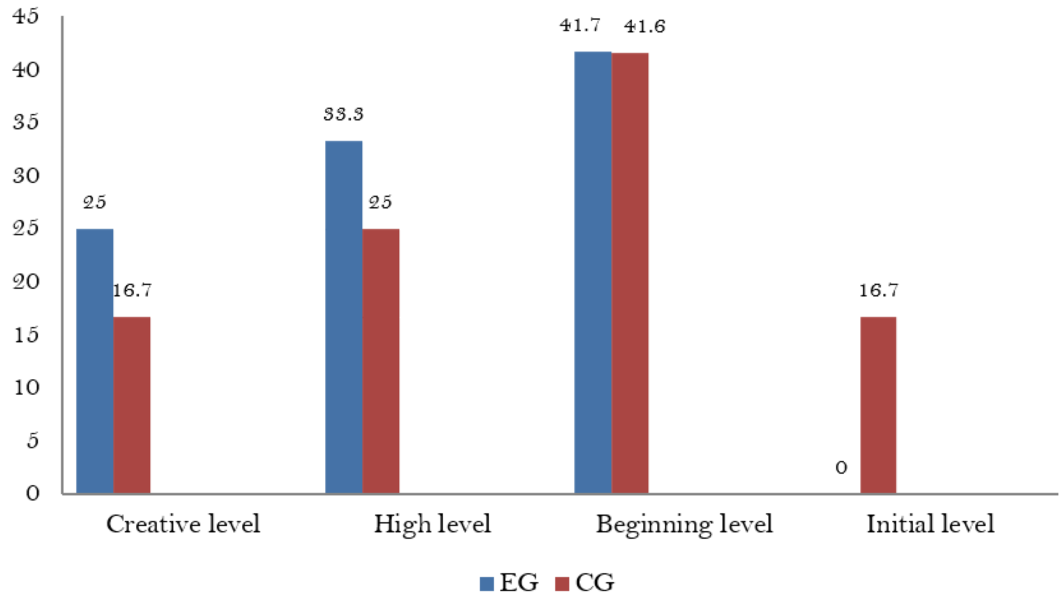

Figure 5. The final study's pedagogical observations of the students.

Five students (41.7%) make up the majority of the students in the EG at the primary level. Four students (33.3%) gave high-quality work. In the creative level of the controlled experiment, there were 3 students (25%). The participants in the CG showed the following initial levels of formation of research abilities: initial level: 2 students (16.7%), initial level: 5 students (41.6%), high level: 3 students (25%) and creative level: 2 students (16.7%). The percentage of students with an initial skill-forming level decreased by 8.3 percentage points to 0%. The level in the CG was 16.7% and there were neither positive nor negative dynamics. In the EG, the percentage decreased by 16.6% and in the CG by 8.4%. The high level of ability formation increased significantly in the EG by 16.6%. The CG showed no changes. At the creative level, there were 2 participants in the CG, i.e., the level increased by 8.4%. The experimental group increased by the same percentage.

The level of formation of the evaluation criteria for the research ability of junior students is shown in Figure 6.

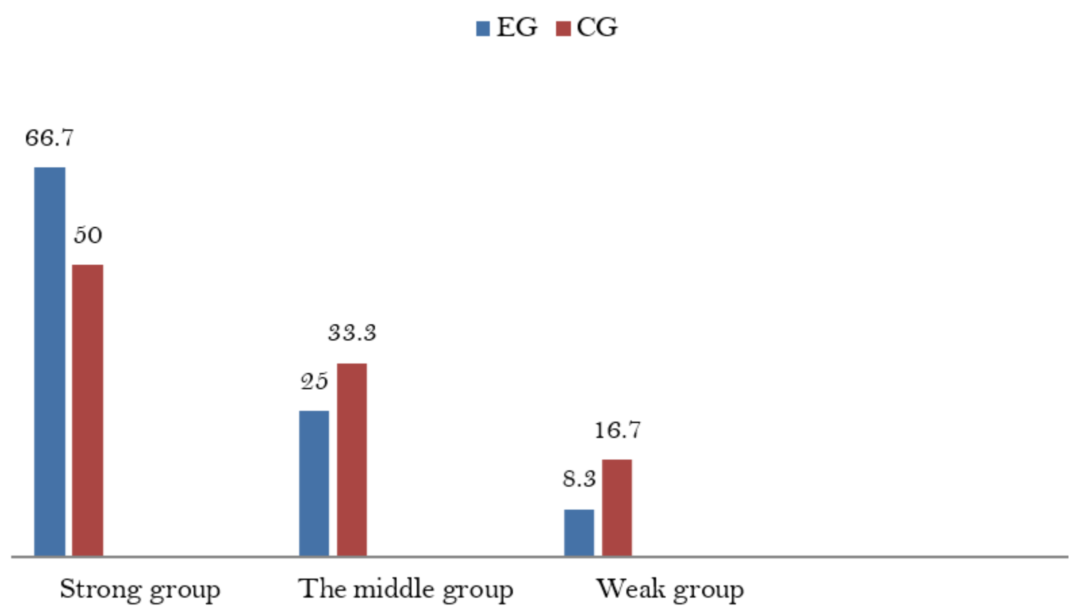

Figure 6. The results of the questionnaires of teachers.

In the EG, the level of the participants in the weak group remained unchanged at 2 (16.7%). There was one more student in the CG, increasing the percentage of low-income students by 8.3%. The average student group consisted of 6 participants (50%) in the EG and 5 participants (41.7%) in the CG. Consequently, in the EG, the average level of development of research abilities decreased by 8.3%, the same decrease occurred in the CG. In the EG, there were 4 students (33.3%) with high ability levels. In the CG, there were 3 participants (25%). The level of strong students in the CG did not change but in the EG, it increased by 8.3%.

The final result is the survey of students (see Figure 7).

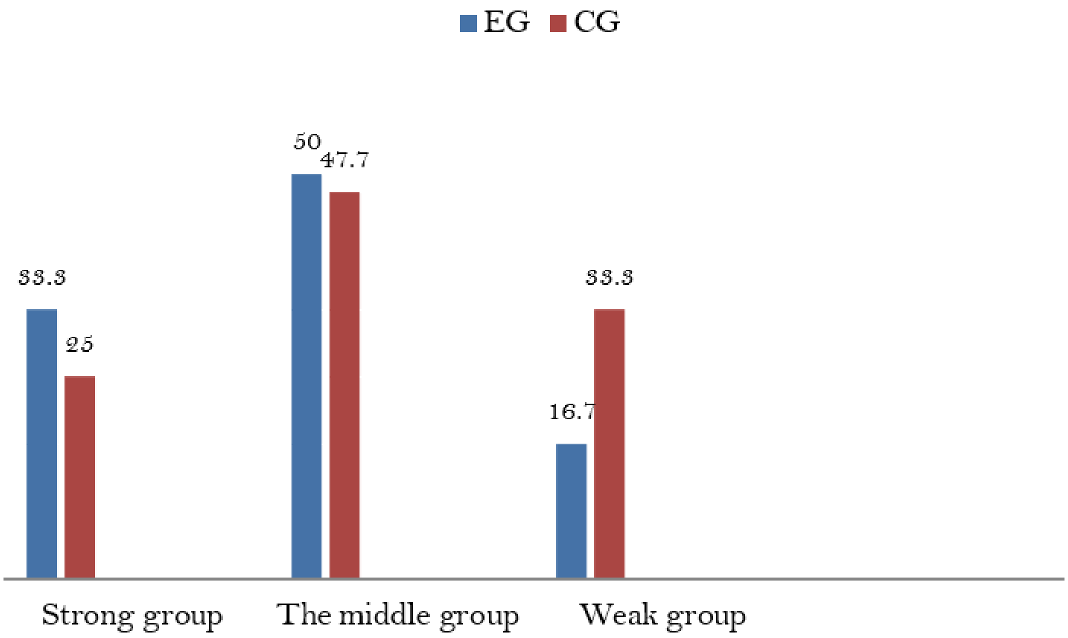

Figure 7. The findings of the student survey

The experimental group's ability for research improved by 16.7% after data analysis. The experimental group's findings were as follows: Low level: 8.3% (1 student), medium level: 33.3% (4 students) and high level: 58.4% (7 students). The dynamics of the control group's outcomes are inconsequential. The high level dropped to 8.4%. The main level of development of research abilities in the EG is high. In the CG, the high and medium levels remained at the same location.

All data has been converted to Table 2 and Figure 8 to show the dynamic evolution of lower-grade research skills in both groups.

Table 2. Comparative results of ascertaining and control experiments

Experiment	Levels					
	Creative		Productive		Adaptive	
	EG	CG	EG	CG	EG	CG
Ascertaining experiment	25%	33.3%	50%	41.7%	25%	25%
Control experiment	33.3%	25%	50%	41.7%	16.7%	33.3%

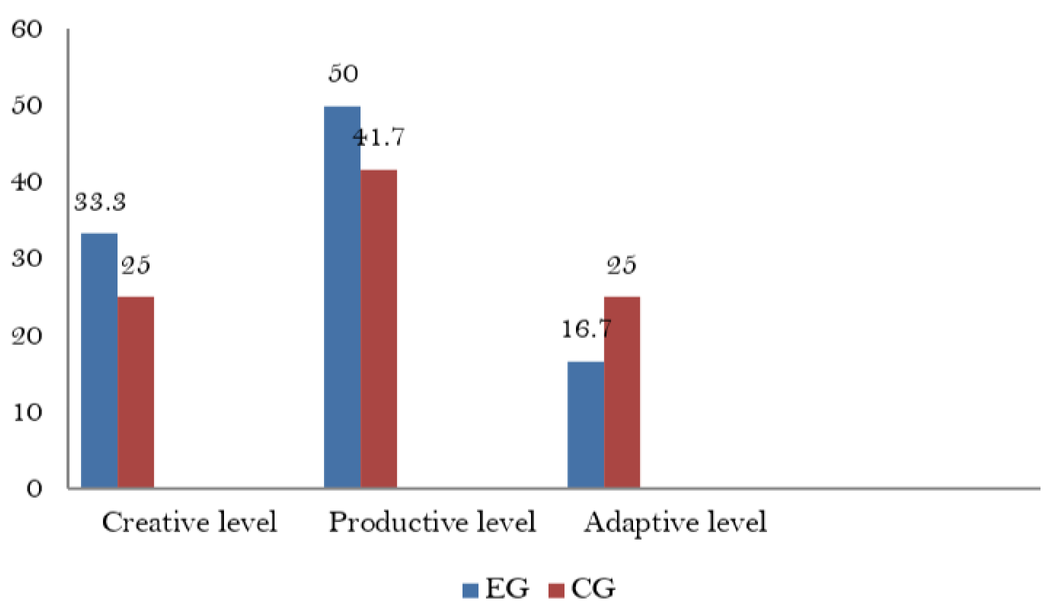

Figure 8. Levels of formation of research skills in the EG and CG at the control stage

Controlled experiments showed that 4 students (33.3%) in the CG and 2 students (16.7%) in the EG were at the adaptation level for research capacity formation. The productive level of the capacity formation index of the six participants in the EG is 50%. In the CG, this level was made up of 5 students (41.7%). 4 students (33.3%) in the EG and 3 participants (25%) in the CG both attained the creative level of research ability formation. In the control group, it increased by 8.3% while in the experimental group, it decreased by the same percentage. The participants with high levels of research abilities remained the same in both groups. The creative level noticed the following changes: in the experimental group, it increased by 8.3% while it decreased by 8.3% in the control group.

5. Discussion

According to the study's findings, practice-based STEM training may encourage the development of younger students' research abilities and the improvement of their analytical skills as evidenced by an increase in students' research abilities as well as their capacity for analytical and creative thought.

The study's main finding was that there are barriers to STEM education in our country's primary schools. The majority of the students in both groups' research abilities were in the early stages of development, according to pedagogical observations made to better comprehend educational processes in real-world contexts. These results are consistent with those of other researchers by Montgomery and Fernández-Cárdenas (2018) and Struyf, De Loof, Boeve-de Pauw, and Van Petegem (2019).

Another area of attention is STEM education for teachers and their professional development. This study's results show that instructors lacked the abilities to support an integrated approach to STEM instruction which is consistent with other findings (Minichiello, Hood, & Harkness, 2018; Wu & Rau, 2019). Clarification and systematization of teachers' beliefs about the theory and practice of STEM education were necessary in order to prepare primary school teachers, taking into account global experience and the positive outcomes of the Kazakhstani educational system.

Improvements in students' research abilities and the enhancement of their analytical skills were achieved through practice-based STEM training. This is consistent with the arguments made by Ilyas, Meiyani, Ma'rufi, and Kaewhanam (2022); Thibaut et al. (2018) and Mohd Shahali, Halim, Rasul, Osman, and Mohamad Arsad (2019).

According to Wang, Sang, Huang, Li, and Guo (2023); Gubenko, Kirsch, Smilek, Lubart, and Houssemand (2021) and Yang, Ng, and Gao (2022), educational robotics is becoming increasingly important and relevant in the modern world. Children learn about the rules of the actual world, how to put theory into practice and how to observe and think critically through the cooperative actions of robots.

Practice-based STEM in our study is a combination of knowledge and practical skills that students acquire. Assembling basic models was the first step in the research project "Robots of the Future" before moving on to more complicated ones. Robots are given clear assignments to fulfil using programme blocks. The robot is tested after being put together. Students develop ways to accomplish the goal following each test. There is an environment of discussion and opinion sharing at the project discussion stage. Students connect with teachers and colleagues while working on projects because effective communication and cooperation are important in practice-based STEM. As a result, research abilities and analytical skills are enhanced. This gave them more confidence in their abilities and taught them how to get to their goal, overcome obstacles and check their work multiple times without stopping at obstacles. Students learn to properly communicate and present their work in groups where they can freely express and defend their opinions. Their skills developed as they did more practical work and they developed an interest in technical fields. Thus, students use their expertise from numerous disciplines to improve robots which helps them develop their natural-science understanding of the world (Adams, 2021). They demonstrate the main advantages of our study's findings such as the opportunity to study comprehensive topics rather than isolated academic disciplines, the ability to demonstrate scientific and technical knowledge when students not only comprehend its purpose but also actively engage in its implementation and the development of research and analytical skills to address issues that arise when completing specific tasks. This makes students more aware of their potential and reexamines their resources. Additionally, it fosters the development of analytical abilities necessary for productive teamwork and effective communication as well as an increased interest in the academic fields that serve as the foundation for the technological sector. It also creates the conditions necessary for the demonstration of research skills and analytical abilities during project activities (Ayverdi & Öz Aydın, 2020; Bernacki, Chavez, & Uesbeck, 2020). This approach combined different interdisciplinary information to foster attributes such as curiosity, technical thinking, teamwork abilities, etc. which allowed for a whole new level of growth in students' research aptitudes as well as their ability for analytical and creative thought (Falloon, Hatzigianni, Bower, Forbes, & Stevenson, 2020). Furthermore, our findings on the positive impact of interdisciplinary knowledge are consistent with those of other researchers Bush, Cook, Edelen, and Cox Jr (2020) and Quigley, Herro, Shekell, Cian, and Jacques (2020).

Consequently, STEM training methods and content foster the development of younger students' research skills as well as their analytical and creative thinking abilities (Chen & Chang, 2018; Huang, Jong, King, Chai, & Jiang, 2022; Stohlmann, 2018; Tytler, Prain, Aranda, Ferguson, & Gorur, 2020).

6. Research Implications

The study's practical significance is determined by the following facts:

(1) A description of the essence and possibilities of using the innovative approach of STEM education can contribute to the development of programs and methodological recommendations by teachers to remove barriers to STEM education in primary schools in our country.

(2) The developed methods and content of teaching practical STEM education and the research project "Robots of the Future" can be introduced into the educational process of primary schools.

(3) The selected criteria, indicators and levels of formation of research abilities as well as their ability to analytical thinking in younger students can be used to diagnose research abilities in children of primary school age.

7. Conclusion

Our findings demonstrate a high level of interest in STEM and a country's rising acceptance of it. However, the low quality of precision science education, a lack of material and technical infrastructure and a lack of learning enthusiasm among primary and middle school students are major issues in Kazakhstan's education system. The necessity for new forms, techniques and technologies in the teaching of STEM across the country was made clear by an analysis of challenges related to the concerns of this study. The conflict arises from the necessity to produce future experts through STEM education to organize targeted efforts to develop young students' research abilities and to organize education in the context of an innovative approach developed in modern schools. As a result, the current study seeks to determine how students' research and analytical skills can be improved by conducting a study in Shymkent City, Southern Kazakhstan using practice-based STEM training. The study's findings revealed that STEM training influences students' perceptions of the value of STEM education in lower grades. STEM training methods and content successfully promoted the development of younger students' research abilities as well as their capacity for analytical and creative thought.

8. Limitations and Future Research

Using practice-based instruction, children's research skills and ability for innovative and critical thinking increased as a result of STEM instruction which helped younger children acquire these talents. There are still certain gaps in our understanding of how to best develop younger students' research skills and their ability for critical thought, despite our analysis of STEM training strategies and content. We offer the following ideas that may help in future research:

1. Additional research work must be done on how to clarify and systematize teachers' ideas about the theory and practice of STEM education taking into account world experience and the achievements of the Kazakhstan education system.
2. It would be useful to conduct research to determine the pedagogical characteristics of STEM and adapt them to the practice of teaching the subjects of the natural-mathematical cycle and computer science in schools in Kazakhstan.
3. There is a need for research on developing teacher competencies related to technological maps of lessons and the selection of organizational forms and methods in STEM.

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