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MODERN WAYS OF PROBLEM-ORIENTED TEACHING OF APPLIED BIOLOGY IN THE FRAMEWORK OF DIGITALIZED STEM EDUCATION

Abstract. This article presents the experience of utilizing problem-based learning (PBL) in applied biology, focusing on solving real-world challenges within the framework of digitalized STEM education. The selection of topics for experiments was aimed at addressing specific issues relevant to the southern region of Kazakhstan, with practical problem-solving tasks assigned to the formed teams. The experimental study involved 81 participants, enrolled in the 3rd year of the educational Biology program at the Zhanibekov University in Shymkent. The level of team performance was determined using a self-developed assessment questionnaire based on the criteria of the PBL evaluation approach. Throughout the task execution and presentation stages, teams provided case studies that included presentations developed on modern online platforms, as well as FILA charts, which served as the main PBL tool. A comparative analysis of the effectiveness of problem-based learning was conducted between the control and focus groups. The research findings demonstrate that the experimental groups achieved higher evaluation scores in both case studies and test tasks. Furthermore, innovative and highly effective approaches emerged during the resolution of practical tasks. The experiments also revealed increased student interest in addressing real-world local problems in applied biology.
Keywords: problem-based learning, applied biology, focus group, FILA chart, performance efficiency, criterion-referenced assessment.

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Цифрландырылған STEM-білім беру шеңберінде қолданбалы биологияны проблемалық-бағдарланған оқытудың заманауи тәсілдері

Аңдатпа. Бұл мақала қолданбалы биологияда проблемалық оқытуды (PBL) пайдалану тәжірибесін ұсынады, бұл ретте цифрландырылған STEM білім беру шеңберінде нақты әлемдегі мәселелерді шешуге баса назар аударылады. Тәжірибе тақырыптарын таңдау Қазақстанның оңтүстік өңіріне қатысты нақты мәселелерді шешуге бағытталды, қалыптасқан командаларға практикалық есептерді шешу тапсырмалары берілді. Эксперименттік зерттеуге Шымкент қаласындағы Ө. Жәнібеков университетінің биология мамандығы бойынша білім беру бағдарламасының 3 курсында оқитын 81 білім алушы қатысты. Топтың тиімділік деңгейі PBL бағалау тәсілінің критерийлеріне негізделген өз бетінше әзірленген бағалау сауалнамасы арқылы анықталды. Тапсырма мен презентация кезеңінде командалар кейстерді, соның ішінде заманауи онлайн платформаларда әзірленген презентацияларды, сондай-ақ негізгі PBL құралы ретінде қызмет еткен FILA кестелерін ұсынды. Бақылау және фокус-топтар арасында проблемалық оқытудың тиімділігіне салыстырмалы талдау жүргізілді. Зерттеу нәтижелері эксперименттік топтар кейстерде де, тест тапсырмаларында да жоғары бағалау ұпайларына қол жеткізгенін көрсетті. Сонымен қатар, практикалық мәселелерді шешуде инновациялық және жоғары тиімді тәсілдер пайда болды. Тәжірибелер сонымен қатар студенттердің қолданбалы биологияның нақты жергілікті мәселелерін шешуге деген қызығушылықтарын арттырды.

Кілт сөздер: проблемалық оқыту, қолданбалы биология, фокус-топ, FILA кестесі, қызмет тиімділігі, критериалды бағалау.

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Современные подходы проблемно-ориентированного обучения прикладной биологии в рамках цифровизированного STEM-образования

Аннотация. В данной статье представлен опыт использования проблемно-ориентированного обучения (PBL) в прикладной биологии, с упором на решение реальных задач в рамках цифровизированного STEM-образования. Выбор тем для экспериментов был направлен на решение конкретных вопросов, актуальных для южного региона Казахстана, с практическими задачами по решению проблем, поставленными перед сформированными командами. В экспериментальном исследовании приняли участие 81 участник, обучающиеся на 3-м курсе образовательной программы по биологии в Университете Ө.Жәнібеков в Шымкенте. Уровень эффективности команд определялся с помощью самостоятельно разработанной оценочной анкеты на основе критериев подхода к оценке PBL. На протяжении всего этапа выполнения заданий и презентации команды предоставляли кейсы, включающие презентации, разработанные на современных онлайн-платформах, а также таблицы FILA, которые служили основным инструментом PBL. Был проведен сравнительный анализ эффективности проблемно-ориентированного обучения между контрольной и фокус-группами. Результаты исследования показывают, что экспериментальные группы достигли более высоких оценочных баллов как в кейсах, так и в тестовых заданиях. Кроме того, при решении практических задач появились инновационные и высокоэффективные подходы. Эксперименты также выявили возросший интерес студентов к решению реальных локальных проблем прикладной биологии.

Ключевые слова: проблемное обучение, прикладная биология, фокус-группа, таблица FILA, эффективность деятельности, критериальное оценивание.

Introduction

Contemporary pedagogical approaches introduce various innovations into the education system. This is initiated by the ubiquitous development of technology and, consequently, by teachers attempting to implement new technologies into teaching, enabling the comprehensive development of students in relation to the reality around them. Computers, tablets, online learning platforms, smartphones, virtual reality or artificial intelligence, among others, are increasingly being used in the educational process [1]. There are numerous studies on the opinions or attitudes of teachers, students and stakeholders towards the digitalization of education [2–3]. For instance, several Kazakhstani educators were investigating students' attitudes toward mobile learning in the modern real-world context. The objective of these studies was to enhance the coherence of educational programs and students' cognitive development, increase their interest in learning, and establish connections with everyday life by solving problem-based scenarios presented in class [4].

One of the innovative educational methods is problem-based learning (PBL), which is proposed to be divided into "pure" and "hybrid" types. The underlying concept of PBL is to utilize authentic, real-world contexts to construct a stimulating yet challenging learning environment [5]. Current challenges with PBL include its growing demand compared to traditional learning methods [6]. Problem-based learning has been identified as a more effective approach to education than conventional methods by numerous scholars. his enhanced effectiveness can be attributed to its ability to make educational programs more appealing, motivate teachers to adopt innovative pedagogical practices, and fosters the development of novel instructional techniques. The method's perceived advantages have led to its adoption by numerous prestigious universities worldwide. Empirical research has demonstrated that PBL supports systematic group work, increases students' interest in education and research, and promotes the development of skills in utilizing online resources [7].

PBL also faces a number of challenges that can reduce the effectiveness of the method. M. Kennedy [8] details among the problems the selection of the size of the task that forms the basis of PBL. If the task is a very small part of the curriculum, the program will become crowded with minutiae. If, on the other hand, the task is too extensive, effectively finding a solution may be difficult for both students and teacher to grasp. Another challenge is the tendency to succumb to trends. The use of the PBL method may be the result of a prevailing fashion rather than a real adaptation of the method to a given educational context, allowing for optimal learning outcomes. Another challenge relates to the preparation of teachers themselves to teach using the problem-based method. Newcomers in particular may find it difficult to use the method in an effective way [8].

With this in mind, it is necessary to conduct research on the quality and effectiveness of problem-based learning. It is particularly important to conduct this research in relation to participants in the learning process (including, in particular, in formal education) at different educational levels, from pre-school to higher education, as well as to educational systems in different parts of the world. Recognizing in this context a gap in the literature in relation to the educational system in Kazakhstan, our study aims to investigate the effectiveness of problem-based learning in practical tasks related to applied biology within the framework of digitized STEM education in one of the pedagogical universities in Kazakhstan.

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The scientific novelty of the study is the employment of the research in Kazakh context, in relation to underexplored field of higher educational system. For the first time, this study presents the results of problem-based learning in applied biology within the context of digitalized STEM education. It substantiates the potential for effective mastery of educational material through the resolution of real-world practical tasks, especially those relevant to urban environments. In addition to shedding new light on PBL, our study may benefit those involved in training future teachers as well as biologists who are considering using PBL to plan the educational process. It will enable them to determine how to tailor their teaching methods to better meet the expectations of their learners.

The theoretical part

Despite the widespread adoption of PBL, challenges remain in establishing high-functioning groups. Researchers from McMaster University in Canada [9] addressed this issue by studying group dynamics over time. They conducted focus group discussions with medical students enrolled in PBL programs. Students reflected on their experiences across four different PBL groups, constructing time-function graphs to illustrate the evolution of group functionality over 8 to 12 weeks. The authors identified three archetypes of PBL group development. In the first group (slow-paced), development followed a complex, gradual trajectory resembling Tuckman's model, often observed in inexperienced teams or those facing unfamiliar tasks. The second group (rapidly changing) experienced sudden shifts in functionality due to internal or external disruptions. The third group faced periodic declines, where maintaining group performance became a common challenge. Sudden changes and declines were more frequent in mature groups with extensive PBL experience. The study concluded that group functionality in PBL evolves according to three distinct patterns over time. Tuckman's classic stages are characteristic of inexperienced groups or those encountering new tasks, while experienced groups often face abrupt changes or stagnation. Based on these findings, the authors recommend that both instructors and students involved in PBL recognize the necessity of novelty and disruptions in more experienced groups to stimulate growth [9].

According to research conducted by RMIT University Vietnam [10], problem-based learning programs can contribute to achieving the Sustainable Development Goals (SDGs) through higher education curricula, learning materials, and relevant assessments, supporting large-scale learning in universities. Using the SDGs and their indicators as a basis for coding, the authors evaluated the learning materials of seven PBL programs. In the first phase, content analysis was conducted to assess the extent of sustainable development integration across 156 relevant courses. In the second phase, a semi-automated mapping protocol was applied to analyze the learning materials of 120 relevant courses. The findings from the experiments of international colleagues revealed that the programs align with the SDGs, encompassing a total of 60 indicators. The Game Design program led in this regard, while Professional Communication lagged. Conversely, the Fashion Enterprise program demonstrated the highest level of integration compared to the professional communication courses [10].

In another study on the development of mathematical connections through the use of a problem-based learning module, Indonesian researchers found that integrating PBL into modules can enhance both mathematical connections and habitual mathematical thinking. According to the authors, a deep understanding of mathematics as an interconnected system related to real-world situations improves cognitive skills and fosters the application of mathematical knowledge across various contexts. Through this module, students began to grasp the material within the context of its practical applications in everyday life [11].

A study conducted by the University of Rwanda (College of Education, University of Rwanda, Uganda) examined the impact of PBL, supplemented with YouTube videos, on secondary school students' understanding of physics. The study [12] gathered performance data through a

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physics achievement test, while student attitudes were measured through two surveys—one focused on problem-solving abilities and the other on critical thinking within the PBL framework using YouTube videos. According to the authors, the problem-solving approach survey and the motivational critical thinking scale are widely used tools in physics education. The experiment provides valuable insights into the impact of innovative teaching methods on students' academic performance, attitudes toward learning, and classroom practices. It addresses essential questions about the effectiveness of PBL approaches and their potential implications for science education [12].

The PBL method equips students with the ability to develop and apply a knowledge system in response to a given problem. In task-based learning, it is irrelevant whether the assigned task contains a specific correct or incorrect answer [13]. Several domestic scholars predict the integration of PBL with technological methods in modern education. For instance, a study by Kazakhstani researchers forecasts that online technologies will be widely employed in the future and will rapidly evolve with the support of modern innovations [14].

Research methods and materials

Objective: The objective of the experimental research was to investigate the effectiveness of problem-based learning in practical tasks related to applied biology within the framework of digitalized STEM education.

To achieve the research goal, the following tasks were formulated:

1. Investigate and analyze the results of implementing problem-based learning within digitalization through the applied biology module;
2. Develop criteria-based assessment parameters for PBL tasks (case studies, FILA charts, and presentation materials on online platforms) throughout the experiment;
3. Conduct a comparative analysis of the effectiveness of PBL within digitalized STEM education compared to traditional educational approaches.

Research Participants: As the study was designed to investigate the effectiveness of PBL in the authors' affiliated institution, the study sample was purposive. The study took place in the Department of Biology at the Zhanibekov University in Shymkent. The study involved 81 participants, enrolled in the educational program Biology. They were 3rd year students. The study sample included 40 students in the experimental groups and 41 in the control group (Table 1). The experiment lasted four weeks, with weekly monitoring of team activities focused on solving practical tasks. Classes were held 1 time for 100 minutes a week. In both groups, classes were conducted by the same mentor/teacher. The process of case generation, including the FILA table, was carried out only in focus groups. In the control groups, the results were formed in the form of traditional presentations. Special attention was given to the fair distribution of workload within teams and performance evaluation based on the established criteria.

Table 1 – Number of Participants in the Experiment

Total number of participants	Groups							
	Control groups (number of students)				Focus (experimental) groups (number of students)			
	Female	Male	Female	Male	Female	Male	Female	Male
	20	1	20	0	17	2	20	1
81	21		20		19		21	

The primary method employed was "pure PBL", aimed at solving pressing problems related to sections of applied biology. According to the curriculum, the experimental teams were assigned a real-world task: "Practical Measures for Restoring and Preserving the Productivity of Soil Used in

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the Agricultural Sector. A comparative analysis of the effectiveness of problem-based learning was conducted between the control and focus groups. The findings are presented in the 'Results' section.

Procedure: During the experiments, students were given the opportunity to present creative and novel perspectives on problems and suggest potential solutions. The primary stages of PBL in a digital environment within the focus groups consisted of the following steps:

1. Formation of Experimental Teams. At the initial stage, with the participation of the moderator (educator), experimental teams were formed, and key roles were assigned within each team. The subsequent steps of the experiment—familiarizing with the main problem and collaboratively dividing the problem-solving stages—were carried out independently by the teams. At these stages, the moderator's role was limited to observation. The formation of control and focus groups was carried out within the framework of study groups consisting of 19-21 students each. The approximate age of the participants in the experiment was 20-21 years. At the same time, it should be noted that both the initial educational level and the computer and communication skills of the participants in the groups had similar indicators on average. This fact made it possible to exclude situations when the best students fall into the experimental group. The majority of the participants in the experiment consisted of female students and four male students. At the same time, in one of the control groups there were exclusively female participants. During the experiment, students independently assigned roles in teams, including choosing a leader.

2. Setting the Core Problem Task Based on Subject Areas. This stage was preceded by a 50-minute introductory lecture on the theoretical foundations, supported by a video presentation in Canva. In addition, students have previously received additional information in the lecture collection. Nevertheless, the "problem assignment" involved the application of not only theoretical knowledge, but also the generation of new approaches and creative ideas in solving problems.

The experimental problem addressed a relevant topic related to the restoration and preservation of soil productivity in the agricultural sector in southern Kazakhstan. The task provided to the students was as follows:

"Soil fertility ensures not only crop growth but also enhances crop quality and productivity. However, in recent years, a significant slowdown in the vegetative period of crops has been observed. This issue results in decreased quality and volume of agricultural products. Additionally, the quality of cultivated soil is declining under intensive use. Your team's task is to find solutions to restore soil fertility in the agricultural fields of southern Kazakhstan".

3. Studying and Discussing the Task in Groups. This phase involved analyzing the root cause of the problem and exploring various solutions. Additionally, the Facts, Ideas, Learning Issues, Action Plans (FILA) chart was constructed at this stage.

The process of collecting and analyzing data on the problem was carried out for the next 50 minutes of the lesson with the support of a teacher who directed the focus of their attention. Also at this stage, the students made a plan and distributed the search areas among themselves. In the future, before the next lesson, all the teams independently formed cases. At the same time, the focus group participants classified the results of the analysis into the FILA table, which is a key tool for problem-oriented learning. It should be noted that the participants were not previously familiar with this tool. During the experiment, students could use mobile phones, as well as the results of the latest scientific research on this issue on special platforms of Internet resources. In addition, a list of the main educational sources needed in the search for information was provided. The preparatory period in the control and focus groups was a week. At the same time, only the experimental group, collecting material and generating ideas, worked with the FILA table.

4. Idea Generation and Action Planning to Solve the Problem. Generating ideas and planning actions to solve a problem. The students started searching for algorithms of actions and selecting the most constructive suggestions without the support of a teacher. During the discussion, focus group participants assessed the strengths and weaknesses of each preliminary idea. The

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moment of critical evaluation of ideas was conducted at the request of the teacher. Nevertheless, the selection of ways to solve the problem was carried out by the team independently. Arguments were put forward by all participants throughout the lesson, and the process of discussing and selecting each proposed idea lasted two days.

5. Case Presentations. All participants presented the outcomes of their work as a final step. In general, the final stage lasted for one week in all groups, but at different times. Each group presentation lasted for 100 minutes, including the discussion stage, the stage of answering the teacher's questions, and the assessment stage.

The primary tool used in the experiment was the FILA table [15], designed to facilitate problem-solving by breaking down tasks into multiple stages. This tool enables the structured organization of tasks, allowing for a more systematic approach. According to the FILA framework, all information within the focus groups was divided into the following components:

1. Identifying facts related to the given problem.
2. Generating ideas and hypotheses aimed at solving the tasks.
3. Analyzing the problem, its root causes, and potential consequences.
4. Developing action plans directed toward solving the tasks.

The FILA table is an intellectual tool used to foster students' thinking processes. It is actively employed during lessons that adopt a problem-based learning approach. In our experiment, the FILA table provided a systematic approach to problem-solving, simplifying both the participants' planning and the moderator's supervision of task completion.

Data analysis method: To assess the effectiveness of problem-oriented learning, a monitoring of academic performance was conducted within the focus groups at the conclusion of the experiment. The level of academic performance was determined using the criterion-based evaluation approaches for PBL that we developed. The proposed framework for studying PBL achievements is particularly relevant as it serves as a productive tool for STEM education (Table 2).

Table 2. Criteria for Evaluating Student Achievements in Problem-Oriented Learning

	Criteria for Evaluation	**Points**
1.	Reliability and Variability of Information (Facts)	1-5
2.	Focus of the Collected Basic Material on Seeking Solutions (Facts)	1-5
3.	Conclusions on Identifying Causes and Root Causes of the Problem (Facts)	1-5
4,	Solutions to the Problem Considering the Manifestation of Creativity and Fresh Perspectives (Ideas)	1-5
5.	Algorithms for Idea Generation Utilizing Digital Content Capabilities (Technological Presentations, Videos, Animations, Images) (Ideas)	1-10
6,	Relevance and Novelty of Proposed Solutions, as well as Their Complexity and High-Tech Nature (Topic Study)	1-10
7.	Level of Independence in Conclusions and Their Practical Value (Topic Study)	1-10
8,	Team Interaction and Level of Independence Among Participants (Topic Study)	1-10
9.	Quality of Presentation of the Completed Case, Volume of Developments, and Number of Proposed Solutions (Solutions, Action)	1-20
10.	Quality of the Report Considering In-Depth Study of the Topic and Proposed Solutions (Solutions, Action)	1-20
	Final score	100

The assessment of the achievements of the participants in the experiment was carried out by the teacher who conducted the lessons.

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Results

Participants used the FILA table to list the key facts of the problem and generate ideas for potential solutions. Throughout our experiments, the FILA table proved to be an effective pedagogical tool, helping to structure and simplify the problem-solving process. Furthermore, it enabled participants to focus on more complex aspects of the problem. By monitoring the FILA table during the experiment, we were able to observe the dynamics of progress and problem-solving within the focus groups (see Table 3). This table is based on the results of the work of the students of focus group 1, whose achievements amounted to the maximum results relative to other groups.

Table 3. The Problem of Restoring and Preserving the Productivity of Fertile Soil

Facts	Ideas	Group Discussion and Problem	Idea Generation and Action Plan
1.Irrational use of natural resources, including soil; 2.Non-compliance with agricultural practices for cultivated plants; 3.Exceedance of pesticide and other chemical compound limits; 4.Alteration of soil chemical composition from divalent cations (Ca) to monovalent cations (Na, K).	1.Implementation of optimal crop rotation elements; 2.Application of new technological methods for soil fertilization; 3.Investigation of soil structure, symbiotic components, and consistency in field conditions and in the laboratory.	1.Discussion and search for optimal solutions; 2.Investigation of issues related to soil compaction in cultivated areas; 3.Study of problems associated with the desiccation of the upper horizon in southern Kazakhstan; 4.Examination of the causes of reduced mechanical strength, buffering capacity, and yield in the soil of cultivated areas; 5.Comparative analysis of the intensity of agricultural land exploitation for the purpose of obtaining superprofits; 6.Use of satellite systems for monitoring agricultural fields; 7.Digital automated systems for controlling soil composition, cyclical irrigation, and fertilization.	Investigation of alternative solutions to the problem: 1.Comparison of new technologies for enriching soil composition (vermiculture, leguminous crops, bacterial preparations); 2.Implementation of new approaches to seed treatment using natural methods, as well as laser and other radiations; 3.Expansion of opportunities for soil enrichment with new alternative sources of nutrient biomass of algal, fungal, and bacterial origin.
SUMMARY: Soil is a vital natural resource.	Systematization of technological methods for soil rehabilitation.	Systematization of the causes of soil quality degradation; investigation of the application of digital technologies.	Structuring of action algorithms in real conditions.

However, the focus groups (M = 89.00, SD = 4.24) demonstrated significantly higher scores compared to the control groups (M = 75.50, SD = 3.54) in terms of the presentation of completed cases and the quality of reports, $t(2)=3.46$, p = .037 (1-tailed), as well as the proposed high-tech solutions (Figure 1). Conversely, a notable strength in the control groups was the superior knowledge exhibited by certain participants, who possessed more detailed information. For instance, some participants in the control groups provided quality conclusions regarding the identification of causes and root causes of the problem and displayed greater variability in gathering reliable information.

Creativity in addressing the proposed problem, along with the subsequent generation of productive ideas and methods of presentation in the cases, was particularly evident in the focus

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groups, especially in Focus Group 1. Thus, the high level of activity and communication fostered through four weeks of collaborative efforts resulted in superior achievements at the conclusion of the experiment (Figure 1).

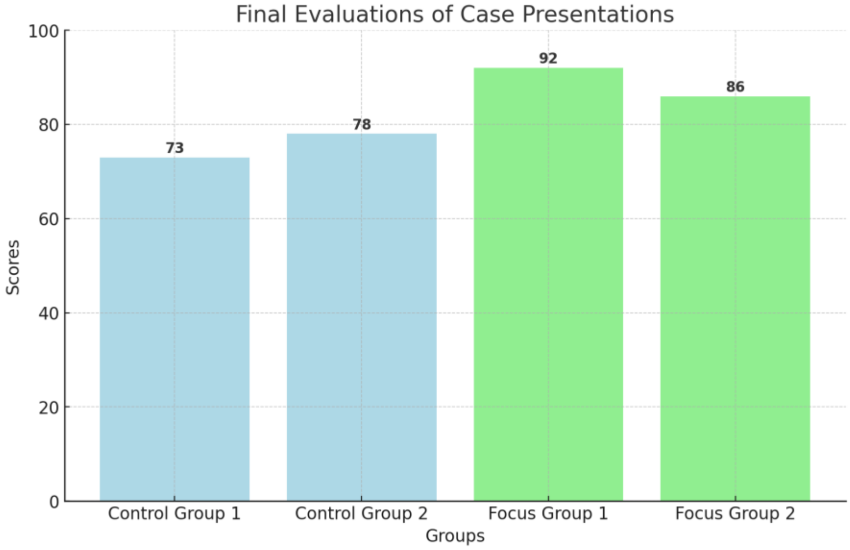

Figure 1 – Final Evaluations of Case Presentations material in the control and focus groups

The second stage of analysis, which examined the reasons and roots of the assigned problem, along with the subsequent generation of solutions, revealed the leading team. Focus Group 1 emerged as the leader at this stage, demonstrating a high level of creativity and a fresh perspective on problem-solving. Based on the results of the teacher's assessment, focus group 1 achieved the maximum result relative to other groups of 92 points (Figure 1).

At the third stage of the experiment, aimed at studying and developing algorithms for solving the problem while considering the high-tech digital capabilities of modern science, Focus Group 1 again had the advantage, based on results of the FILA table (Table 3). During this stage of the research, Group 1 paid particular attention to the possibilities of utilizing high-tech methods for analyzing the problem, such as satellite monitoring systems for agricultural fields. Additionally, the team considered the potential for using digital technologies. For example, they proposed the implementation of automated soil quality control, irrigation systems, and fertilization through a computer program.

The final stage of problem-solving, related to the generation of specific solutions, yielded equally high results in both focus groups. Specifically, both teams arrived at identical conclusions. The conclusions in Focus Group 1 were distinguished by the novelty of the proposed solutions, while Focus Group 2 primarily focused on the practical value of the suggested methods (see results in Table 4).

Table 4 – Results of Monitoring the FILA Tables in Focus Groups

Focus groups	Criteria evaluation indicator, points				
	Facts, (15 points)	Ideas, (15 points)	Learning Issues, (30 points)	Action Plan, (40 points)	Total points, (100)
1	13	15	28	36	92
2	12	13	26	35	86
Average	12.5	14	27.5	35.5	89

The stage of criterion-based evaluation of student achievements in the control and focus groups allowed for the identification of the total score values to compare the effectiveness of problem-oriented learning and traditional educational approaches. The calculation of total scores was determined using the following effectiveness calculation formula:

$$\mu se = \frac{K_0}{K_n} \cdot 100\%$$

where μse is the effectiveness coefficient of students for the given module, K_0 is the number of criteria achieved by an individual student, and K_n is the number of criteria achieved by all students in the focus group (Figure 2).

According to this figure, the effectiveness coefficient in both the control (*M* = 62.45, *SD* = 9.82) and focus (*M* = 81.35, *SD*= 1.34), $t(2)=2.69$, p = .057 (1-tailed) groups exhibited a pattern similar to the academic performance trend shown in Figure 1. Consequently, the results of the calculations demonstrate that the performance in the groups, on average, corresponds to the performance of a typical participant in the experiment. This result confirms the fact that the approaches to learning reflect on the level of academic achievement both within teams and at the individual level.

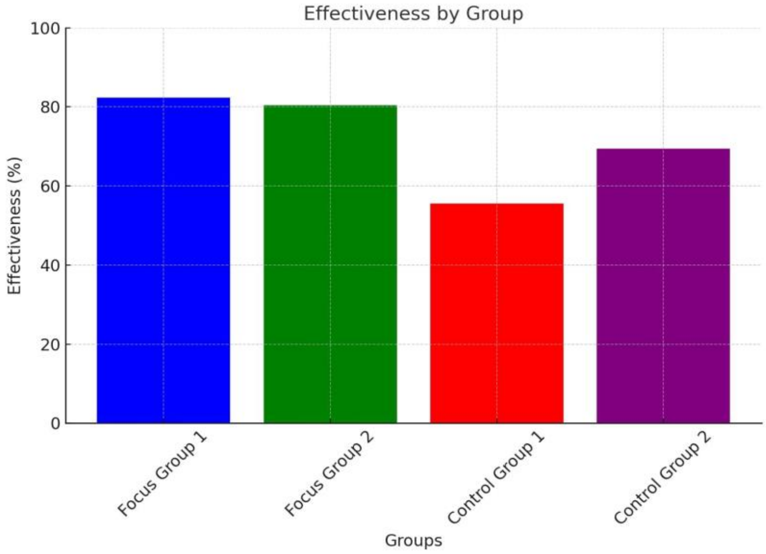

Figure 2 – Results of the Calculation of Academic Performance Effectiveness in Control and Focus Groups

The next stage of the research involved examining the academic performance of all participants over time. For this purpose, a comparative analysis of students' knowledge was conducted before and after the experiment. The monitoring tool used was the results of pre-tests and post-tests, designed based on biology modules. The assessment of initial knowledge and the knowledge gained after training was carried out using both univariate and multivariate test items. The pre-tests mainly consisted of univariate items and were evaluated as medium difficulty tasks. At the same time, the post-tests included multivariate questions, incorporating an advanced level of difficulty.

According to Figure 3, the baseline knowledge level in applied biology across all four groups was similar, with minor fluctuations of 1-3 points (*M* = 79.50, *SD* = 1.29, *Range* = 78-81). The final assessment revealed a predominant improvement in the focus groups (*M* = 92.50, *SD* = 0.71) with

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problem-oriented learning compared to control groups (*M* = 84.00, *SD* = 1.41). The difference in these groups was 7-10 points, confirming the superior potential of learning through real-world, practical problems (Figure 3).

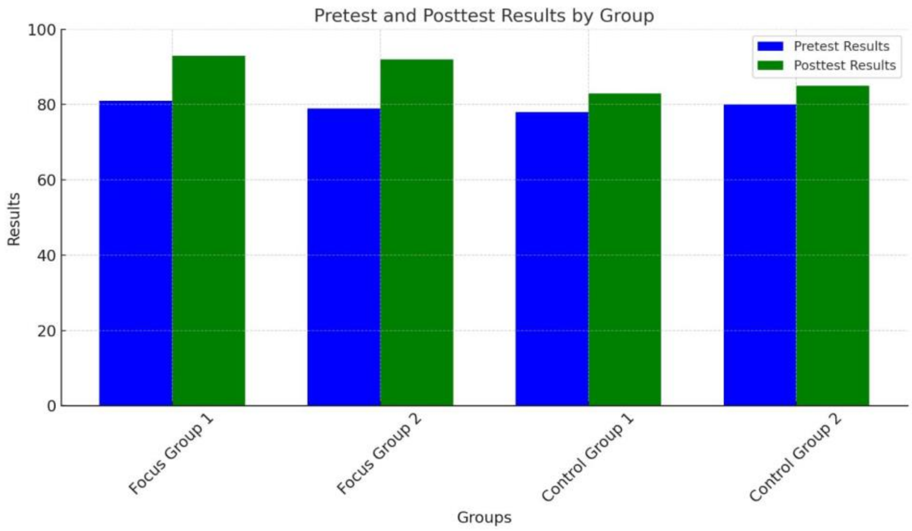

Figure 3 – Results of academic performance of the basic level of knowledge in applied biology pre- and post- testing in control and focus groups

Based on the pre-test results, all teams demonstrated a similar baseline level of knowledge on average. Following the post-test results, the academic performance in the focus groups increased by an average of 12.5 points, while in the control groups it increased by 5 points. The average post-test score difference between the control and focus groups was 7.5 points.

Discussion

The experimental results from our research allow us to define this approach as *"digital pedagogy"* – a product of the synthesis of creative pedagogical methods and the capabilities of digital technology, including elements of artificial intelligence. This finding is supported by studies from experts in modern pedagogy, who extensively use PBL [16]. The PBL has established itself as a valuable pedagogical tool with several advantages. Firstly, it develops skills for independent study and team-based discussion of knowledge. Secondly, it fosters practical competencies in structuring theoretical information and identifying key elements. Thirdly, it enhances critical analysis and self-reflection when generating new solutions.

According to our research results, various working styles were observed within the groups: logical, exploratory, and presentational. Additionally to the findings of Aranzabal and colleagues [17], the logical working style was exhibited by students as the ability to grasp the core of a problem, refine it, and apply mathematical and logical skills. The exploratory style was more commonly observed during the experimental and investigative phases, leading to the independent interpretation of problem features. Additionally, some students demonstrated strong presentational abilities, showcasing creative and unconventional approaches to problem-solving, as well as effectively presenting solutions.

The primary tool for both the experiment and the monitoring of learning dynamics was the FILA table, which allowed experimental teams to structure and determine the variability of the information they received. In addition to the basic use of the tool [18], monitoring of the FILA tables allowed not only for quantitative comparisons, but also for the qualitative observation of the overall dynamics of team work during the experiment. The comparative analysis of the sections of

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the table helped track all stages of problem-solving, starting from the establishment of facts. The initial stage enabled a comparison of the quality and reliability of the collected information in the experimental groups. Furthermore, the level of focus of the collected initial information for further generation of solutions was assessed. Based on teacher observations, following the four-week experiment, an analysis of achievements was conducted in both the control and focus groups based on the criterion-based evaluation system we developed (Table 3). The results revealed that the level of interest and depth of engagement with the assigned problem was higher in the focus groups. Additionally, there was a higher level of team interaction, which was linked to the initial distribution of responsibilities.

Additionally, we developed a criteria-based evaluation approach to assess the results of problem-based learning and analyze the outcomes of the assessments.

The analysis of the interaction and communication processes within the experimental teams, as well as the contribution of each participant and their level of independence in developing solutions, led to the following conclusions:

1. Problem-oriented biology education within the framework of digitized STEM education resulted in higher outcomes compared to traditional teaching approaches.

2. The comparative analysis of student achievements in the focus groups showed roughly similar results with a difference of 6 points out of a possible 100 points.

3. The investigation into organizational issues concluded that the level of preparation, presentation of cases, and interaction within the focus groups demonstrated significant advantages. These conclusions are supported by higher scores in evaluating the quality of reports, depth of study of the problem, and generation of solutions.

In determining the effectiveness coefficient across all groups participating in the experiment, the performance of teams, on average, corresponded to the performance of individual students. This result led us to conclude that creative teaching methods not only improve team performance [19] but also enhance the achievements of each individual participant. It is possible that real local issues, personally affecting each participant, evoke greater interest. This fact stimulates the personal engagement of project participants to delve into the root causes of the problem. Additionally, team-based idea generation and discussions require consideration of others' opinions. As a result, only productive ideas remain after critical discussions within the group. Collaborative problem-solving also allows for the problem-oriented selection of practically valuable options. Particularly relevant is the generation of new approaches using high-tech methods and digital technology capabilities. The advantages of problem-oriented learning within STEM education allow students to acquire professional competencies, which are undoubtedly reflected in their academic performance.

Conclusion

Modern requirements in STEM education, which demand more advanced professional competencies, stimulate the development of new creative teaching approaches. One of the most in-demand approaches is problem-based learning, which has proven to be a strong asset in contemporary pedagogy.

In our study, we examined the trajectory and outcomes of learning through the lens of a problem-based learning approach. Our aim was to gain insight into how the dynamics of this process and the dynamics of reciprocal group interactions apply to the subject teaching. A distinctive feature of our research is the use of real local problems related to applied biology tasks. Taking into consideration our university practices, finding solutions in this field does not always yield reliable positive results. Nevertheless, through the active participation of our students in focus groups and productive moderation by the teaching team, we achieved positive progress in solving the problems.

The limitations of the survey are a consequence of the methodology employed. An experiment was conducted at a selected Kazakh university with the participation of students enrolled in a biology course. As a result, we had minimal control over the size of the study group. Furthermore, the evaluation was based on the assessments made by the teaching staff. Therefore, the study does not include the opinions and self-assessments of the students, which could provide further insight into the results obtained. It would be beneficial for future research to encompass this component.

In addition to providing new insights into problem-based learning, our study may prove valuable for those engaged in training future educators and for biologists contemplating the integration of PBL in their educational strategies. This will facilitate the ability to adapt teaching methodologies in a manner that aligns more closely with the expectations of the learners.

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