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Enhancing engineering thinking skills of pre-service IT teachers through cross-cutting educational technologies and stem projects

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ABSTRACT

The skill of engineering thinking is one of the relevant and in-demand competencies of the pre-service teachers of Information Technology (IT teachers) in STEM education. The aim of the research is to develop the engineering thinking skills for pre-service IT teachers using cross-cutting educational technologies and STEM projects. The paper shows the two students' authors` projects in which the students master engineering design and develop the teacher guide with worksheets. Professional training skills are developed as a result of the guide enhancement. During the training, observations were carried out between the control and experimental groups to measure academic performance data and identify any differences between them. The practical teachers and the STEM experts were involved to determine the level of the acquired skills. The results showed that the students who participated in the experiment significantly improved their engineering thinking level and provided themselves with the knowledge and skills necessary for a successful career in scientific, technical and engineering fields. The research allowed determining the effectiveness of the approach based on the use of cross-cutting educational technologies in the development of the author's integrated STEM projects.

Contribution/Originality: The research is aimed at the application of project-based STEM learning for the training of IT teachers in the context of the metaverse. Most of the research focus on the development of engineering skills among natural science teachers but the training of IT teachers' remains poorly studied.

1. INTRODUCTION

The priority of the education system is to prepare young people to work in the dynamic environment characterized by sophisticated technologies, the globalized and competitive economy, and social diversity worldwide. STEM education is necessary to prepare graduates for the labor market which is confirmed by regulatory documents in the field of education in our country. Kazakhstan is an industrial country that needs engineering personnel.

In the modern program-driven information world, AI-based technologies, the Internet of Things (IoT), blockchain, Virtual/Augmented reality (VR/AR) are of great importance (Al-Ansi, Al-Ansi, Muthanna, &

Koucheryavy, 2024; Kuleto, Mihoreanu, Dinu, Ilić, & Păun, 2023; Logeswaran et al., 2024). It is computer science that has caused a fundamental change in the world in which we live and society needs IT specialists to develop innovative technologies of the future (Ahmad, Hani, & Yunifa, 2024; Karapakdee, Wannapiroon, & Nilsook, 2024; Yim & Su, 2024).

Thus, according to the Statista analytical platform, in 2023 at least 60 million people were employed in the global sector of information communication technologies (Sherif, 2024a). Despite this, in 2023, 54% of organizations in the world still lacked IT specialists (Sherif, 2024b). According to the TRACK model, in such conditions, the role of modern IT teachers is increasing who must not only have solid fundamental knowledge and innovative teaching methods but also be technologically competent (Mishra & Koehler, 2006).

The importance of the teacher's role is also emphasized in the OECD research (Organization for Economic Cooperation and Development) which states that to achieve sustainable economic growth it is necessary to develop the intellectual potential of the country through the implementation of high-quality education, the training of talented students, and the development of their cognitive, engineering and research skills (OECD, 2023).

With the development and penetration of digital technologies of the metaverse into all areas of the global economy and everyday life, driven by trends like artificial intelligence (AI), IoT, VR/AR, and blockchain (Chandrashekhar, Saheb, Panda, Balamurugan, & Peng, 2023; Liu, Gong, Tan, & Demian, 2023; Murala, 2024), IT teachers must be prepared not only to professionally use these technologies as the cross-cutting educational ones (Kovaleva, Ushakova, & Gubina, 2023; Marzo-Navarro & Berné-Manero, 2023; Vaganova, Tsarapkina, Zheltukhina, Knyazeva, & Krasilnikova, 2021) but also to teach students how to develop cutting-edge technologies. In this case, mastering the skill of engineering thinking becomes relevant for an IT teacher (Atman et al., 2007; Dym, Agogino, Eris, Frey, & Leifer, 2005; Moore et al., 2014; Wind, Alemdar, Lingle, Moore, & Asilkalkan, 2019) responding to modern challenges and trends in the development of the metaverse technologies which play a key role in the training of talented IT personnel (Chandrashekhar et al., 2023; Murala, 2024; Vaganova et al., 2021).

The metaverse, representing a special type of virtual environment allows teachers and students to create, explore and interact with each other in a realistic and exciting way through dynamic and exciting activities, simulations and other types of learning (Battal & Taşdelen, 2023). The technologies of the metaverse determine the conditions for the modernization of world education, making it more accessible, inclusive, personalized and effective (De Bem Machado, Domingos, Sousa, & Rocha, 2023).

According to some scientists` opinions, one of the effective approaches for developing engineering thinking skills among IT students is the use of cross-cutting educational technologies based on 3D and AR/VR which allow teaching the full life cycle of technology development from an idea to a real project (Castedo et al., 2024; Marzo-Navarro & Berné-Manero, 2023; Vaganova et al., 2021). In addition, there are individual studies showing that STEM-integrated projects are able to develop not only engineering thinking skills but also meta-competencies such as critical thinking and applied research skills which generally contribute to the comprehensive development, success and readiness of the future personality to solve real professional tasks (Atman et al., 2007; Berisha & Vula, 2021; Ozkizilcik & Cebesoy, 2024).

Developing engineering and research skills through the implementation of quality education is very important for the development of the country's intellectual potential. Therefore, research on the use of cross-cutting educational technologies and STEM projects to improve engineering thinking skills is of great importance.

However, the effectiveness of the joint application of the cross-cutting educational technologies based on 3D, AR/VR and STEM project methods for the formation of engineering thinking skills among pre-service IT teachers is of interest despite the available research. In this regard, the authors of the article consider it necessary to address the following research issues:

1. What is the degree of preference for using STEM projects in the engineering design process?

2. How effective is the use of integrated STEM learning using cross-cutting educational technologies for developing the engineering thinking skills of pre-service IT teachers?

2. THEORETICAL FRAMEWORK

Nowadays, many educational reforms and research focus on various approaches to STEM teaching but there is insufficient information about the STEM-oriented teacher training programs that primarily prepare pre-service teachers for STEM implementation (Shernoff, Sinha, Bressler, & Ginsburg, 2017). Teachers face difficulties in finding real examples to create a STEM learning context and implement a flexible STEM curriculum (Berisha & Vula, 2021). According to Aydin-Gunbatar, Tarkin-Celikkiran, Kutucu, and Ekiz-Kiran (2018) the solution to tackle these problems is to change the teacher training programs.

The authors have proposed a training program aimed at developing engineering thinking skills among the pre-service IT teachers. The program is implemented as a part of the STEM technology elective course included in the educational program for the future student teachers (see Figure 1). The program is fulfilled using the cross-cutting educational technologies and integrated STEM learning. The prerequisites of the course are information technology, educational robotics, programming, 3D modeling and augmented reality.

According to the characteristics of the effective integrated STEM projects proposed by Roehrig, Dare, Ring-Whalen, and Wieselmann (2021) training was based on the following principles of the integrated STEM implementation: The interdisciplinary approach, real-life tasks, research activities, engineering design, collaboration and the cross-cutting educational technologies.

Figure 1 shows a model for preparing the training of the pre-service IT teacher in the metaverse environment. The developed conceptual model demonstrates the structural and logical scheme of interaction of learning blocks for the development of engineering thinking in the preparation of the pre-service IT teacher in the metaverse environment. The principles correspond to the three main stages of the implementation of integrated STEM using the cross - cutting educational technologies based on which each project is implemented: (a) the motivational section, (b) the engineering research design section and (c) the productive section. At the stage of the motivational section, the goals of the project are determined as well as the choice of the project topic that will integrate scientific, technical, engineering and mathematical aspects.

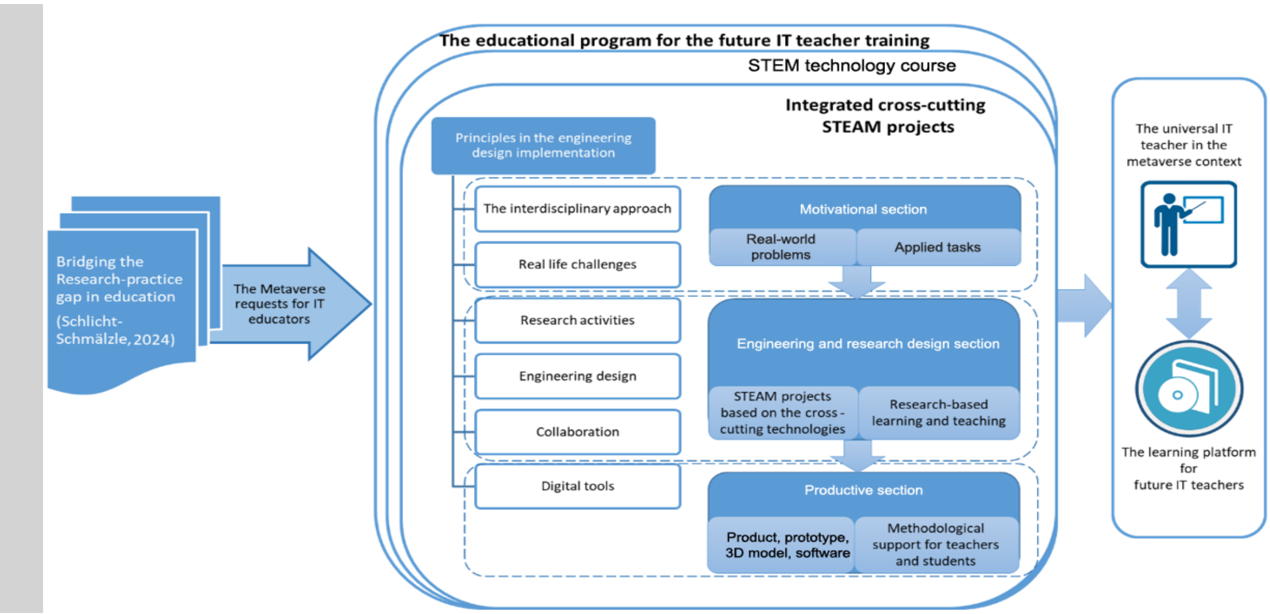

Figure 1. Conceptual model of training a pre-service IT teacher in the metaverse context.

Source: Schlicht-Schmälzle (2024).

In the first section, a team of participants is formed and roles are assigned. In the second section, research on the chosen topic is being carried out in the research design section and the project concept is being developed. The resources needed for the implementation of the project are planned. In the third productive section, prototypes or models of the project, software or hardware development are created. Prototypes are being tested and finalized. At all of the sections, digital resources (presentation, online services, software, etc.), material and technical bases (laptops, tablets, various robotic platforms, 3D printer, 3D scanner, etc.) and the use of the cross-cutting educational technologies based on 3D, AR/VR, consultation of the supervisor and the subject teachers are used to support the students.

From a diverse range of the tasks, students can choose the project that meets their intellectual and technical interests. Teachers will form teams of two to four people. The students are divided into groups based on the preferences of the students. After discussion, the group is divided into mini teams and develops the design of the author's project (online service MindMap, Canva and Draw.io). Then the student teams work together on the STEAM project throughout the semester. Students in the team explore the problem, brainstorm, find and propose all kinds of solutions. As far as solutions are proposed and the best of them is selected, they begin to develop a prototype.

3. REVIEW OF LITERATURE

In recent decades, the profession of engineering and its role in society have undergone significant changes. In the context of the rapid development of the metaverse technologies, modern engineers face increasingly complex problems that require not only deep technical knowledge and skills but also an understanding of the environmental, social, economic and cultural aspects of aspects (Bal et al., 2024; Colmenares-Quintero, Caicedo-Concha, Rojas, Stansfield, & Colmenares-Quintero, 2023; Wind et al., 2019).

Engineering thinking has become an essential component of engineering education based on the preferences of the students. The development of engineering skills is considered by integrating engineering design into science classes (Zhan, Sun, Song, Yang, & Zhan, 2023). Integrated STEM projects are capable of developing not only engineering thinking skills but also critical thinking and applied research skills (Kuvac & Koc, 2023; Ozkizilcik & Cebesoy, 2024). Some authors focus on the impact of elective courses in science, technology, engineering and mathematics (STEM) on the engineering and design of pre-service teachers (Aydin-Gunbatar et al., 2018; Aydın, Öztay, & Ekiz, 2021; Domenici, 2022; Irmak & Öztürk, 2022; Ozkizilcik & Cebesoy, 2024).

Engineering occupies an important place in STEM policy documents and real problems are presented as engineering design tasks (Moore, Johnston, & Glancy, 2020). Engineering is considered central in most definitions of integrated STEM (Berland & Steingut, 2016; Mehalik, Doppelt, & Schuun, 2008; Moore et al., 2014; Nathan et al., 2013). The most common combination even among studies that advocate for integrating only two fields referred to as integrated STEM is science and engineering (Moore et al., 2020). In particular, students are expected to participate in engineering practices to develop possible design solutions to real problems within the framework of integrated STEM education (Berland & Steingut, 2016). The most important stage of the engineering design process for pre-service IT teachers is the creation of a prototype (Hynes, 2012). One of the key tools in the development of STEM education is the cross-cutting educational technologies based on robotics and 3D, AR/VR when creating prototypes in projects (Nurbekova, Mukhamediyeva, & Assainova, 2018; Ouyang & Xu, 2024). Integrated STEM projects and the cross-cutting educational technologies are powerful tools for developing engineering thinking among students, providing them with the opportunity to apply knowledge, skills and creativity professionally to solve real problems as well as training students to develop advanced technologies. Many studies have been devoted to STEM teaching in education (Dakeev, Pecen, Yildiz, & Luong, 2021; Herro, Quigley, & Cian, 2019; Mangina, 2018).

According to the current trends in the development of the metaverse technologies, engineering thinking skills play a special role in the training of an IT teacher. It is possible to prepare IT teachers for modern challenges in the field of science and technology today through the use of technologies and concepts of the metaverse to improve the educational process. The metaverse allows students from different parts of the world to work together on projects in real time (De Bem Machado et al., 2023). This contributes to the development of teamwork skills on projects. The metaverse can provide access to high-quality STEM education for people with disabilities and those who live in remote regions where there is no opportunity to attend traditional educational institutions. The cross-cutting educational technologies contribute to improving the quality of education and increasing the effectiveness of educational processes (Marzo-Navarro & Berné-Manero, 2023; Vaganova et al., 2021). The connection between the cross-cutting concepts and the content of STEM subjects plays an important role in the development of STEM curricula (Vaganova et al., 2021).

A review of commonly used teaching strategies in integrated STEM education (Mustafa, Ismail, Tasir, & Mohamad Said, 2016) showed that project-based learning approaches are the most common. A project-oriented project as a pedagogical approach will be more effective in improving the learning outcomes of students than in traditional learning (Barak & Yuan, 2021). The authors of Putri, Japar, and Bagaskorowati (2019) suggest the promotion of project-oriented learning for effective higher-level mental activity. Project-based learning promotes the creative development of students' abilities (Pan, Lai, & Kuo, 2023). The creativity of pre-service teachers improves for all cognitive styles after applying the project-based learning model (Puspita, Doyan, & Harjono, 2024). Thibaut et al. (2018) investigating the learning methods used in the implementation of integrated STEM projects found that the most common structures used were STEM content integration, problem-oriented or problem-based learning, query-based learning, design-based learning and collaborative learning. However, none of these reviews analyzed the ways in which STEM fields were explicitly or implicitly integrated into each of these learning approaches.

The review of available research in the field of engineering thinking development for pre-service IT teachers through the cross-cutting educational technologies and STEM allows us to draw the following conclusions:

- Most of the research focus on the development of engineering skills in pre-service teachers of natural science through integrated STEM projects. However, this problem has not been sufficiently disclosed for pre-service IT teachers with technological knowledge. Research in this area gives priority to measuring the ability of teachers to use the cross-cutting educational technologies as a learning resource to solve daily tasks; less attention is paid to activities for the development of engineering skills of students.
- In the available research, there is no practical application of STEM learning based on applied projects with a detailed description of implementation examples and developed methodological support for pre-service IT teachers.

A preliminary study was conducted to collect the necessary data considering the given gaps in the research. The results and conclusions of the study will be described in detail in the next section.

4. METHODS AND MATERIALS

4.1. Research Design

This research was conducted to study the effectiveness of the approach to introduce the STEM technology curriculum into the IT teacher training program to develop engineering thinking skills. The course is designed for 10 credits; this is 300 hours. Of the available 300 hours, 90 are contact hours and 210 are allocated for the student's independent work. The experiment was conducted from 2022 to 2024 on the basis of the Margulan University (Kazakhstan, Pavlodar) among the pre-service IT teachers.

The experimental design was used with a Control Group (CG) and an Experimental Group (EG) of the students of the educational program "Informatics". After the learning process, the observation was conducted between the control and experimental groups to measure the effective development of the engineering thinking skills and identify any differences between them.

During the course, the constructive learning approach was used, implemented using the project and problem-based research methods. The course is based on the implementation of joint group work of the students on the development of the author's scientific STEM project. Tables 3A and 4A present examples of STEM projects using cross-cutting educational technologies. The basis of the projects is the engineering design stage of the prototype. Students develop the engineering design skills as well as the ability to work effectively in a team as a result of the project work done through the cross-cutting educational technologies.

The assessment of the students' engineering thinking skills was carried out through a preliminary questionnaire and knowledge control during the study of the STEM technology discipline. The result of studying the discipline is passing the exam in the form of defending the author's STEM projects prepared by students. The practical teachers and the STEM experts evaluate the exam according to the following criteria: creativity, scientific thinking, effectiveness of the used methods of the engineering research, degree of the topic disclosure, degree of the engineering design disclosure, oratorical skills, quality of demonstration material and group work.

4.2. Participants

The research was conducted based on Margulan University located in the city of Pavlodar, northern Kazakhstan. The research involved 162 students who studied the STEM technology course. Students of the computer science educational program studied this discipline in the spring semester of the third year of study from 2022 to 2024. This discipline was introduced as an elective course and is studied in the spring semester of the third year of study. The semester lasts fifteen weeks. The knowledge control ends with an exam. During the experimental period from 2022 to 2024, 162 students of the computer science educational program mastered this course.

4.3. The Tool and the Test for Validity and Reliability

During the experiment, the STEM teachers and experts monitored the students' proficiency in the engineering thinking skills and collected the data. The STEM teachers and experts observed both the joint and individual results of students. The total average value of their proficiency in the engineering thinking skills was calculated for the experimental group through the evaluation of the STEM projects and for the control group through the evaluation of the final project work. During the semester, the experimental group studied the course through the development of the integrated STEM projects and the control group studied the course through the performance of lectures and practical tasks of the traditional type.

The criterion observation map was developed through a review of the literature and previous studies. The final form of the assessment tool consisted of six engineering skills. The tool used the 3-point Likert Scale (3 = high level, 2 = medium level, 1 = weak level).

The results in Table 1 show that there is a high correlation coefficient and statistical significance at α=0.05. It demonstrates that the tool has a strong internal consistency and is usable. The researchers tested the reliability of the instrument using the Cronbach's alpha coefficient (Cronbach's alpha coefficient) which had a value of 0.80, confirming that the criterion observation map can be used as the research tool.

Table 1. The constructive validity of the observation card.

No.	Criteria for evaluating the engineering thinking development	Correlation coefficient	Significance level
1	Creative ability	0.781	0.00
1.1	The author(s) of the work show creative ability in developing a new scientific approach to solving the problem through the cross-cutting technologies.	0.787	0.00
1.2	The author(s) show a creative ability to use new approaches to the use of equipment.	0.836	0.01
1.3	The author(s) show creative ability in formulating the practical significance of the research.	0.765	0.00
1.4	The author(s) show creative ability in formulating the conclusions of the research.	0.739	0.00
2	Scientific thinking	0.727	0.00
2.1	To what extent is the considered problem presented clearly and unambiguously.	0.723	0.01
2.2	How clearly the solvable engineering task is highlighted so that the probability of obtaining the planned results is high?	0.758	0.00
2.3	Whether there is a clear plan for solving the problem.	0.734	0.00
2.4	Whether the author (Team) has an idea for the next stage of the research that guarantees a solution to the problem.	0.695	0.01
3	The effectiveness of the engineering research methods	0.785	0.00
3.1	In the process of work, the cross-cutting technologies, modern efficient equipment or modern theoretical methods were used, which allowed to obtain fundamentally new results in this field of knowledge.	0.679	0.00
3.2	The effectiveness of the used methods of engineering research has been proven.	0.891	0.00
4	The degree of the topic disclosure (Thoroughness)	0.793	0.00
4.1	How fully the material in the project is covered, thoroughly and clearly stated; the work has been completed to the planned stage?	0.753	0.00
4.2	Whether the author(s) know other approaches to solving the problem.	0.834	0.00
5	The degree of the engineering design disclosure.	0.873	0.00
5.1	The relevance of the engineering project and the identified problem.	0.893	0.00
5.2	The model or prototype of the engineering solution to the problem.	0.921	0.00
5.3	The engineering solution to the problem.	0.882	0.00
5.4	Integration of sciences and their contribution to the engineering solution of the problem.	0.796	0.00
5.5	The conducted experiments and practical application of the product.	0.873	0.01
6	Oratorical skills, quality of demonstration material and group work	0.849	0.00
6.1	How advantageous, clear and complete the project material is presented in the report.	0.793	0.01
6.2	How clearly the results of the project are highlighted.	0.862	0.00
6.3	The degree of contribution of each team member to the group activities.	0.893	0.00

5. RESULTS

The degree of motivation for studying the STEM technology course was determined and experimental input data for the control and experimental groups were obtained based on the results of the survey. 92.1% of the respondents consider the topic of developing author's STEM projects to be interesting, as they are aimed at solving real problems. The most interesting is the engineering design of the prototype and the possibility of using the cross - cutting educational technologies during the entrance survey of students when evaluating the structure of the STEM project (see Figure 2).

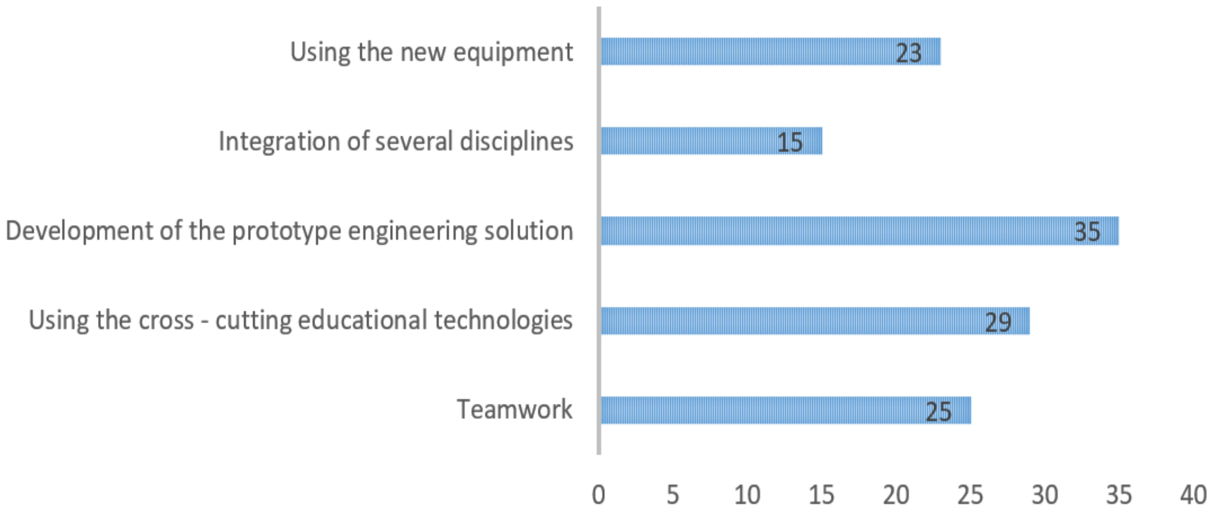

Figure 2. Assessment of the students' preference for the stages of the STEAM project development.

Figure 3 shows the result of students completing tasks for developing the STEAM projects. As can be seen from the histogram, the most difficult task was to develop the teacher guide with worksheets when developing the author's STEM project because the students were faced with the development of methodological support for the school for the first time. The students were provided with a ready-made template for more effective work on the guide.

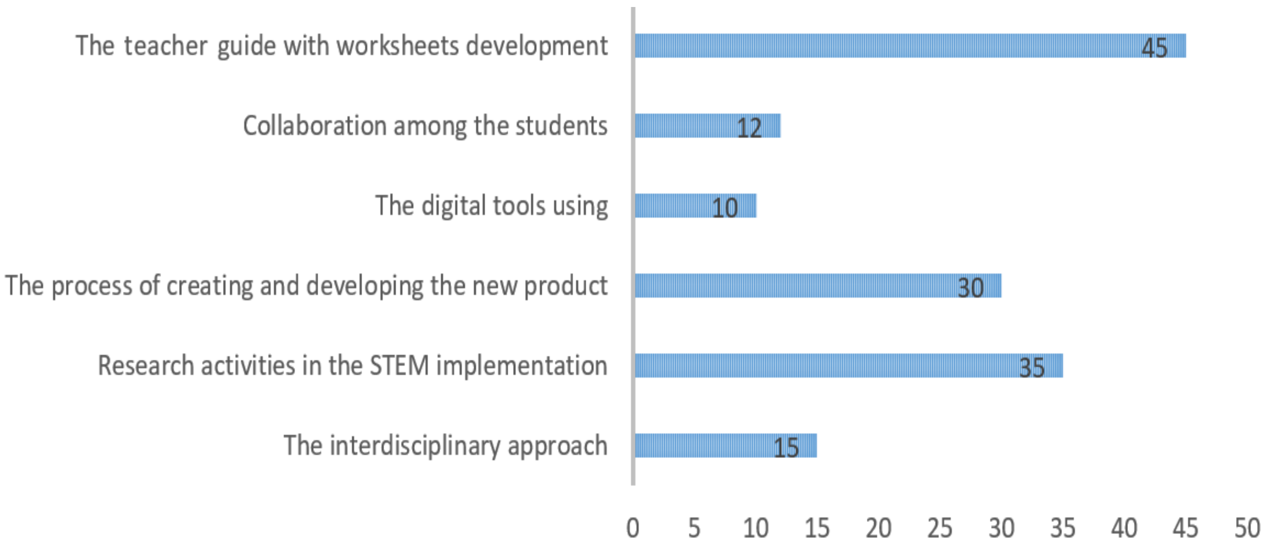

Figure 3. The degree of the tasks completion for the development of the STEAM project.

At the end of the course, students developed the author's STEM projects on various topics such as smart greenhouse, muscle pump of life (see Table 3A), playing, developing, growing (see Table 4A), smart cradle biodiversity of Kazakhstan, automated street lighting systems and training in creating AR objects. The developed STEM projects were evaluated using the criteria assessment at three levels (low, sufficient and high). The qualitative data were obtained that made it possible to evaluate the following knowledge and skills of students in project development due to a system of criteria assessment:

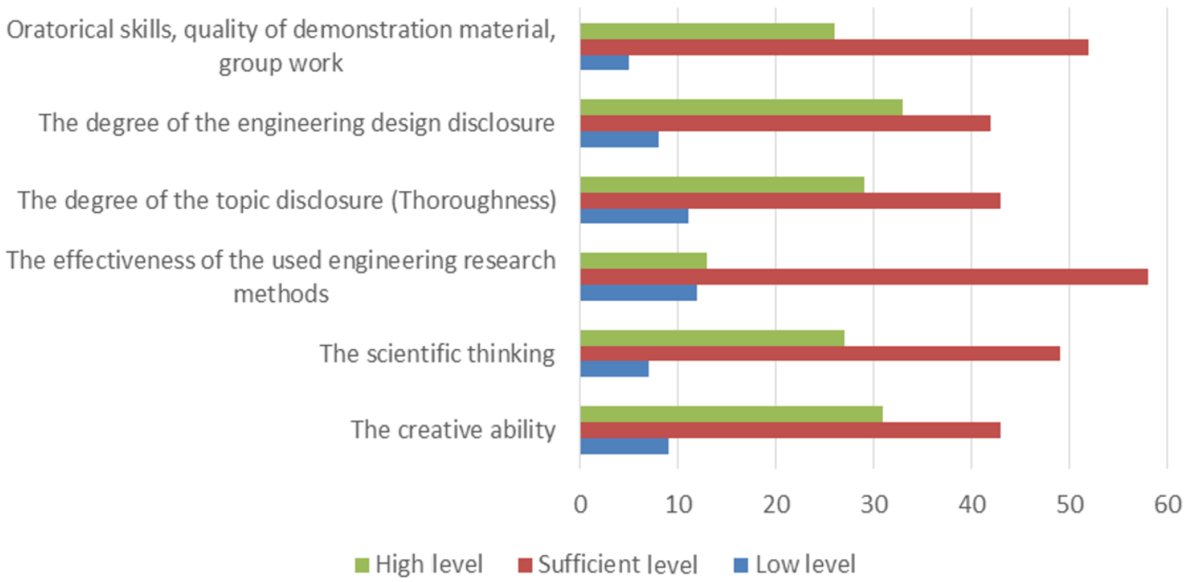

Figure 4. The result of the assessment of the students' knowledge and skills in the STEAM projects development (The experimental group).

The histogram reveals that a small number of students showed a low level of knowledge and skills assimilation in "the degree of the topic disclosure", "the effectiveness of using the engineering research methods", "scientific thinking" from the results of the projects evaluation (see Figure 4). The basics of scientific research are studied in the fourth year of study after this course. In this regard, students experienced challenges at these stages of project development.

The analysis of data on the level of development of engineering thinking skills among future computer science teachers is presented in Table 2.

Table 2. Data on the level of engineering thinking development among the pre-service IT teachers at the stage of the entrance and final control.

Skills	Low level		Sufficient level		High level	
	EG	CG	EG	CG	EG	CG
Creative ability	9	23	43	38	31	18
	11%	29%	52%	48%	37%	22.7%
Scientific thinking	7	27	49	43	27	9
	8%	34%	59%	54%	33%	11.3%
The effectiveness of the used engineering research methods	12	27	58	43	13	9
	14%	34%	70%	54%	16%	11.3%
The ability to design and implement engineering models and prototypes	11	29	43	33	29	17
	13%	37%	52%	42%	35%	21.5%
The ability to work in a team and the organization in the distribution of roles	8	21	42	39	33	19
	10%	27%	51%	49%	40%	24.0%
Knowledge and skills in using digital tools in solving tasks	5	17	52	43	26	19
	6%	22%	63%	54%	31%	24.0%
Engineering design skills	8.67	24.00	47.83	39.83	26.50	15.17

The results indicate that improvement is confirmed by the positive dynamics of the average student performance in terms of academic performance. The students of the control group have an average score during the final control of 39.83 points at the sufficient level. In the experimental group, the average score during the final assessment is 47.83 points which corresponds to an increase in academic performance of 8 points. The evaluation indicators among the students of the control group during the final control is 15.17 points at the high level, in the experimental group the average indicator during the final assessment is 26.50 points which corresponds to an increase in the academic performance of 11.33 points. Meanwhile, the performance indicators at a low level decreased markedly in the experimental group and amounted to 8.67 points which is 15.33 points lower than in the control group.

The r-Pearson linear correlation coefficient was chosen to determine the proportional variability of these levels of engineering thinking skills development with a normal distribution of values. The use of the Pearson correlation coefficients is used for the data that can be considered quantitative and normally distributed. These coefficients help determine how strongly one variable is related to another which is useful when analyzing the educational data such as student performance and motivation. The distribution of the data for the experimental group (EG) and the control group (CG) according to the indicator "engineering design skills" is shown in Table 2.

The coefficient measures the linear relationship between the two quantitative variables and is calculated using the following formula:

$$r = \frac{n\sum(x_i y_i) - \sum x_i \sum y_i}{\sqrt{[n\sum x_i^2 - (\sum x_i)^2][n\sum y_i^2 - (\sum y_i)^2]}}$$

Where

- x_i and y_i - are the values of two variables.
- n - is the number of pairs of values.

After calculations, the Pearson correlation coefficient for the engineering design skills data is approximately 0.67. This indicates a moderately strong positive linear relationship between the indicators in the experimental and control groups. The analysis of the indicators shows that the introduction of the STEM technology curriculum and the use of the cross-cutting technologies and the STEM projects in the training program for the pre-service IT teachers is effective and becomes relevant since significant and positive results have been obtained.

Thus, this research allowed determining the effectiveness of the approach based on the project-based STEM learning, student teamwork, research activities and the use of cross-cutting educational technologies for the author's integrated STEM projects development.

6. DISCUSSION

The purpose of this research was to develop the engineering thinking skills among the pre-service IT teachers with the cross - cutting educational technologies using and the development of the STEM projects. The educational reforms emphasize the need for students to develop the engineering thinking skills necessary to compete in the global labor markets, including academic, technical and social skills (Breiner, Harkness, Johnson, & Koehler, 2012; Deming & Noray, 2020; McGunagle & Zizka, 2020). The inclusion of the engineering design process in the training of the pre-service IT teachers is useful for improving their cognitive structure in engineering thinking. During the experiment, the elective course "STEM technologies" was introduced into the training program for the IT teachers at Margulan University. The conceptual model of the training of the pre-service IT teacher in the metaverse conditions has been built in which special attention is paid to the activities of the students working on the project tasks to create specific products (prototypes and models).

Learning through the cross-cutting project-based educational technologies allowed students to design and develop the project to solve real-world problems from the metaverse and the teaching staff performed an advisory role within the framework of experimental training. The control and experimental groups were identified for the organization of training. The training was traditionally conducted in the control group. In the experimental group, training was based on the use of the cross-cutting technologies in the STEM projects development. The interest in developing engineering and design thinking among university students through the introduction of STEM projects into the educational process is discussed in the works (Wind et al., 2019). According to the highlighted principles of the engineering design by Roehrig et al. (2021) training in the experimental group was based on the following three main stages: the motivational section, the engineering research design section and the productive section. In accordance with the stages and principles of the engineering design implementation, the criterion observation map was built and verified for the developed STEM projects. During the development of the project, the students plunged into the process of the engineering design in solving real problems and developed the author's product. In turn, Atman et al. (2007) and Hynes (2012) proposed to implement projects through phased engineering design, the final product of which will be a project that develops the engineering thinking among the students. As an example, the two integrated STEM projects are presented, working on which the pre-service IT teachers have developed the author's product through the cross-cutting technologies in the direction of STEM and the teacher guide with worksheets for this project.

On the one hand, developing the author's product, the students delve into the stages of the engineering design in more detail, developing the engineering thinking skills. On the other hand, develop the teacher guide with worksheets for the project and develop the professional skills in teaching.

It is worth noting that in several existing research on this topic, there is no practical application of STEM education based on applied projects with a detailed description of the implementation examples and developed methodological support for pre-service IT teachers. In this research, upon graduation, the pre-service IT teachers developed the teacher guide with worksheets. Students will be able to use their own developments in their further professional activities.

At the next stage, the practical teachers and STEAM experts monitored the learning outcomes and evaluated the developed projects.

The results of the control stage determine the sufficient effectiveness of training with the cross-cutting technologies and the STEM projects in the engineering thinking skills development for the pre-service IT teachers. Thus, the participants of the EG showed a sufficient and high level of academic performance at the control stage. It was noticed that the students showed enthusiasm, interest in studying the course, and a desire to contribute to the development of the region through the development of their product. They showed a desire to work in a team and showed solidarity while implementing the STEM projects.

The calculation of the correlation for the entire group of respondents confirmed the importance of the STEM education for the engineering thinking skills development among the pre-service IT teachers. The result indicates a moderately strong positive linear relationship between the indicators in the experimental and control groups. Thus, according to the analysis of indicators, the implementation of the STEM technology curriculum in the training program for the pre-service IT teachers is effective and positive results have been obtained. The project-based learning through the integrated STEM projects provided the participants of the experimental group with useful knowledge that they can apply in their professional practice.

7. CONCLUSION

As a result of the research, new ways were identified for the engineering thinking skills development through the STEM projects development and the cross-cutting educational technologies using. The integrated STEM projects through the cross-cutting technologies are an effective means for developing engineering thinking among the students. They allow them to use knowledge, skills and creativity to solve practical problems. As part of the research on the cross - cutting technologies in STEM, learning is considered an effective tool for the engineering thinking development. This approach is applied within the framework of the STEM technology course, which is part of the training of pre-service IT teachers in the field of STEM education.

Two research questions were identified in the article. The conducted experiment proves that integrated STEM learning through cross-cutting educational technologies based on the projects effectively affects the engineering thinking development. The students who participated in the experiment significantly improved the level of their engineering thinking. This confirms the value of ongoing research studying students at different stages of their studies and as they progress along the educational trajectory.

The proposed model of training the pre-service IT teacher in the metaverse environment consists of the following three sections: motivational, engineering research design and productive. Each section has its own functional significance in the IT teacher training course. The principles of integrated STEM learning, considered in the model make it possible to implement the interdisciplinary approach and research activities in the teacher training, develop projects with real tasks from the metaverse, instill engineering design skills, work in a team and use the cross-cutting technologies. The results of this research show that the model of training the pre-service IT teacher can increase the level of engineering thinking of the pedagogical university students.

8. RECOMMENDATIONS

8.1. Recommendations for teachers of the Pedagogical University

The study shows that a curriculum aimed at developing engineering thinking skills based on the use of the cross-cutting educational technologies and the integrated STEM projects can be an excellent tool for developing engineering thinking skills among pre-service IT teachers. Thus, it can be useful for the teachers who seek to improve the competencies and skills of students.

8.2. Recommendations for Teachers of Secondary Schools

The study showed the effectiveness of the design and the problem-based research method based on the use of the cross-cutting educational technologies combined with the integration of several subject areas in relation to engineering design. We recommend using this approach for the school teachers in teaching STEM technologies, robotics, and extracurricular activities.

8.3. The Prospect of Further Research

One of the new areas is the application of artificial intelligence in STEM education in addition to the complex integration of the relevant STEM fields based on the use of the cross-cutting educational technologies. Many studies are devoted to the problems of integrating various artificial intelligence methods and complex educational elements to meet learning needs, identify educational and technological effects in STEM education. The author notes that the potential of artificial intelligence in the cross-cutting educational technologies to improve STEM education is a fertile ground for further study of the integration of technology and the educational system.

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Appendix A

Table 3A. The integrated STEM project "muscle pump of life".

STEM project		
Day: 04/28/2023	Topic: Development of the author's STEM project	Course: 3rd year -average target level of knowledge
Section: Research work in the STEM direction (Engineering design)	Lesson objectives: To develop the author's product in the direction of STEM and teacher guide with worksheets for this project.	Required materials: Software for project implementation, 3D printer and scanner, filament, laptops, tablet, video clip, materials for prototype modeling, internet access.

As an example, consider the project of the third – year students B.A. Akhmetov, Zh.D. Bakytzhan, M.K. Kairulla on the topic "Muscle Pump of Life" for children 9-13 years old. The project has been developed for middle school students in the STEM direction using the cross-cutting educational technologies based on 3D, which will help to integrate the studied topics in the subject areas of Biology, Fine Arts, Mathematics, Chemistry, Computer Science, Technology, and Engineering. The methodological guide for the engineering design and implementation of a 3D model of the heart organ is being developed. The relevance lies in the development of engineering skills through the STEM-projects.

The interdisciplinary approach is used on the lesson, in which joint educational activities of students and teachers are carried out. In the process of the project activity, both of them master the skills of engineering thinking. The point of the requirements for the integration of sciences has been fulfilled. In this regard, when researching the topic, the students will plunge into various fields, for example Biology, Computer Science, Pedagogy, Teaching Methods, Design, Modeling, 3D Printing, Mathematical Calculations, etc. The students are along with interdisciplinarity and integration of knowledge.

The students explore the structure and functions of the heart and transfer their acquired knowledge to the design of the 3D model and print the finished product. Figure 5A illustrates the product obtained through the 3D modeling process.

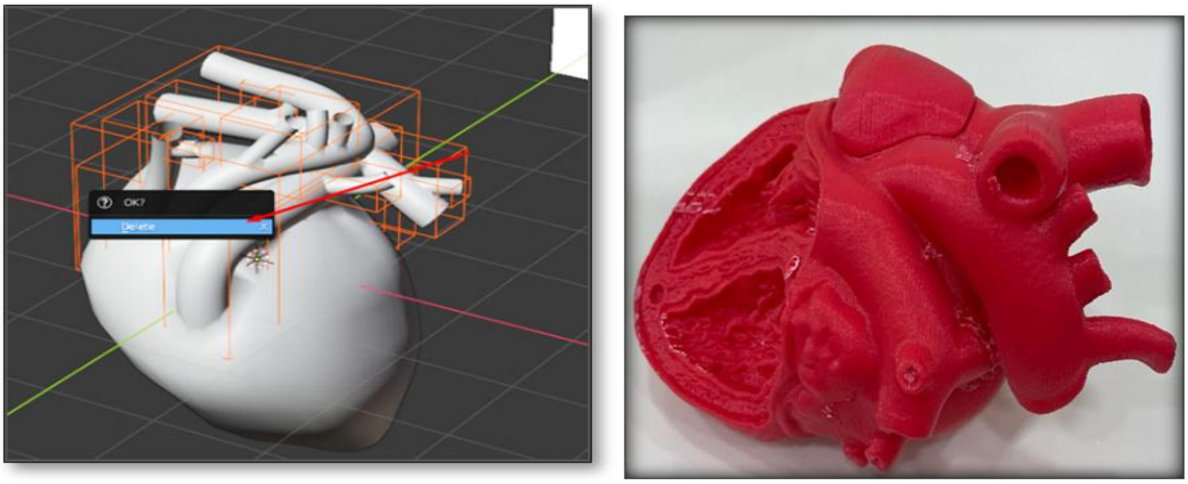

Figure 5A. The finished product - the 3D model of the heart.

The finished product was printed on a modern device designed for the production of high-quality 3D objects.

The project-oriented work has a kind of applied nature. To build the model, the physiological structure of the heart was studied thoroughly for detailed design and printing of the prototype.

In the process of the problem-based research approach conducted by the students together with the teacher and other members of the project group, the ability to interact and to solve tasks is developed. The product obtained in the course of activity is important. An effective collaborative environment is also being formed: teamwork on one project.

After designing and implementing the 3D heart prototype, students begin to develop the last item so that the development of a Teacher Guide with Worksheets for this project. Figure 6A shows fragments of the Teacher guide. The developed «Muscle Pump of Life" Teacher Guide is a step-by-step instruction on how to complete a project for the teachers. It consists of an introduction – key information, a developed series of lessons with explanations and tasks in the form of worksheets.

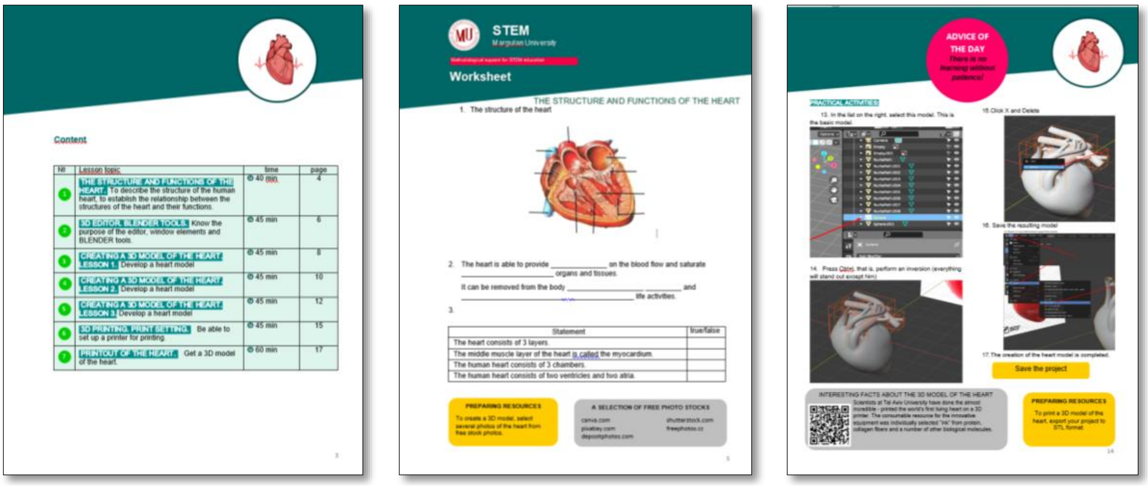

Figure 6A. Fragments of the "The muscle pump of life" teacher's guide.

The development includes a series of lessons developed considering modern teaching approaches and containing detailed information on the author's project.

The assessment is carried out by the presentation and defense of the final product, and by the developed Teacher Guide with Worksheets.

Table 4A. The integrated STEM project "playing. developing. growing up".

STEM project		
Day: 04/28/2023	Topic: Development of the author's STEM project	Course: 3rd year -average target level of knowledge
Section: Research work in the STEM direction (Engineering design)	Lesson objectives: To develop the author's product in the direction of STEM and teacher guide with worksheets for this project.	Required materials: Software for project implementation, 3D printer and scanner, NPD (Numerical printing device), filament, laptops, tablet, video clip, materials for prototype modeling, Internet access.

As an example, consider the project of the third - year students S.R. Alipbayeva, A.A. Baktybai, J.O. Baysal, S.K. Mursalim on the topic "Playing. Developing. Growing up" for children of 2-6 years old.

The project has been developed for children with special educational needs, in particular, training instructions for the development of sensory motor skills of the hands are being developed.

The interdisciplinary approach is used on the lesson using the cross-cutting educational technologies based on 3D, numerical printing devices, chatbots, in which joint educational activities of the students and the teachers are carried out. In the process of this activity, both of them master project thinking. The point of the requirements for the integration of sciences has been fulfilled. In this regard, when researching the topic, students will plunge into various fields, for example, Computer Science, Pedagogy, Psychology, Teaching Methods, The Use of Design Technologies, Construction, 3D Printing, Mathematical Calculations, etc.

The students explore the impact of hands and fingers motor skills development on the psychological development of children with special educational needs using gaming technologies. At the next stage, various games are selected. After that, based on their knowledge of the technologies studied during the study of the STEM technology discipline (Design and Construction in the Field of Robotics, 3D Modeling, 3D Printing, Augmented and Virtual Reality, Learning the Basics of Artificial Intelligence in Education, etc.), the students begin to develop handouts for games.

Figure 7A illustrates fragments of work on the project when creating handouts.

Figure 7A. Fragments of work on the project.

The following cross-cutting educational modeling and 3D printing technologies, calculations and wood cutting on a numerical printing device were used in the development of the material. Figure 8A illustrates the process of 3D printing and wood cutting.

Figure 8A. The process of 3D printing and wood cutting.

When working on the project, problems related to the student's life are considered. The context that is interesting, important and relevant now.

In the process of the joint research conducted by the student together with the teacher and other members of the project group, the ability to interact is developed. The product obtained in the course of activity is important. An effective collaborative environment is also being formed: teamwork on one project.

Students fulfilled the point of the requirements for the «National Priority of Kazakhstan» during the development of the puzzle. The pictures from folk tales were used as images for the puzzle

Another item that meets the requirements for the final product is the Telegram Bot "Balaqai Bot", created to support the project. The Bot contains all the useful information about the project. It describes the positive impact on the mental development of children using the games proposed in the project. The classification of games by age is proposed. The bot contains the instructions for all the games developed in the project, as well as the video instructions for the modeling such games. Thus, the information contained in the Bot will be useful for both children, students, and teachers.

Figure 9A illustrates fragments of the Teacher guide. "Playing. developing. growing up". The developed Teacher Guide "Playing. developing. growing up" is a systematic instruction for teachers. It consists of an introduction – key information, a developed series of lessons with explanations and tasks in the form of worksheets.

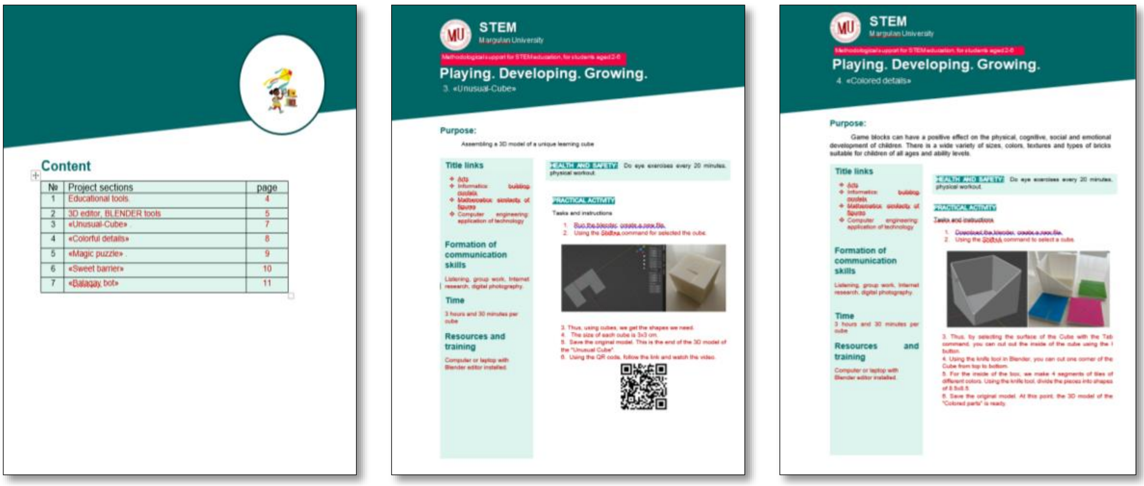

Figure 9A. Fragments of teacher guide "Playing. developing. growing up".

The development includes a series of lessons using the cross-cutting educational technologies and containing the detailed information on the author's project.

Thus, the students master not only knowledge and technologies in the field of STEM, but also learn to transfer knowledge as pre-service teachers through active teaching methods, through collaboration, group work, mutual learning, research method, etc.

The assessment is carried out by the presentation and defense of the final product, and by the developed Teacher Guide with Worksheets.