Project-Based Learning as an Integration of Critical Thinking and Teamwork Skills of Future Teachers of Mathematics and Computer Science

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Abstract. The paper analyzes and suggests different ways of modeling students' project activities through the components of the pedagogical process, such as content, operational, diagnostic and effectiveness. Critical thinking and teamwork skills of students are substantiated as integrated and dynamic personality traits that reflect the formation of soft and hard skills, as well as the ability of self-development. The study is the implementation of a project-based learning for students as an integration of critical thinking and teamwork skills of students through digital technologies and computer mathematics. The matrix reflecting the dependency of a student's critical thinking skills on the ability to work in a team during educational projects has been developed, tested, and analyzed. The study proves that the integration of critical thinking and teamwork skills of students through digital technologies and computer mathematics affects self-development, improves academic performance, develops soft and hard skills through project activities, the synthesis of which is the professional competencies of a future specialist.

Keywords: Project-Based Learning, Critical Thinking, Teamwork Skills, Self-Development, Digital Technologies, Future Teachers of Mathematics and Computer Science.

1 Introduction

Today, digital technologies are an integral part of teachers' professional activities, students' educational activities, and their self-development [1]. Practical experience of using interactive methods and information teaching technologies at a pedagogical university shows that project-based learning is among the most effective tools for combining them. Projects in the training of future teachers are implemented through digital technologies and educational project management; educational projects: key to the devel-

opment of students' professional skills; building a society of the future through educational projects [2]. It is educational projects in students' learning activities that ensure the integration of critical thinking and teamwork skills [3].

The purpose of the study. The study is the implementation of a project-based learning for students as an integration of critical thinking and teamwork skills of students through digital technologies and computer mathematics.

Objectives of the study:

- to analyze the current state of scientific thought on the research topic;
- to describe the process of modeling students' project activities as an integration of self-education and self-development, teamwork, critical thinking, and digital competence development;
- to develop a foresight wheel of digital technologies for the implementation of students' project activities;
- to conduct and verify the results of pedagogical research on the topic of the study.

Project-based learning is an effective teaching method that allows students not only to study a particular topic in depth, but also to learn to think critically, make independent decisions, work in a team, and generate new ideas. That is why project-based learning as an integration of students' critical thinking and teamwork skills is relevant.

2 Materials and Methods

We agree with Petrescu's opinion [4] that the effectiveness of training and implementation of an educational project appears at the intersection of the coordinates of three elements that must be in balance: idea, action and result. According to Buhlai et al. [5], the experience of using active and interactive teaching methods in universities shows that one of the most effective teaching tools is project-based learning, which most accurately interprets real professional situations and allows for student-centered learning. They can be described as "a process of qualitative transformation of the educational environment for students, which aims to increase their autonomy and critical thinking skills based on a project based approach that encourages new means of curriculum development, teaching, and learning".

Project-based learning is "an active student-centred form of instruction which is characterised by students' autonomy, constructive investigations, goal-setting, collaboration, communication and reflection within real-world practices" [6].

A study of the effectiveness of the project-based learning approach as a way to engage students in learning [7] found a significant relationship between project-based learning and collaborative learning, disciplinary subject matter learning, iterative learning, and authentic learning, which in turn contributed to student engagement. The results show that the project-based learning methodology improves student engagement by enabling knowledge and information sharing and discussion. Thus, the project-based learning approach is highly recommended for use by students in education and its use should be encouraged in universities.

In the study of the impact of project-based learning on student academic achievement, a meta-analysis was conducted to synthesize existing studies that compared the impact of project-based learning and traditional learning on student academic achievement. The results showed that the overall weighted average effect size (d(+)) was 0.71, indicating that project-based learning has a medium to large positive impact on student achievement compared to traditional learning. In addition, the average effect size was influenced by subject area, location of the educational institution, hours of instruction, and information technology support, but not by educational level and small group size [8].

Mesía et al. [2] studied projects in education for the improvement of teaching. through a) digital technologies and management of educational projects; b) educational projects: key to developing students' skills; c) building the society of the future through educational projects. Petrescu [4] suggests the following steps to achieve a learning project: «conscious involvement and participation in the process of building knowledge by establishing links between previous experiences and transposing information into knowledge systems; orientation towards achieving objectives established starting from the awareness of the aspects that we intend to change through the project; measurable short- and long-term results "project success or sustainability". Lotsman et al. [9] concluded that the use of creative projects in the educational process is effective in increasing the learning motivation of first- and third-year students. Considering the approach to the project in terms of learning effectiveness, Petrescu [4] supports the opinion of colleagues that the involved persons should be "active and strategic; have an ability to cooperate, dialogue and create knowledge with others; can formulate objectives and action plans; monitors of the learning process and adaptable to new contexts". This makes it possible to differentiate learning depending on the level of knowledge and skills of students, their experience, individual characteristics of perception of educational material, ability to solve problems of varying complexity, etc. [10].

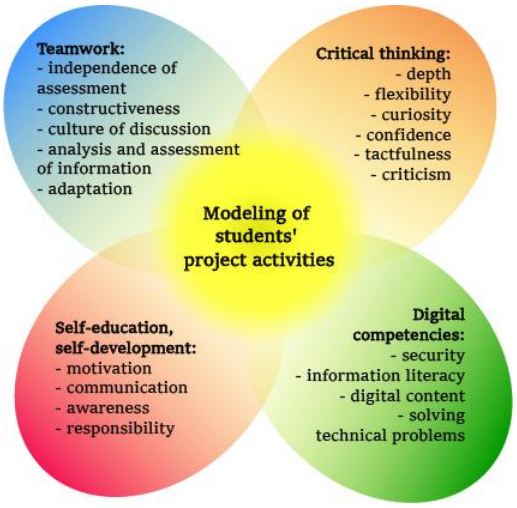


Fig. 1. Modeling of students' project activities (author's development) automatically.

By modeling students' project activities, we mean the process of qualitative transformation of the educational environment in a particular discipline, aimed at developing students' ability to work in a team, their ability to think critically, work with information through the development of digital competencies, which ultimately leads to the need for self-education and self-development. Details of the components of project activity modeling are shown in Fig. 1. These are the skills recognized as basic at the World Economic Forum in 2020 in Davos.

The modeling of students' project-based learning through the components of the pedagogical process (content, operational, diagnostic and effective) is carried out by using digital technologies and computer mathematics of the foresight wheel in the educational environment in lectures, practical and laboratory classes, during the control of students' learning achievements and the implementation of the principles of non-formal education. A systematic review of the literature on the contribution of digital technologies and pedagogical architectures to the learning process was conducted by Fiuza & Mocelin [11]. The evolution of educational technologies has led the scientific community of mathematics education researchers to the conclusion that the use of digital technologies has two main functions: (a) as a support for the organization of the teacher's work and (b) as a support for new ways of working and presenting mathematics [12]. In today's context, the use of technology for mathematics teachers has begun to have a third function: as a support for communication, community interaction, communication, and material sharing. Clark-Wilson et al. [13] added a fourth function, commercial and industrial, which is to support more independent work of students and focuses on the development and assessment of previously taught mathematical knowledge and skills in various online formats. To solve the problem of choosing a digital tool according to the type of lesson, we have developed a foresight wheel of digital technologies as an element of forecasting and preparing students for the lesson, which will help to realize the expected learning outcomes. When planning a lesson, the teacher chooses tools that are effective in helping students master the learning material (see Fig. 2).

The foresight wheel of digital technologies demonstrates the similarities and differences in the use of applications and online resources in the project-based learning of future teachers of mathematics and computer science:

- the first outer ring contains digital tools common to all types of educational activities;
- the second ring is divided into common tools for lectures and non-formal education, as well as combined tools for laboratory and practical classes and monitoring of learning achievements;
- the third ring distinguishes between tools for lectures and laboratory and practical classes, and combines tools for monitoring learning achievements and non-formal education;
- the fourth ring demonstrates tools that should be used only for the appropriate type of class.

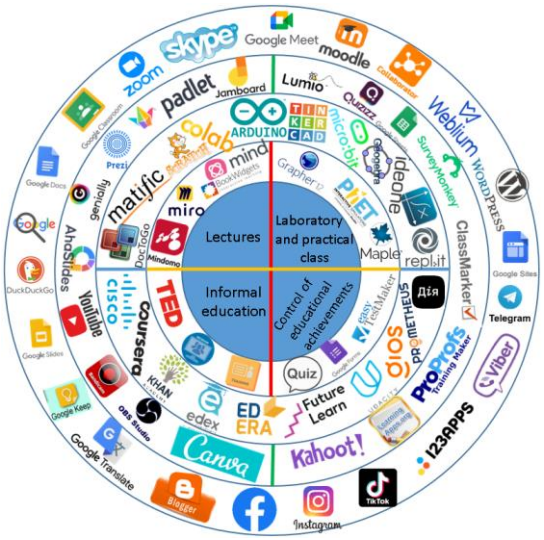


Fig. 2. Modeling the foresight wheel of digital technologies (author's development).

The use of individual applications and resources from the foresight wheel is demonstrated in the article on the example of the project "Modeling and Creating a Program for the Fire and Security Alarm System" in the discipline "Fundamentals of Robotics and Creative Programming".

The distribution of digital tools by types of students' educational activities is described in detail in the article by the authors [1].

Working in a team or in small groups develops students' skills of teamwork, professional communication, the ability to listen and perceive other ideas, offer their own and defend them with arguments. Psychologists consider work in small groups to be one of the most effective forms of learning, as group discussions increase learning motivation and develop students' communication skills [14]. We proceed from the fact that in solving the problem of forming students' cognitive interests in the study of professional mathematical and computer science disciplines, their analytical and synthetic activities play a leading role, since only under such conditions is it possible to form a system of knowledge and acquire skills in mathematical modeling in solving problems.

The main features of project-based learning in a team are:

- teamwork, where students learn to complement each other and work for the same result;
- the importance of the activities of each team member;
- communication;
- synergy, where the joint result can exceed the simple sum of the results of all team members;
- the possibility of discussing ideas;
- the opportunity for students to unleash their potential and creativity.

Students' project activities and the ability to work in a team effectively influence the development of students' critical thinking, by which we "understand a separate type of thinking that causes purposeful productive mental activity, characterized by the ability of a person to clearly identify the problem to be solved; independently find, process and analyze information; logically build their thoughts and justify them, think mobile, strive to find optimal solutions, be able to defend their own position, be open to perception, and be open to the perception of others" [3].

Table 1. Interrelation of basic concepts, personality traits and critical thinking skills.

Blocks of critical thinking representation	Personal qualities	Skills required for critical thinking
Analyzing a problematic message	Curiosity, good awareness, diligence in search of information, observation	The ability of an individual to clearly identify the problem to be solved; to independently find, process, and analyze information. The ability to comprehend one's actions and realize the schemes and rules by which one acts.
Understanding	Confidence, independence, responsibility	Logically build your thoughts and justify them; think in a mobile, dynamic way; strive to find optimal solutions. Ability to independently defend one's beliefs and find answers to objections; analyze information; use scientific methods, principles and rules of logic (argumentation, proof, negation).
Evaluation and self-assessment	Flexibility, balanced decisions, tolerance	Ability to reconsider one's own position. Ability to organize control and self-control; compare final results and goals, objectives, and action plan; analyze the causes of inconsistencies and own mistakes; make decisions to eliminate inconsistencies in work.
Constructive criticism, self-criticism	Impartiality, open-mindedness, courage in expressing opinions, tact, communication skills	Ability to analyze one's beliefs, arguments for critical evaluation and correction; self-assessment and self-correction; ability to actualize one's own qualities and those of other people; ability to defend one's own position, to be open to accepting other views

Ukrainian scientist Tiahlo [15] identifies the following blocks of critical thinking: analysis of a problematic message, understanding, evaluation and self-evaluation, constructive criticism and self-criticism. Based on the research of many scholars, as well

as their own research on students' project activities, the authors of the article have established the relationship between basic concepts, personality qualities and critical thinking skills (see Table 1).

3 Experiments

First-year students majoring in 111 Mathematics, 014.04 Secondary Education (Mathematics) can carry out creative projects: "Monotonic functions and their properties", "Convex functions and their properties", "Application of the derivative function of one variable".

First-year students majoring in 014.09 Secondary Education (Computer Science), 111 Mathematics, 014. 04 Secondary Education (Mathematics) while studying the discipline "Gamification in Education" carry out projects "Webquest in Teaching Informatics", "Comics in Mathematics Lessons", "Quizzes in Mathematics (Informatics) Lessons", "Dynamic Game Technologies in Education", which stimulates students to think creatively, develop critical thinking, seek solutions to problems and develop strategies to achieve goals, use modern digital educational technologies, work in a team, resolve conflicts and achieve common goals.

Second-year students majoring in 014.09 Secondary Education (Informatics) can carry out the project "Computer Classroom of My Dreams," which allows students to realize bold ideas and gain practical skills in designing a local area network for a computer classroom with Internet access using tools.

For third- and fourth-year students majoring in 111 Mathematics, 014.04 Secondary Education (Mathematics), we offer projects: "Modeling of real processes using differential equations", in which a student, solving applied problems (e.g., in physics, biology, economics, etc.), translates them into a physical, biological, or economic model (using computer technology), creates a mathematical model, solves a mathematical problem, and interprets its answer in terms of the content of a real applied problem. Similarly, the Mathematical and Computer Modeling of Systems and Processes projects are offered to students based on materials (topics) studied in numerical methods, optimization methods, and operations research.

The third-year students majoring in 014.09 Secondary Education (Computer Science) are offered the project "Modeling and Creating a Program for the Fire and Security Alarm System" in the discipline "Fundamentals of Robotics and Creative Programming". Projects in robotics and creative programming can be based not only on solving problems in the relevant field of human activity, but also on simulation modeling of the operation of specific devices or automation devices [16]. Therefore, the stages of their implementation may differ from those proposed above.

Let's consider the stages of the project "Modeling and creating a program for the Fire and Security Alarm System" in the discipline "Robotics and Creative Programming".

1. Analysis and selection of the necessary components to build a computer model of the selected system.

The study of the components showed that to create a computer model of the system in the Tinkercad Circuits Arduino environment, the following basic elements should be selected:

- arduino Uno board;
- breadboards (BreadBoards);
- motion sensor (RIP Sensor);
- gas sensor (Gas Sensor);
- temperature sensor TMP 36 (Temperature Sensor);
- 1 kΩ resistors (Resistors);
- light emitting diodes (LED);
- DIP Switch DPST;
- piezo element (Piezo);
- conductors.

2. Development of the block diagram of the system "Fire and burglar alarm" in the virtual development environment.

In Fig. 3. Block diagram of the Fire and Burglar Alarm system.shows the block diagram of the "Fire and burglar alarm" system. This diagram is created automatically in the Tinkercad Circuits Arduino environment.

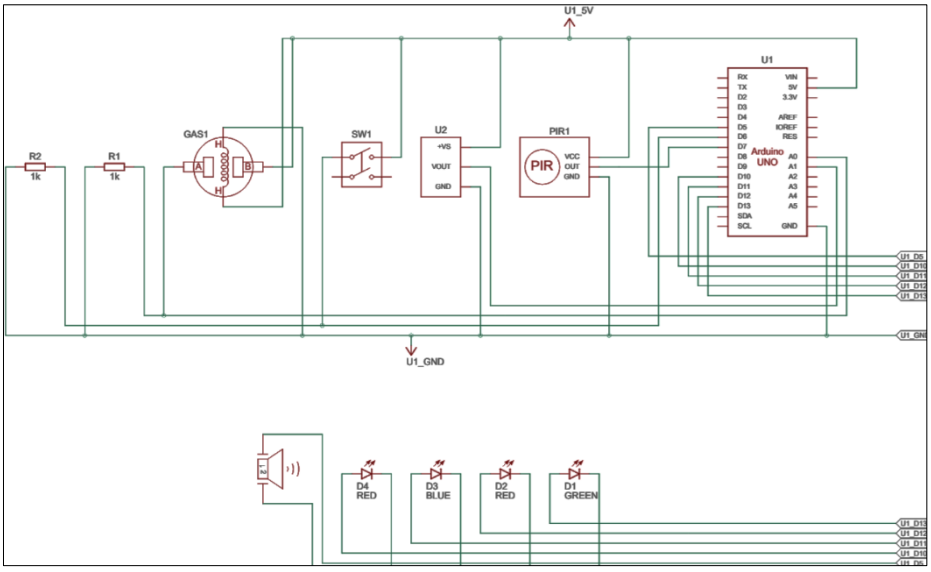


Fig. 3. Block diagram of the Fire and Burglar Alarm system.

The diagram shows the main elements of the subsystem, namely:

- Arduino UNO – debugging board;
- piezoelectric element – a device that will be used to generate sound notifications;

– RIP – motion sensor;
– GAS1 – gas sensor;
– SW1 is a switch;
– D1-D4 – LEDs;
– R1-R2 – resistors;
– U2 – temperature sensor.

3. Prototyping on the Tinkercad platform.

Tinkercad is an online service now owned by Autodesk, a company that develops professional CAD systems.

In Fig. 4 the final prototyping scheme for the Fire and Burglar Alarm system.

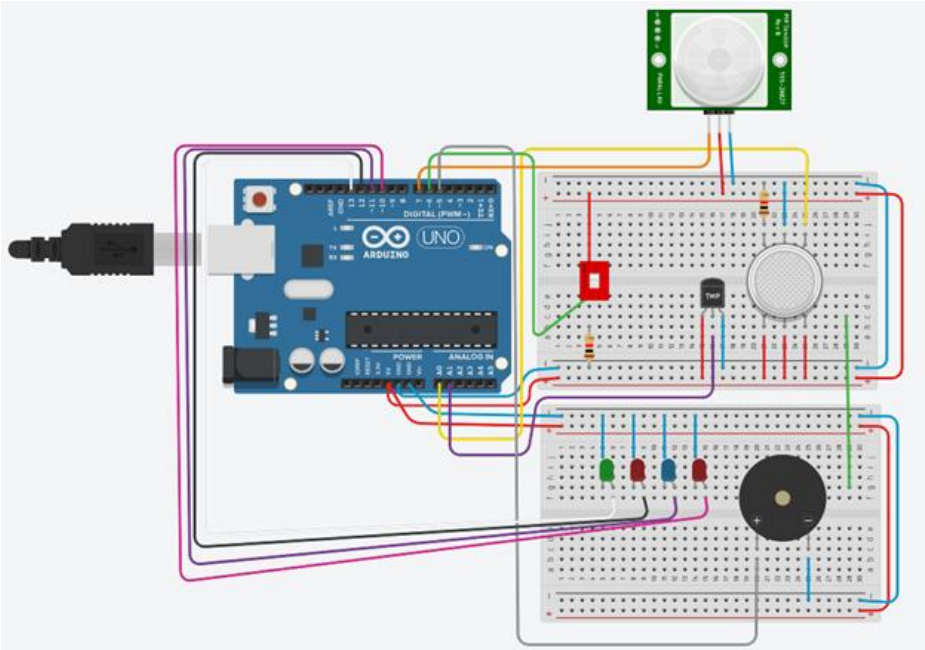


Fig. 4. Prototyping scheme of the "Fire and burglar alarm" system.

The Arduino UNO is used as the main microcontroller that receives and transmits data and commands to all elements. The piezoelectric element is used to send sound commands when the gas concentration and air temperature are above a threshold value. The sound signal also starts to sound when the motion detector is triggered. The activation of the alarm system is indicated by the LEDs turning on. The breadboards are used to better utilize the capabilities of the debugging platform, namely to connect the power and ground pins of the Arduino UNO board to the pins of the electronic components. The motion sensor is connected to digital pin 7 of the microcontroller board. The gas sensor and temperature sensor are connected to the analog pins A0 and A1 of the Arduino UNO board.

4. Performing the software implementation using the virtual development platform.

The code is written on the Tinkercad platform compatible with Arduino IDE and uses C++ as a programming language. It is also possible to write code in a simpler block programming language. In order to start writing the program code on the Tinkercad platform, you need to open the necessary field called Code, which is shown in Fig 5.

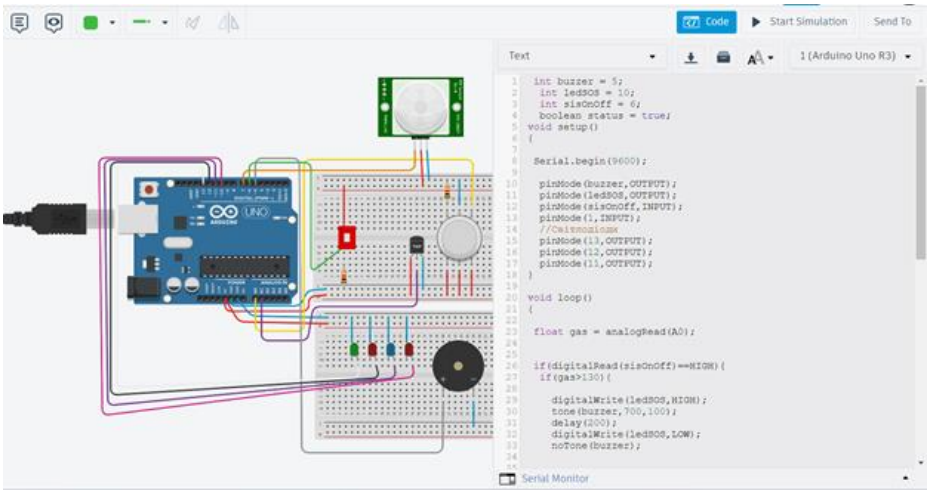


Fig. 5. A code snippet in the Tinkercad program.

The setup function is executed once at the beginning of program execution, and is most often used for single debugging of any technology, for example, to initialize a serial interface monitor, in the selected project, the setup function will also sound a beep to turn on the device. The loop function is the main function for writing code, because it is an endless loop during which the programmed commands will be executed. The loop function is where the commands are placed that will be executed all the time while the Arduino board is turned on. Starting with the first command, the microcontroller will reach the end and immediately jump to the beginning to repeat the same sequence. And so on for an infinite number of times (as long as the board is connected to power).

5. Simulate the system in the Tinkercad Circuits Arduino online environment.

To simulate the project and check the correctness of the program, use the "Start Simulation" button. If the program is written without errors that the compiler could not find, then the "Start Simulation" button will light up green, and the schematic design environment will display the actions that will be performed during program execution. During the simulation, you cannot make changes to the program code. In order to edit the code, the simulation must be stopped. During the simulation, it is possible to change the values on the necessary sensors or sensors.

The study is based on educational projects that are developed, tested, and implemented in the educational process of students of different specialties of the Faculty of Mathematics, Physics, and Computer Science of Vinnytsia Mykhailo Kotsiubynskyi

State Pedagogical University. The final sample included $N = 82$ students of the first to fourth year of the bachelor's degree (approximately 18-20 years old, 56 % female) studying in the specialties 014.09 Secondary Education (Computer Science, Mathematics) and 111 Mathematics. Students answered the questionnaire during regular lecture classes. The survey was conducted with the utmost respect for the privacy and confidentiality of students. The administration of the Faculty of Mathematics, Physics and Computer Science was informed in advance about the study. No consent was required from the students' parents, as all students were over 18 years old at the time of the survey. In addition, the survey was conducted in compliance with ethical standards, ensuring the safety and well-being of the participants, and the researchers received permission from the faculty administration. Throughout the project, the ethical standards of the American Psychological Association (APA) and the guidelines of the Ethical Code of the Scientist of Ukraine [17] were carefully followed. All activities were conducted online during school hours in the classrooms of the Faculty of Mathematics, Physics and Computer Science. Trained assistants were present during the data collection and provided students with guidance as needed.

The 1st-4th year students majoring in 014 Secondary Education (Computer Science), Secondary Education (Mathematics) and 111 Mathematics were asked to indicate the dependence of critical thinking skills on teamwork. This dependence is presented by means of a Google form in the form of a grid with multiple choices, which makes it possible to select one or more qualities of critical thinking personality that, in the student's opinion, affect teamwork (see Table 2).

4 Results

In our study, we conducted the project activities of students of mathematics and computer science specialties in small groups (2-4 students) and ended with a public defense of their own projects. Working in small groups (teams) has many positive aspects: it takes into account the individual characteristics of students, opens up significant opportunities for cooperation. This method of work does not deprive students of the opportunity to express their own point of view on solving a specific scientific or educational research problem and at the same time facilitates discussions, develops skills of collective search and collective decision-making. The main task of the teacher is to combine the work of each student without changing the style of activity, to obtain an optimal result: the first model the options for solving the problem, while the others offer the best solution.

In organizing project activities, we distinguish goals and objectives for first- and second-year students and third- and fourth-year students. In the first case, it is important to form a productive cooperation between the teacher and the student, focused on a creative understanding of the discipline, and, consequently, on professional development. Here, we propose a set of research-oriented tasks under the motto "Create it yourself," which involves the acquisition of skills in the following activities (as close as possible to scientific ones in terms of their equipment):

- the ability to create tasks independently and, on this basis, to form their own task bank;
- the ability to build an applied and mathematical model for practice-oriented tasks, solve a mathematical problem, and interpret the results for a specific practice-oriented task using computer technology;
- design new objects in the discipline and build a fragment of theory.

After completing their projects, future math and computer science teachers were asked to answer the question: "How do you think the development of a student's critical thinking skills depends on their ability to work in a team?" A multiple-choice grid was created in a Google form.

To highlight the integrative skills of working in a team from the standpoint of critical thinking of its members, we created an incident matrix reflecting the dependence of the qualities of critical thinking on the ability to work in teams. The sign of the concept of "team" is the ability to work in a team X=Xi, i=n, and the sign of the concept of "critical thinking" of the subject is the personality quality Y=Yj, j=m, where n is the number of rows and m is the number of columns in the incident matrix (see Table 2).

Table 2. The incident matrix reflects the dependence of critical thinking skills on the ability to work in a team (number of respondents).

Qualities	Skills Y=Yj								
X=Xi	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9
X1	82	61	53	58	44	36	27	17	45
X2	52	47	74	83	43	57	38	68	63
X3	34	67	53	19	81	83	64	58	56
X4	46	56	79	8	34	65	9	47	34
X5	66	16	84	63	26	19	41	58	38
X6	27	26	67	83	74	17	58	26	48
X7	34	79	28	35	68	74	76	12	83
X8	18	62	21	76	51	39	17	69	43

X1 – thinking independently, X2 – analyzing information through joint discussion; X3 – identifying problems and finding a way out of a situation, X4 – being constructive, contributing ideas and setting goals, X5 – honest and frank communication, X6 – open and constructive criticism, X7 – evaluating and changing points of view, trust and respect, X8 – having a culture of communication.

Y1 – curiosity, Y2 – diligence in search of information, observation, Y3 – confidence in your knowledge, intelligence, Y4 – confidence, independence, Y5 – responsibility, Y6 – flexibility, tolerance, Y7 – tactfulness, Y8 – communication skills, Y9 – ability to reconsider one's own position.

5 Discussion

The study was conducted by lecturers of the Department of Mathematics and Computer Science (see Fig. 6).

The study showed a correlation between students' critical thinking skills and their ability to work in a team, such as 1) curiosity and the ability to communicate honestly and openly, to think independently; 2) diligence in seeking information, observation and the ability to evaluate and change points of view, to trust and respect; 3) confidence in their knowledge, intelligence and ability to identify problems and be constructive, to propose ideas and set goals; 4) confidence, independence and the ability to analyze information through collaborative discussion and to criticize openly and constructively; 5) responsibility, flexibility, tolerance and the ability to identify problems and find solutions; 6) tact and the ability to reconsider one's position and the ability to evaluate and change one's point of view, to trust and show respect; 7) communication skills and a good communication culture.

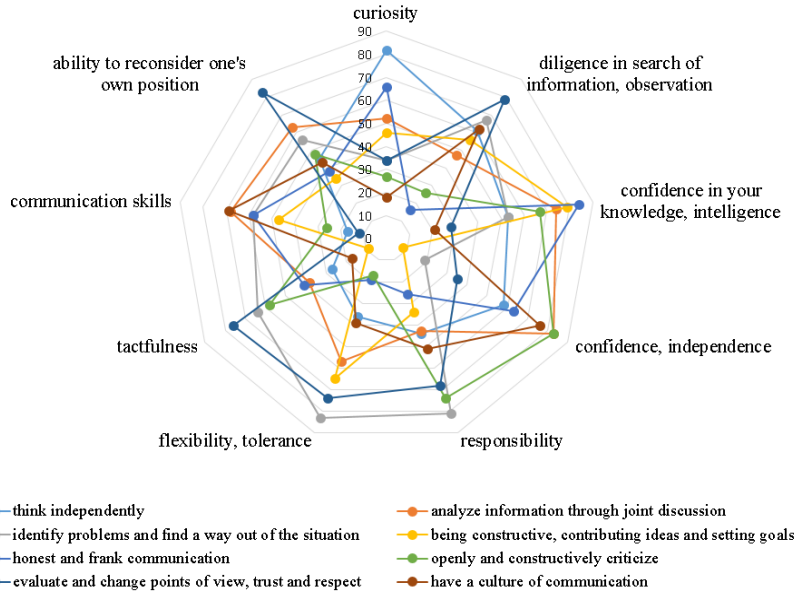


Fig. 6. Dependence of student's critical thinking skills on the ability to work in a team (author's development).

The results of our study correlate with the results of other researchers and confirm their relevance. For comparison, we considered related studies on student outcomes and measures of project-based learning in higher education [18], critical thinking as an important component of mathematical competence of future teachers of mathematics [3], areas that require special attention in terms of the need to research and consider them when developing project-based learning resources in universities [5] etc.

6 Conclusion

The authors analyze the current state of scientific thought on the research issue.

The study proves that the integration of critical thinking and teamwork of students by means of digital technologies and computer mathematics affects self-development, improves academic performance, develops soft and hard skills through project activities, the synthesis of which is the professional competencies of a future specialist.

A foresight wheel of digital technologies for the implementation of project activities of future teachers of mathematics and computer science has been developed.

The study showed that educational projects in university students' educational activities positively impact their cognitive activity and contribute to their professional development. From the very first year, these projects help students develop valuable skills, including:

- solving applied problems: By tackling real-world challenges, students learn to apply their knowledge and analytical skills;
- working with educational and popular science literature: This includes navigating various sources like textbooks, research papers, and even accessible scientific articles;
- utilizing bibliographic resources: Students gain experience using indexes, catalogs, and bibliographic databases to effectively locate relevant information;
- information analysis: They learn to identify key points and critically evaluate large amounts of data;
- digital technology and computer mathematics systems: The project fosters proficiency in using relevant software for calculations and data analysis. Work on the project and its public defense stimulates student activity, motivation and desire for self-development and self-education.

Work on the project and its public defense stimulates student activity, motivation and desire for self-development and self-education.

A pedagogical study on the topic of the work was conducted and its results were verified.

We see prospects for further research in analyzing the effectiveness of using project activities as an integration of critical thinking and teamwork of future teachers of mathematics and computer science to develop a university development strategy, formulate priorities for the development of the educational sector in society to achieve qualitatively new results in the development of the country, region, and community.

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