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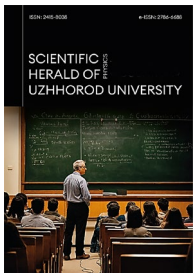

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Formation of students' research competence in the study of biology

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Abstract

Relevance. The research relevance is predefined by the contradiction between the potential of biology to form a competent person and the realities of teaching it. In modern literature, little attention is paid to the methodology of forming students' research competence during the study of biology. This motivates the search for new approaches to organising students' research activities.

Purpose. The research aims to develop, implement, and evaluate various forms of organising research activities to form students' research competence in the study of biology.

Methodology. The study utilized theoretical and empirical methods of data analysis, including Student's t-test and one-factor analysis of variance.

Results. At the beginning of the study, only one-third of the eighth-grade students had a high level of research competence. An elective course, "Applied Microbiology," was developed to allow students to conduct research work. Results showed that students who took the elective course performed better in research activities than the control class students, with a high level of reliability ($p<0.05$). Single-factor analysis of variance indicated a statistically significant increase in the number of students with high levels of research competence in the experimental class ($F_{amp} = 7.04$, $p<0.05$), whereas the control class showed no significant improvement ($F_{amp} = 0.73$, $p>0.05$).

Conclusions. The study demonstrates that traditional biology lessons alone do not significantly develop students' research competence. The "Applied Microbiology" elective course effectively enhances research skills, highlighting the need for innovative educational approaches. This course can serve as a model for improving biology education and fostering research competence among students.

Keywords: practical skills; competence-oriented approach; elective course; biological experiment.

Introduction

Today's society poses several issues for educators related to the preparation of mobile individuals capable of successfully applying academic knowledge as well as practical abilities and skills to solve assigned tasks. In addition, such a person should have a scientific type of thinking, be creative, and be socially active. One of the ways to address these issues is to apply the competency-

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based approach in education. Under the "State General Education Standard of the Republic of Kazakhstan", among other key competencies, research competence occupies an important place [1]. As defined by I.M. Castillo-Martínez and M.S. Ramirez-Montoya [2], research competence is an important characteristic of an individual who can independently plan and carry out research activities based on knowledge, skills, and a value-based system. Such a school discipline as biology seems very promising for the formation of research competence in students, as it involves a significant amount of experimental work. In addition, according to Y.V. Pochekayeva [3], in the Republic of Kazakhstan biology is included in the list of the most priority subjects for study.

R. Ristano et al. [4] believe that conducting a biological experiment promotes the acquisition of biological knowledge and skills, as well as the development of basic thinking operations (analysis, synthesis, classification, systematization, etc.) and creative abilities. Today the problem of the formation of research competence in students is relevant. Although many works are devoted to this problem in the modern psychological and pedagogical literature, there are still many unresolved aspects of this problem. Thus, the survey conducted by I.V. Shimlina and L.B. Suvorova [5] among 8th-9th graders in the Republic of Kazakhstan revealed that one-third of the respondents had no idea at all about conducting research activities, and just over 35% were not interested in conducting them). In addition, most students had difficulties with simple thinking operations, such as synthesis, analysis, and establishing cause-and-effect relationships. This situation occurs during classes when the teacher focuses on theoretical material, and research work is often not carried out, or is carried out in the monotonous form of writing essays. In addition, as pointed out by F. Böttcher-Oschmann et al. [6] point out that little attention is paid to the methodological aspect of developing students' research skills when studying school biology.

Modern education is aimed at the formation of a competent person in the process of learning. In addition, it is the organization of research activities is one of the main components of the process of formation of research competence of students. However, today in biology education there is a contradiction between the potential of this school discipline for the formation of research competence of students and the existing realities of teaching biology [7-9]. Despite the importance of this problem, now there are few published works on the effective organization of students' research activities. Thus, insufficient attention has been paid to the problem of how to develop research competence in biology. All the above motivates us to search for new approaches to the formation of students' research competence.

The research aims to develop, implement, and evaluate various forms of research activities as a means of developing students' research competence in the study of biology.

To achieve this goal, the following research objectives were formulated:

1. To develop and test the program of the elective course "Applied Microbiology" for the formation of the 8th-grade students' research competence in the study of biology.

2. To evaluate the level of research competence of students.

3. To develop and implement methodological instructions for the experimental work provided by the work program.

To evaluate the pedagogical impact of the developed elective course on the formation of the research competence of students.

Materials and Methods

Experimental work was carried out based on the communal state institution "Specialized Lyceum No. 20 for gifted children with learning in three languages" of the city of Taldykorgan of the Department of Education of Almaty region of the Republic of Kazakhstan. The study involved 40 8th-grade students. For the formative experiment, Class 8A was chosen as the experimental class (EC) and Class 8B as the control (CC) (20 people in each group).

At the beginning of the experiment, the test work was carried out in the control and experimental classes to assess the research competence of students. For this purpose, three levels of practical knowledge, skills, and abilities were identified: low, medium, and high. In the experimental class, in addition to the standard biology lessons, preparation for research was conducted in the classes of the authors' departmental course "Applied Microbiology". When teaching the students of class 8A to do research, 24 elective classes were held (on average one class per week). In this course, theoretical classes accounted for 33%, while practical classes accounted for 67%. During the "Applied Microbiology" course, students formed the necessary practical abilities and skills, as well as learned theoretical material.

Practical skills include the following:

– acquiring basic skills in working with a microscope and microbiological equipment;

– mastering the techniques of seeding and reseeding, as well as the peculiarities of preparing nutrient media;

– a study of the characteristics of cultivation of the main microorganisms on different nutrient media;

– mastering the methodology of crop accounting.

The theoretical part includes:

– a study of the basic processes of microbial functioning;

– to develop students' understanding of the cellular level of the organization of life;

– development of basic thinking operations: analysis, synthesis, systematization, classification, the ability to formulate conclusions and draw the results of the research work.

In the control class, students were prepared for their research work traditionally during standard lessons. In all classes, the educational process was based on the same biology curriculum and took place at the same time. The same teacher was involved. Under the curriculum, laboratory work on the topic "Bacterial leaching of minerals" was carried out for the control and experimental classes. The preparation and conduct of this experimental activity for CC and EC were the same. In both cases, students received technical and organizational briefings. The students carried out the completion of the work, recording, and processing the results obtained independently. After the laboratory work, the teacher

assessed the theoretical knowledge and practical skills. For this purpose, three levels of research competence were identified within each class: low, medium, and high.

The work used theoretical methods (analysis of psychological-pedagogical and methodological literature), empirical methods (conducting a pedagogical experiment), as well as statistical methods (interpretation of quantitative data obtained). Student's t-test and one-factor analysis of variance were used for static data analysis. The results were processed using the standard software packages "PASW Statistics 17" and "Statistica 6.0". The normality of the distribution of quantitative indicators was checked using the Kolmogorov-Smirnov criterion. In all cases studied, the variables had a normal distribution.

Results

In recent years, teachers have begun to actively introduce into the educational process technologies aimed at developing students' research skills and abilities. An analysis of current pedagogical literature [10-12] suggests that the competency-based approach is becoming increasingly popular, and educators are actively developing students' key competencies. By the notion of "research competence" a student's mastery of sound theoretical knowledge, practical skills, and the skills to conduct research activities are considered. In the structure of research skills can be distinguished through such components:

– motivation, which is the interest of the student in doing research;

– content – theoretical knowledge necessary to organize the experiment and the interpretation of the results;

– practice – a set of skills and abilities necessary for solving the research tasks.

The construction of a modern high school biology course should be based on the application of research methods that combine solid academic knowledge with the skills and abilities to organize and carry out research work:

– the ability to formulate a scientific problem;

– the ability to determine the main hypothesis of the experiment;

– skills in planning and conducting experimental work;

– the ability to analyze the result and form conclusions.

Before teaching students about research activities, a test was conducted to assess the level of research competence of 8th-grade students. As shown in Table 1, students in grades 8A and 8B have approximately the same level of research skills and abilities. In addition, there were more children in grade 8B with an average level of research competence than in grade 8A: 57% and 53%, respectively.

Table 1. Elementary level of research competence in 8th-grade students

	8A (EC)	8B (CC)
High	29%	28%
Average	53%	57%
Low	18%	15%

As shown in Table 1, students in grades 8A and 8B have approximately the same level of research skills and abilities. In addition, there were more children in grade 8B with an average level of research competence than in grade 8A: 57% and 53%, respectively. Preparation for research activities for the experimental class was conducted as part of an elective course "Applied Microbiology" and in standard biology lessons, the control version of the training was conducted only during the class lesson training. Table 2 outlines the main differences between the two selected school options for building students' research competence.

Table 2. Comparative characteristics of 2 options for teaching research work

	EC	CC
The main components of the program of the elective course		
Theoretical preparation for experimental work	+	-
Reading special literature	+	-
Conducting experimental work on the following topics: 1. "The device of a binocular microscope. Basic methods of research." 2. "Microbiological Ware. Basic Principles of Operation." 3. "Preparation of nutrient mediums". 4. "Planting and transplanting bacteria and fungi onto nutrient media" 5. "Working with "crush drop" drugs" 6. "The internal and external structure of a bacterium" 7. "Various techniques for staining microbiological preparations" 8. "Microbiological Study of Air. Interpretation of the obtained data". 9. "Microbiological Study of Soil. Interpretation of the results".	+	-
Preparation for the laboratory work "Bacterial leaching of minerals"		
Theoretical preparation	+	+
Technical instruction	+	+
Conducting laboratory work and interpreting the data obtained	+	+
Checking and evaluating the level of formation of students' research competence	+	+

As shown in Table 2, students from the experimental class have performed several laboratory works, as well as studied the theoretical foundations of the elective course "Applied Microbiology", developed by the authors. While studying this course, students formed several practical skills and abilities: working with a binocular microscope, preparing microbiological dishes for experiments, preparing different types of nutrient media, sowing and transplanting a variety of microorganisms, distinguishing species of microorganisms by morphological features, preparing and staining preparations, conducting a microbiological study of the environment.

The organization of the laboratory work "Bacterial leaching of minerals" was the same for the control and experimental classes. Below is a fragment of methodological recommendations for laboratory work.

Topic: Bacterial leaching of minerals.

Theoretical knowledge is needed to do the job. Bacterial (or microbial) leaching is the extraction of individual chemical elements from complex substances. It is achieved by extracting them with bacteria in water. This method makes it possible to extract several chemical elements of value (e.g., copper, uranium) or, on the contrary, harm (e.g., arsenic) from minerals. This method was first registered in the USA in 1958 when copper and zinc were produced. The most used microorganisms for this method are *Thiobacillus ferrooxidans*. They promote oxidation reactions resulting in the formation of iron compounds. *Th. thiooxidans* – sulfur bacteria are also actively used in bacterial leaching.

This group of bacteria belongs to the chemotrophs, which use the energy of chemical reactions for their vital processes. The use of these bacteria is possible at temperatures from 25^0C to 35^0C, with a pH value of 2 to 4. Microbial leaching produces the necessary chemical elements much faster than other chemical methods. Today, bacterial leaching is successfully used to extract zinc, cobalt, manganese, arsenic, and other chemical elements. However, the method does not stand still and is actively developing. For example, gold can be extracted using *Aeromonas* bacteria. Advantages of the bacterial leaching method: fast reaction rate, ease of use, and low cost of obtained chemical elements and compounds.

Research progress:

1. Study the theoretical component of this method.
2. Familiarize yourself with the main characteristics of the microorganisms that are involved in the bacterial leaching process. Fill in the comparative table.
3. Describe the advantages of the bacterial leaching method.
4. Perform the chemical reaction. Write the results in the table and analyze them: $4\ FeSO_4 + O_2 + 2\ H_2SO_4 =$ (bacteria) $2\ Fe_2(SO_4)_3 + 2\ H_2O$; $Fe_2(SO_4)_3 + MeS = MeSO_4 + 2\ FeSO_4 + S^0$.
5. Conclude. Describe the prospects for the use of microbiological technology.

During the formative experiment, assessed the level of theoretical knowledge, as well as practical skills and abilities to conduct research work. The results of the control carried out after the laboratory work are presented in Figure 1. It is worth noting that the control included testing not only academic knowledge but also the understanding of the information of different levels, testing the ability to formulate and solve a scientific issue. The key skills of microbiological research were also tested. In addition, the control included tasks to test the basic thinking operations of students: analysis, synthesis, systematization, classification, and so on.

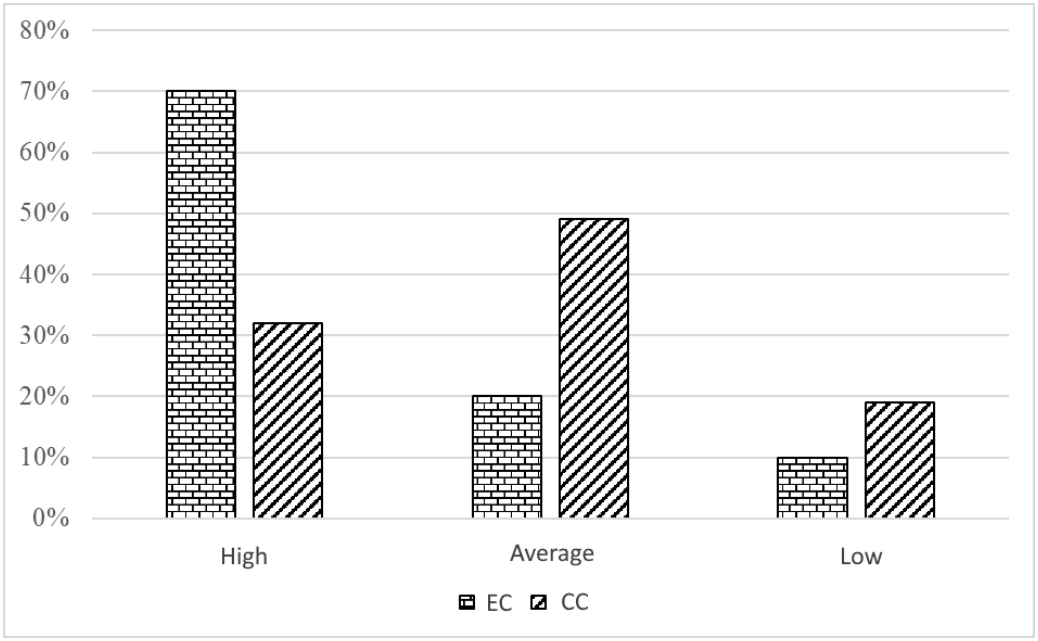

Figure 1. The results of measuring the level of research competence in the experimental and control classes after the laboratory work "Bacterial leaching of minerals"

It was determined that the highest rates of research competence were obtained in the experimental class. Among the students in the control class, the number of children with a high level of knowledge, skills, and abilities to conduct research work was 2.2 times less (32% vs. 70%) compared to the students who attended the elective course "Applied microbiology". In other words, seven out of ten students in Grade 8A had a high level of research competence after the laboratory work. Whereas, in Grade 8B only three out of ten students had such a level of research competence. In the experimental class 10% of students failed in the research activities, in the control class this figure was 1.9 times higher – 19%. Thus, it can be concluded that the elective course "Applied Microbiology" with a significant amount of laboratory work, contributed to better preparation of 8th-grade students to conduct research activities and the formation of their high level of research competence.

To assess the degree of the statistical reliability of the obtained results of the control conducted in the experimental and control classes, the Student's criterion was used: $t_{emp} = 6.07$. For the level of significance $p = 0.05$, was found t_{cr} using Student's criterion table: $t_{cr} = 2.04$. Since the empirical value of the criterion is greater than critical, and thus the differences in knowledge, skills, and abilities of research work between the students of the experimental and control classes are statistically reliable at a high level of significance. In other words, it can be argued with a 95% probability that students who had previously studied in the elective course "Applied Microbiology" performed much better in research activities and formed a strong base of theoretical knowledge and practical skills, unlike students in the control class, who were taught only in standard biology classes.

It is worth noting the dynamics of the student's level of research competence at the beginning of the experiment (Table 1) and at the end of the experiment (Figure 1). The results show that in Grade 8A there was a 2.4-fold increase in the number of students with a high level of research competence (29% and 70% respectively). Whereas the number of students who did not master research activities decreased by 1.8 times (18% and 10%, respectively). In the control class, the number of students with a high level of research competence did not change significantly, and the number of students with a low level increased 1.3 times (15% and 19%, respectively).

Using a one-factor analysis of variance, statistical reliability between the level of research competence of students in the experimental class at the beginning and the end of the experiment was estimated: $F_{amp} = 7.04$. For the significance level $p = 0.05$, F_{cr} was found from the Fisher-Snedekor distribution table: $F_{cr} = 1.96$. Since the empirical value of the criterion is greater than the critical value, the difference in the level of research competence before the elective course and after it is statistically reliable at a high level of significance. One-factor analysis of variance was also applied to statistically evaluate the differences between the levels of research competence of students from the control class: $F_{amp} = 0.73$, $F_{cr} = 1.96$. Since the empirical value of the criterion is less than the critical value, the difference in the level of research competence is statistically unreliable.

Thus, the authors' elective course with theoretical and laboratory work, allowed forming the research competence of students in grade 8A, while training only in standard biology lessons in grade 8B was not enough for students to master academic knowledge, practical skills, and skills of conducting research work at a high level.

Discussion

One of the key requirements that society places on the modern education system is the formation of a mobile personality with a solid base of theoretical knowledge, skills, and abilities that students can effectively apply in everyday life. The process of developing students' research competence is crucial to achieving this goal. As M.K. Abdullaeva et al. [13], chemistry and biology in secondary schools are of particular interest for the formation of research skills and abilities, as they have huge prerequisites for organizing and conducting experiments. On the other hand, to date, there is no unified conceptual and methodological solution to this issue. A survey of middle school students conducted in Pavlograd Province (Republic of Kazakhstan) showed that 35% of respondents were completely uninterested in research activities [5; 14-16]. The authors attribute this state of affairs to the monotony of research work in schools in Kazakhstan: abstracting literature and writing essays. Students also experienced significant difficulties with thinking operations, especially in establishing cause-and-effect relationships.

At the beginning of this study, it was shown that only 29% of 8thA students and 28% of 8thB students, had a high level of research competence (Table 1). This may indicate that current biology teaching practices are not reaching their full potential. C. Sommer, M. Lücken [17], and G. Ergasheva [18] have also described a similar situation. Research in the study of biology can be organized through various forms of both theoretical and practical classes. Its main goal is to acquire solid academic knowledge and practical skills, as well as the ability to conduct research. It is important to note that through research activity not only the process of acquiring new knowledge, practical skills, and experimental work skills are understood, but the formation of a scientific type of thinking. Undoubtedly, the skills formed in the process of performing research activities are closely related to the thinking operations of students. The given definition reflects one of the goals of organizing such an activity, which is that a student with a high level of development of key competencies is ready to carry out research activities.

Following T.H. Chiang and D. Trezise [19], research competence performs several important functions, among which can be highlighted the developmental, which consists of the development of thinking operations, creative component, and other characteristics of personality, learning – responsible for the mastery of subject knowledge and skills. In addition, this competence helps to form a scientific type of thinking and contributes to the formation of value attitudes toward themselves and the surrounding world. The authors' elective course "Applied Microbiology", designed to teach students the

theoretical and practical components of microbiological research, was introduced to students in the experimental class. In conducting such research activities, students develop not only biological knowledge and skills but also basic thinking operations (analysis, synthesis, classification, etc.) and creative abilities [20; 4]. It is only possible to comprehend and consolidate the acquired general biological knowledge, skills, and abilities through a combination of the classroom-lesson system of learning, students' independent work, and various forms of research activities [21; 22]. The students in the experimental class who received theoretical training and did experimental work in the elective course did better in research activities when performing the laboratory work "Bacterial leaching of minerals" than the students in the control class who were taught biology in the standard lessons [23-25].

Among students in Grade 8A, there were 70% of children with a high level of knowledge, skills, and abilities to conduct research, whereas among students in Grade 8B, there were only 32% (Figure 1). These differences were statistically significant at a high level of significance. Successful experience in the formation of research competence is given in the work of R.M. Magsino [26]. The author developed the course "Marine Biology" and organically implemented it in the traditional system of education, using practical and theoretical tasks, as well as the method of problem-based learning. As a result, students not only improved their research skills but also their thinking operations (analysis, comparison, classification), as well as demonstrated the ability to organize and conduct experimental work). It is worth noting that problem-based learning methods are highly effective methods for shaping students' research competence [27-29]. Based on the observations, it can be concluded that the use of problem tasks activates the thinking operations of students, motivates them to search for non-standard answers, and contributes to the formation of research skills and abilities.

T.K. White et al. [30] also noted a statistically significant increase in students' research competence. This result was achieved due to the introduction of more research activities into the curriculum. It can be concluded that the modern system of biological education needs to shift the emphasis on the practical activities of students, and research competence is not only academic knowledge, and research skills, but also the creative abilities of the individual, its characteristics manifested in the motivation for scientific knowledge of the world. Findings from the present work, as well as research by several authors [31; 32], have helped formulate the fundamental conditions for successful student research activities: assessment of the initial level of students' research competence; motivating students to do experimental work; well-organized methodological and technical support for students.

In addition, during the formation of research competence during the elective course students consistently passed three main milestones. The first of them is the formation of motivation for scientific knowledge. For example, when organizing work with a binocular microscope, studying the history of its discovery and the importance of this method of work, students were interested in conducting experimental work. The second milestone is experimenting using systematic instructions. Thus, for example, children mastered the skills and abilities to prepare and use a microscope to examine finished microbiological preparations. Moreover, the third component was getting the results of the research activity and its interpretation. The independent students assessed their skills in handling a microscope. To assess the pedagogical impact of the developed elective course, the authors compared the level of research competence at the beginning and the end of the experiment. The data obtained indicate that with a 95% probability, it can be argued that the difference in the level of research competence of students is influenced by taking an elective course. Since the majority of students in grade 8A had a high level of research competence only at the end of the experiment, the pedagogical effectiveness of the developed course can be noted. Thus, the use of the authors' developed course "Applied Microbiology" seems promising for the formation of research competence in students.

Conclusions

The results show that in today's biology education system, only 30% of students have solid theoretical knowledge, skills, and abilities to conduct research work. The research authors developed and implemented an elective course, "Applied Microbiology", which allowed students from the experimental class to master the theoretical and practical components of microbiological research. With 95% probability, it can be stated that the elective course had a positive pedagogical impact on the formation of students' research competence. Thus, the students of the experimental class were 2.2 times better able to cope with the new research activity in the form of laboratory work "Bacterial leaching of minerals" in contrast to the students of the control class (the number of students in the high level of research competence was 70% and 30% respectively). It was shown that the research activities provided by the school curriculum in biology did not contribute to the development of research skills. In the control class, there were no statistically significant changes in the level of research competence at the beginning and the end of the experiment, in contrast to the experimental class, where there was an increase in the number of students with a high level of research competence.

Thus, the goal of the research was achieved. The elective course "Applied Microbiology" was developed and implemented. Its pedagogical effectiveness for the formation of research competence of 8th-grade students is confirmed. In this regard, it is advisable to include the developed course permanently in the educational process, especially in institutions with in-depth study of biology the study sets the stage for a more comprehensive search for different forms of organization of research activities of students as a means of forming research competence. The main prospects for future research work are related to the development and implementation of new elective courses and the improvement of biology work programs.

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None.

Conflict of Interest

None.

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Формування дослідницької компетентності учнів у процесі вивчення біології

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Анотація

Актуальність. Актуальність дослідження зумовлена суперечністю між потенціалом біології у формуванні компетентної особистості та реаліями її викладання. У сучасній літературі мало уваги приділяється методиці формування дослідницької компетентності учнів під час вивчення біології. Це мотивує пошук нових підходів до організації дослідницької діяльності учнів.

Мета. Метою дослідження є розробка, впровадження та оцінка різних форм організації дослідницької діяльності як засобу формування дослідницької компетентності учнів у процесі вивчення біології.

Методологія. У дослідженні використано теоретичні та емпіричні методи аналізу даних, зокрема t-критерій Стьюдента та однофакторний дисперсійний аналіз.

Результати. На початку дослідження лише третина восьмикласників мали високий рівень дослідницької компетентності. Для того, щоб учні могли проводити дослідницьку роботу, було розроблено факультативний курс "Прикладна мікробіологія". Результати показали, що учні, які відвідували факультатив, показали кращі результати в дослідницькій діяльності, ніж учні контрольного класу, з високим рівнем достовірності ($p<0,05$). Однофакторний дисперсійний аналіз показав статистично значуще збільшення кількості учнів з високим рівнем дослідницької компетентності в експериментальному класі ($Famp = 7,04$, $p<0,05$), тоді як у контрольному класі не відбулося значного покращення ($Famp = 0,73$, $p>0,05$).

Висновки. Дослідження демонструє, що традиційні уроки біології самі по собі суттєво не розвивають дослідницьку компетентність учнів. Курс за вибором "Прикладна мікробіологія" ефективно розвиває дослідницькі навички, що свідчить про необхідність застосування інноваційних освітніх підходів. Цей курс може слугувати моделлю для вдосконалення біологічної освіти та формування дослідницької компетентності учнів.

Ключові слова: практичні навички; компетентнісний підхід; курс за вибором; біологічний експеримент; біологічний експеримент.