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Pupils' research skills development through project-based learning in biology

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Abstract

The study aims to develop theoretical foundations, methods of forming research skills of pupils in biological education, and experimental substantiation of its effectiveness. The following methods were used: analysis of psychological and pedagogical, biological, scientific, and methodological literature, the definition of the theory, the innovative methods of biological education, practical work, pedagogical practice, control, questionnaires, interviews, statistical analysis, identification, and implementation of training experiments. It is proposed to develop methods and determine the content of the formation of research competence through project activities, conduct and introduce them into the educational process. It is necessary to analyze the psychological, pedagogical, biological, scientific, and methodological literature to determine the theory, innovative methods of biological education, the organization of practical work, pedagogical practice, using a statistical method, which will lead to the creation of a methodology for the formation of research skills of pupils.

Keywords: project-based learning, research, methodology, reflection, group work.

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1. Introduction

The task is to prepare a curious, competitive person armed with modern and deep knowledge, creative abilities, research skills, able to apply his/her knowledge in practice. A new education system has been created, and the educational paradigm is changing. One of the main requirements in the education system is the task of integrating education and science. There was a need to teach the pupils research work from the school bench to instill scientific research skills. Research approaches are updated depending on the type of innovative tools. The goals of project training are to gain knowledge in the program's scope, master the acquired knowledge for comprehensive self-development, master communication skills in working with various groups in solving cognitive and practical problems, and develop system thinking. In biological education, the application of the project method is of great importance. The relationship between the practical implementation of students ' theoretical knowledge reflects the main feature of the project method in the education system. Students learn to think critically, express their opinions, make scientific conclusions, and make reasoned decisions based on the laws of science. The project method is implemented in a complex system with other training methods.

The competence and continuous self-education of teachers is a prerequisite for meeting these objectives. At present, the trinity of "education–science–innovation" is the standard of educational organizations and the imperative of our time. The integration of science and learning has become the key area of school education, as best practice demonstrates. Introducing experiments to teach the basics of science and forming a scientific worldview in the younger generation allows for meeting the objectives indicated in the law on education mentioned above (Minister of Education and Science, 2016).

Chapter V of the Law of the Republic of Kazakhstan "On Education" in article 29 "Organization of educational-methodical and scientific-methodical work" states: "The integration of education and science, provision and improvement of the educational process, development and implementation of new teaching technologies is carried out in educational institutions". Therefore, in the current school curriculum, updated educational innovations, changes, and processes aim to form a personality with values that are capable of global development for future generations (The President of the Republic of Kazakhstan, 2007).

At the same time, it is important, along with training, to instill research skills, applying teaching methods based on innovative technologies. Today, the process of developing research skills has already begun at school. One of the proofs of this, to disseminate the experience of the Nazarbayev Intellectual Schools in secondary schools, has developed a curriculum for the subject "Natural Science", approved by order of the Minister of Education and Science of the Republic of Kazakhstan No. 266 of 2016, the first topic of which is called "I am a researcher" (Minister of Education and Science, 2016). This shows the need to integrate education and science. Also, in the school curriculum, pupils are mainly taught research work, forming research skills, particularly through participation in scientific projects, the implementation of project work.

Project-Based Learning was studied by Shafaei and Rahim (2015), Munezero and Bekuta (2016), Filho, Shiel, and Paço (2016), and Dwikoranto et al. (2019). In these works, one can see the methodological task of education through project activities. The authors analyze the tasks and functions of the teacher and student in the application of conceptual and visual, problematic, and partially searchable research methods. Using the above key methods of education, one can achieve the following. With the help of an explanatory and visual method, pupils develop the ability to assimilate knowledge and memorize. When using the problem method, logical thinking skills are formed.

Project activity is valuable because, in its implementation, it aims to develop students ' cognitive interests, the ability to build their knowledge, navigate the information space, show competence in issues related to the project topic, and develop critical thinking. This form of organization of educational activities is focused on the independent activities of students, individual, pair, or group ones, which children perform for a certain period (Wurdinger & Qureshi, 2015). It is important to define and highlight the project implementation tasks in advance to highlight the system of actions of the teacher and the student. The mandatory requirement each stage of the project should be aimed at a specific result (Khalid, 2018).

While the initial courses often use explanatory, visual, and problem-based methods, the senior courses use semi-exploratory and research methods that give them a direction to choose their capabilities. For example, the semi-search method provides an opportunity for pupils to work independently, as a result of developing the skills of drawing up a research plan, conducting observations, and so on (Dwikoranto et al., 2019; Stentoft, 2019; Mayolo-Deloisa, Ramos-de-la-Peña, & Aguilar, 2019).

Currently, many schools approve the project-based learning method (PBL), a variety of teaching methods, organization of project work, and development of scientific projects. The PBL method also changes the teacher's place as a source of knowledge, the relationship between teacher and student. Pupils focused on research activities from school, acquiring an integrated education at the University, deeply master the industry experience (Zadok, 2019; Karim, Campbell, & Hasan, 2019).

In this regard, the goals, content, and methods of teaching of the modern education system of the country are reviewed, the problems of organizing, improving, and streamlining the education system are studied and need to be solved. One of the main goals of training in educational organizations is the formation and development of applicants, special personalities (Andreeva, 2012; Vasiljeva et al., 2019).

Scientists believe that the most important principles for solving these problems are developing the activity, interest, and personal responsibility and indicating a purposeful, consistent system of organizing measures to identify and stimulate capable and talented pupils (Larmer & Mergendoller, 2015). Pupils' research activities as an integral part of the educational process require constant development. Pupils are good at learning innovation through project-based learning (PBL) through working in groups (Vasiljeva et al., 2020). However, specific projects are complex, stressful, and especially difficult when they start. In this case, orientation, starting with explanatory work, teaches searches (Harburg, Lewis, Easterday, & Gerber, 2019; Nagarajan & Overton, 2019; Park & Lee, 2019; Mitarlis & Hidayah, 2017; LaForce, Noble, & Blackwell, 2017; Vande Wiele, Morris, Ribiere, & Ermine, 2017).

Moreover, pupils independently search for and study literature in research methods, depending on the research topic. They study the research principles, develop a research plan, predict the expected result, and reach a level where they can evaluate all this themselves. Following the new paradigm of modern education, teaching methods are dominated by an interest in the effectiveness of "learning through activity" and methods of organizing practical activities of pupils closely related to it (Khalid, 2018; Wurdinger & Qureshi, 2015).

Currently, project technology is widely used, promoting a set of the above methods at the appropriate stage. In this regard, to develop the research abilities of future specialists, we used the project's technology to study mushrooms that affect vegetables (Robinson, 2013; Robinson & McDonald, 2014; Kolesnikova & Gorchakova-Sibirskaya, 2005).

Project-Based Learning is an effective method to be used in lessons since the whole class revises the topic. Even more, pupils learn to prove their conclusions. Children sum up theoretical knowledge and acquire skills of scientific formulation of biological concepts.

2. Materials and methods

The research was conducted among students of grades 8-10, 11 of secondary schools No. 2 named after Hamza and "Karashyk", Turkestan, Turkestan region. In classes with a natural science direction of study on the subject "Biology", with the consent of students, research was conducted on the application of the project method in the classroom and outside of school hours. The gender distribution was 67 % girls and 33% boys between the ages of 14 and 17.

The research of fungi affecting vegetables, through scientific design work, consisted of the following stages:

1. Selection of the research topic.
2. Definition of the research problem.
3. Collection of scientific information.
4. Choice of research methods.

5. Conduction of research practice.
6. Generalization of the study results.
7. Registration of research work.
8. Presentation and reporting of research results.

The stages of research through this project are described in the following Table 1.

Table 1. Stages of project training and system of actions

Stages of project work	Contents of work	Main actions of the teacher when solving problems	Actions of pupils
1	2	3	4
Preparatory Stage	Defining the project topic and naming titles	- Stimulating topic selection; - Choosing the topic together with the pupils; - Considering the opinions of pupils when planning work, analyzing the topics proposed together with pupils ; - Division of topics into subtopics; - Pupils' choice of sub-topic	- Share your opinion based on your knowledge; - Participation in determining the final goal of the project; - Discussion of the selected topic; - Group work on the topic
Planning Stage	Information collection. Ordering and systematization of information material	- Grouping of pupils depending on the type of activity. Organization of group work; - Sending pupils to self-collect information; - Collective discussion based on the opinion of each group member	- Grouping into subgroups according to the selected activity; - Defining the functions of group members: planning the stages of work on the topic. Determining the time to achieve the result
Drafting a Project	Clarification of the stages of the planned project. Checking the completeness of the information	- Advising pupils, checking the period of execution of their actions	- Individual and group work; - Analysis, search, and generalization of data
Research	Collected information. Analysis and regulation of the intermediate result	- Communication with the Project Manager; - Exchange of views with group members; - Analysis of the intermediate result	- Ability to predict the results obtained, analyze mutual, independent work skills; improve knowledge by conducting research work
Discussion of Results	Analysis of information, decision, discussion of conclusions	- Control, consultation; - Assessment of pupils' activities within the group. Joint discussion of actions, consultations	- Analysis of the results obtained, identification and joint solution of problematic issues; summarizing;

Presentation		- Organization of expert work; - Attracting industry specialists, candidates of science as experts	- Verbal interpretation of the research results with a written design - Presentation of work results, reporting; - Multimedia presentation, layout preparation
Reflexes		- Evaluation of research work	- Discussion of the group's research work, evaluation of each other, analysis of the work, evaluation

The goal of involving pupils in research work using these design technologies was realized. As a result of the analysis of the stages of project training and the system of activities, the analysis of the content of biological education in training following the object and subject of the study was carried out.

For protecting the project work, each of the pupils was asked and thoroughly discussed the following questions:

- What is the name of your project?
- What is the main task of the project?
- How important is it to answer these questions?
- What results have you achieved?
- What were the difficulties during the research?
- How do you assess the quality of project execution and design?
- What did you find interesting in the course of the project?
- Tell us about your role in the project.
- Are you satisfied with the result of your work?
- What did you learn during the project?

Answering these questions, pupils analyzed the work performed. They not only realized the importance of research work but also became convinced of their results.

The criteria for the evaluation of the project: Each criterion was evaluated with a maximum of 3 points:

- Goal setting, planning
- Full disclosure of the project topic
- A variety of sources of information, appropriateness of action
- Personal interests of the author, a creative approach to work
- Design of the project according to the regulations
- The quality of the presentation
- Quality level of project performance

The evaluation of the project was based on the main criteria selected above. Each criterion has become the main tool for determining the significance of the project. For example, the topic of the project itself may indicate the level of the project's work (abstract, practical, creative, etc.).

For showing the dynamics of the results of the project's achievements, a "Portfolio" (portfolio of achievements) was prepared.

We used Project Based Learning not only in extracurricular activities but also at lessons, for instance, at a lesson on the topic "A cell as a structural and functional element of life" (Table 2).

Table 2. The plan of a project-based lesson on the topic "A cell as a structural and functional element of life"

Teacher's actions	Pupils' actions	Learning outcomes
Stage I of the Lesson: Prokaryotes		
Each group receives a task	Group 1. What are the differences between prokaryotes and eukaryotes?	Demonstration of the drawings of prokaryotes and eukaryotes.
	Group 2. Work on the computer, interactive drawings (7 additional sets of materials).	Demonstration of the drawings.
	Group 3. The structure of prokaryotic cells.	
	Group 4. The structure of eukaryotic cells.	
The problem-based question posed in the classroom: "Which cells appear first in the course of evolution?"		
Stage II of the lesson: Eukaryotes.		
Each group receives a task	Group 1. The structure of animal cells.	Demonstration of the poster.
	Group 2. The structure of plant cells.	
	Group 3. What is the difference between plant and animal cells?	
	Group 4. Group the cells.	
A question to the class: "How do fungi cells differ from plant and animal ones?"		Demonstration of comparative charts.
Stage III of the lesson: Organelles.		
Thus, we established that all eukaryotes consist of a cytoplasmic membrane, cytoplasm, and nucleus.		
The demonstration of structural parts of eukaryotes. The teacher reminds the pupils about the structure and function of the organelles.		
Group work	Group 1 analyzes the structure of the nucleus, ribosome, and cell center.	The analysis of the functional materials on the formation of eukaryotes.
	A question to the group: "How are life processes controlled in prokaryotes that do not have a nucleus?"	
	Group 2 analyzes the structure and functions of the plasma membrane, the Golgi apparatus, and plastids.	The presentation "Types of Plastids".
	Group 3 analyzes the structure and functions of mitochondria, lysosomes, and cell membranes.	The presentation of the chart "ATF Energy Center".
	Group 4 analyzes the structure and functions of the endoplasmic reticulum, cytoplasm, and vacuole.	The presentation "The formation of the digestive vacuole."
A generalizing question: "What cell classifications do you know?"		
The teacher demonstrates the animated material "The phases of cell division."		
	Group 1. How do prokaryotes divide?	Demonstration of the division of prokaryotes.
	Group 2. How does indirect division occur?	Demonstration of mitosis.
	Group 3. What is the cell cycle?	Demonstration of a cell cycle.
	Group 4. The role of the interphase.	Demonstration of the processes occurring during interphases.
A question: "What is the role of the interphase in the life of cells?"		

Stage IV of the lesson: Cell Theory.		
	Group 1. What are the differences and similarities between the cells of unicellular and multicellular organisms?	Additional materials.
	Group 2. Compare the current and initial stages of Cell Theory development and name the latest advances in cytology.	
	Group 3. Prepare a talk about the discovery of cells.	
	Group 4. Analyze non-cellular life forms.	

Objectives:

1. To enhance and review the information about the basic functions, the structure of cells, and organelles in the cytoplasm of a cell.

2. Analyze the structure and function of prokaryotes and eukaryotes, features, structure, and communication of cellular organelles.

Topics for revision:

1. Prokaryotes

2. Eukaryotes

3. Cell isolation

4. Specifics of the structure and the features of plant cells

5. Cell Theory

6. Cell-free life form: viruses.

The criteria for project evaluation were as follows, and the highest score for each criterion was 3 points:

- Goal setting and planning
- Coverage of the project topic
- The variety of information sources and appropriateness of actions
- Personal involvement of the author and creativity
- The design of the project following the rules
- The quality of the presentation
- The quality of the project performance

The project was evaluated using the criteria selected. Each criterion was used as a tool for determining the significance of the project. For example, the topic of the project itself could indicate the level of the project work (abstract, practical, or creative).

For representing the dynamics of the project's success, a portfolio of success was created.

Let us consider the stages of the lesson conducted using the mono-project method through a general lesson on the topic of "Blood".

Goals and objectives:

1. The development of the topic "Blood" in the "Zoology" section.

2. Generalization and analysis of research on the topic.

3. Increasing pupils' interest in the studied material.

4. Improving the research skills of the work done.

5. Group work.

Group 1.

The research goal: Blood, its composition, and functions.

Question: Why is blood composition called the "Mirror of the body"?

Demonstration: Blood and its composition.

Members of the group prepare a chart (a poster) about blood composition and functions.

The speaker takes the floor and gives a talk, additionally explaining facts and drawings. The pupils prepare the report using not only textbooks but also interesting sources and studies.

Experimental research work exploring the relationship between human health and blood composition includes a blood test. Using a microscope, pupils study red and white blood cells and their shape. They use chemical and physical methods to measure hemoglobin in the blood, proteins in plasma, and sugar. Pupils may also attend clinics that conduct blood tests.

The teacher asks a problem-based question: "Why do mammals have more red blood cells in a 1 mm cube than reptiles?"

The speakers of Group 2 can also answer this question.

Group 2.

The research goal: Blood diseases.

The problem: Changes in blood composition and their influence on the body.

Demonstration: Presentation of the charts "Blood Diseases" and "Transmission of hemophilia: the hereditary disease of Queen Victoria of England".

The speaker takes the floor and talks about the causes of various diseases: diphtheria, blood failure, and Down syndrome. Pupils solve several genetics problems, thus acquiring skills for solving different genetic problems, even those that require 11th-grade knowledge.

Questions posed by the experts from Group 3:

"If a woman is a carrier of hemophilia and a father has this disease too, how will the children present?"

Having solved all the problems, they prepare an answer.

The opponent from Group 1 asks a question: "From history, we know that Tsar Alexei had hemophilia. How was this disease transmitted?"

The speaker analyzes the records of transmission of this hereditary disease in the Kingdom of England. The teacher analyzes and summarizes the work of the group.

Group 3.

The research goal: Immunity.

The question: What protective force does the human body have to defend itself?

The group presents the charts "Immunity" and "The work of T and B cells". The speaker takes the floor and introduces all types of immunity, analyzes the drawings representing the work of T and B cells, vaccine, therapeutic serums, and explains the terms related to AIDS.

The opponent asks the following questions:

1. How long does it take innate immunity to form?

2. What is the difference between therapeutic serum and vaccine?

The learning outcome: everyone should know that the agents of many diseases could remain in the soil for a long time. A system of special anti-epidemic measures aims to prevent and eliminate infectious diseases. The first step includes determining the sources and ways of spreading infection. The patient is taken to the hospital, or quarantine is imposed.

The next stage is meeting a medical professional who explains the importance of the blood group and the RR factor for the human body. Pupils do practical work in the laboratory that determines the blood group. After that, pupils write a test on the "Blood" section. The teacher assesses pupils and summarizes their work.

In our experiment, we used mono-projects as the main instrument for organizing research work at a lesson and developing pupils' reasoning. It also increased pupils' interest in the subject and developed their research skills and talents. It was easier for pupils to do research work as they could do these tasks in class. Preparing pupils to do research is the basis of profound knowledge and the key to the development of their thinking skills. The pupils could develop their research skills through various forms and teaching methods proposed in the lesson. This kind of work facilitates pupils' research skills, while their cognitive abilities are formed from an early age. Therefore, a teacher should develop pupils' research skills from primary and secondary school. By participating in research, learning about scientific and technological advances, and promoting group work, a teacher can upgrade pupils' research skills.

Outside of school hours, research was also conducted using the project method. Consider implementing the project work on the topic "Analysis of the state of the yard soil". After their distribution into groups, tasks were given for each of them.

Purpose: To learn to determine the acidity of the soil.

Equipment: two test tubes, indicator paper, potassium chloride solution.

Research tasks:

1. Take 2-3 grams of soil from your home or suburban area. Place the soil in a test tube and add 10 ml of potassium chloride solution. When the test tube contents settle, take a strip of indicator paper and dip it in the soil solution for 2 seconds, compare its color with the pH scale reference, and determine the type of soil.

2. Make a conclusion about the need to loosen the soil on your dacha plot by erecting seedlings and ash.

3. Determine whether your parents use fertilizers and pesticides when growing plants in the suburban area.

4. Collect information from others, from sources of information about the rules for the use of chemicals, especially fertilizers.

The students ' search and research activities were the potentials for them to form their experience of creative activity since they assumed not only actions performed according to the model but also independent search and creation of new subjectively significant knowledge. This practice is formed based on a personality-oriented approach to training, one of the ways of implementing the project method in training.

The project method allowed students, on the one hand, to master new knowledge and ways of acting independently, and on the other – to create conditions in practice in which they can apply previously acquired knowledge and actions. This allows you to focus on the creative development of the individual. The training project is considered a collective type of activity. The implementation of interdisciplinary connections, the list of issues, definition of tasks, activities, choice of methods of investigation of these problems and the method of presentation of the project, allocation of roles and responsibilities between the participants - this was in the course of collective discussion. At first, it was conducted to improve the theoretical knowledge of students. After the tasks were distributed, they independently, using information sources, summarized the theoretical material, and were directed to developing research papers. The stages of preparation, planning, research, formulation of results and conclusions, project protection, evaluation of results, and project activity were carried out in work on the project.

3. Results

In our practice, it is impossible to list all the lessons conducted using the project method because its range is very wide. We decided to analyze the main lessons. Project work carried out in the classroom and outside of the classroom does not displace laboratory classes. For example, in the 8th grade, the topic "breathing" ends with the lesson "respiratory diseases, their prevention". Extracurricular students participate in the research project" study of the functional capabilities of the respiratory system of smokers and non-smokers". For doing this, a working hypothesis is proposed: "does smoking affect the functioning of the respiratory system in adolescents? "the methodology for conducting research is being studied. In other words, the project will complement each other with research work and laboratory classes. Students are gradually involved in research work. In grades 8-9, students learned to draw small conclusions based on control and laboratory work results. In higher grades 10-11, they were used to conducting large-scale research, gaining experience from research work, improving their theoretical knowledge.

The formation of pupils’ research skills in project work included three stages of a practical experiment. To verify the accuracy and effectiveness of the methodology proposed, in the 2017-2019 academic year, we conducted a pedagogical experiment in a secondary Karashyk school and a secondary Khamza school No. 2. The experiment embraced 91 pupils, with 46 pupils in the experimental group and 45 pupils in the control group.

At each stage, we experimentally verified theoretical and practical conclusions, analyzed and compared the results obtained, and carried out their mathematical processing. We observed pedagogical requirements and determined the indicators of pupils' research competence.

The ascertaining experiment aimed to assess pupils’ understanding of biological concepts and the practical use of biological objects (medicinal plants, poisonous fungi, hereditary patterns, etc.), research methods, and the importance of research work in Kazakhstan.

The experimental and practical work consisted of three stages:

1. Ascertaining experiment.

2. Formative experiment.

3. Controlling experiment.

The objectives of the ascertaining experiment included studying the methods for organizing Project Based Learning in schools that use traditional methods of teaching biology. At this stage, to assess the pupils' knowledge of biology, we applied questionnaires and tests.

First, we estimated the pupils’ knowledge and then divided them into two groups according to the formula proposed by V. P. Simonov (Seytaliev, 1998):

LK = (1 * “5” assessment result + 0.64 * “4” assessment result + 0.36 * “3” assessment result) * 100%/N

where LK is the level of knowledge, and N is the number of pupils.

We experimented with classes with comparable knowledge levels. We estimated pupils' knowledge levels according to their quarterly grades. Figure 1 presents pupils' knowledge levels at the ascertaining experiment stage.

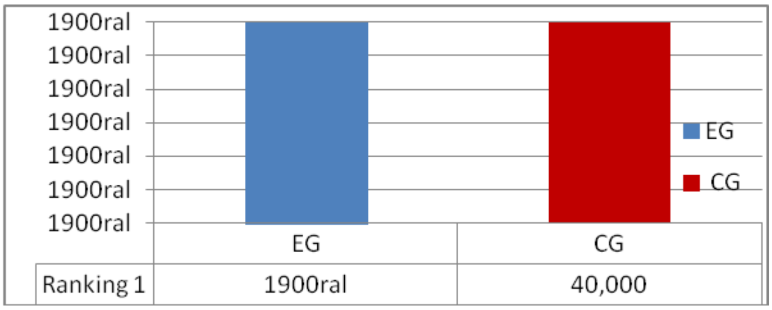

Figure 1. The levels of pupils’ knowledge (EG – experimental group; CG – control group)

To determine the effectiveness of the proposed methodology and to obtain the qualitative and quantitative assessment of the experimental data, we conducted a pedagogical experiment according to these three criteria:

1. How well the pupils could master the content of concepts and the scope of the material learned and understand the relationships among concepts.

2. The ability to express one’s opinion when explaining biological laws.

3. Pupils’ ability to solve problems that require practical application of their knowledge.

To quantify the experimental results when estimating the compliance with the above criteria, we used the following indicators:

The coefficient of knowledge acquisition (Cka) according to the method of A.V. Usov (Filho et al., 2016).

Cka = the number of correct answers/total number of questions

The coefficient of knowledge acquisition as an indicator of the mastery of the educational material should be within the following range 0 < Cka < 1. It demonstrates whether the learning process is completed or not completed. According to Russian and international educators, if Cka > 0.7, then the learning process is considered completed, whereas the learning process is considered incomplete if Cka <0.7.

At the beginning of the experiment, in the control group, the coefficient of knowledge acquisition was 0.43, and 0.61 – in the experimental group.

Table 3. The coefficient of knowledge acquisition and the levels of education

The coefficient of knowledge acquisition	The levels of education
C < 0.3	Insufficient education (no education)
0.3 < C < 0.5	Low
0.5 < C < 0.7	Medium
C > 0.7	High

Having studied the results of the questionnaire, we determined how well pupils understood the content and scope of concepts and their relationships in biology.

4. Discussion

Fifty-two percent of the pupils answered the third question correctly, and 37% answered the tenth question correctly. These indicators prove the need for making the biology course more consistent. Notably, neither the experimental group (EG) nor the control group (CG) showed a high level of knowledge acquisition. At the same time, 67% and 63.5% of the pupils in EG and CG exhibited the medium level, respectively. Besides, 33% of the pupils in EG and 36.5% of those in CG showed a low-level knowledge acquisition.

We asked questions to assess pupils' understanding of the properties, nature, and features of fungi. We found that 63.8% and 66.5% of pupils in EG and CG displayed the medium level of knowledge acquisition, respectively, whereas the corresponding proportions exhibiting the low level were 46.2% and 43.5%. Many pupils claimed that they were unaware that groceries could be contaminated with microorganisms and did not know the differences between various parasitic organisms.

We used questionnaires to measure the ability of the pupils to solve problems that required the practical application of their knowledge of biology. The results showed that pupils had difficulty putting their knowledge into practice (i.e., the results could be classified as belonging to the low level of knowledge acquisition). For instance, 55% and 53.2% of pupils in EG and CG exhibited the medium level of knowledge acquisition, whereas 52.4% and 54.5% in EG and CG could be classified as belonging to the low level.

The formative experiment involved assessing pupils' performance concerning classroom projects and extracurricular activities. The instruction included traditional forms of training for the pupils in CG. Pupils in EG were trained in the application of innovative teaching methods, including research activities. The purpose of the formative experiment was to develop pupils' understanding of biology and reveal their talents. The formative experiment involved imparting knowledge on biology using a new technology based on the activities we developed.

To teach a range of topics, we applied various teaching aids and research methods to facilitate group work and independent practice, which allowed the pupils to develop the competencies and research skills related to this subject. To hone pupils' research skills, we used project-based learning, interactive project research, Demonstration Interactive Laboratory Lessons, Campus Living Laboratory, teaching with visualizations, and investigative case-based learning.

In the final stage of the formative experiment, the pupils completed a project and drew their conclusions. The topics included "Study of the types of diseases affecting cabbage," "Observation of the types of diseases affecting tomatoes and onions," "Study of phytopathogenic fungi in seeds," and "Study of the healing properties of Earth."

In the final stage of the practical experiment, we repeated the test questions asked at the beginning of the experiment and assessed pupils' knowledge. After the experimental teaching was complete, the coefficient of knowledge acquisition increased by 0.12.

At the beginning of the experiment, none of the pupils exhibited a high understanding of the content, scopes of concepts, and their relationships in the biology course. By the end of the experiment, however, an increase of 22.5% was observed; the number of pupils exhibiting the medium level of knowledge acquisition increased by 2.5%, while those showing the low level decreased by 24%.

At the end of the experiment, we assessed pupils' understanding of biological objects' properties, nature, and features. Table 3 demonstrates an increase in the indicator of this criterion. For example, at the beginning of the experiment, none of the pupils exhibited a high level of knowledge acquisition. However, by the end of the exercise, 19.3% of the pupils had achieved it. The number of pupils showing a medium level of knowledge acquisition increased by 1.7%, while those exhibiting a low level of knowledge acquisition decreased by 21%.

The ability to solve problems by applying knowledge in practice at the end of the experiment grew by 18.5%. The number of pupils classified as belonging to the medium level increased by 6.2%, and those classified as low level decreased by 24.7%.

Comparing the learning outcomes between EG and CG, we concluded that the proposed methodology is efficient to teach biology, help pupils choose a profession in the future, and assist their research. The results of the questionnaire and the quality of the pupils' project work/assignments proved that the pupils had mastered the necessary research skills. Table 4 presents the indicators of all components of the pupils' competence in biology (at the beginning and end of the experiment).

Table 4. The indicators of all components of the pupils' competence in biology (at the beginning and end of the experiment), %

Components	The experiment stage	Experimental and control groups					
		High		Medium		Low	
		EG	CG	EG	CG	EG	CG
Mastery of the content and the scope of concepts, understanding their relationships	Beginning	-	-	67	63.5	42	44.5
	End	22.5	-	69.5	73.5	18	35.5
Ability to express one's opinion	Beginning	-	-	63.8	66.5	46.2	43.5
	End	19.3	-	65.5	68	25.2	42.8
Ability to apply one's knowledge	Beginning	-	-	55	53.2	52.4	54.5
	End	19.3	-	65.5	68	25.2	42.8

Figure 2 presents the generalized result of the experiment.

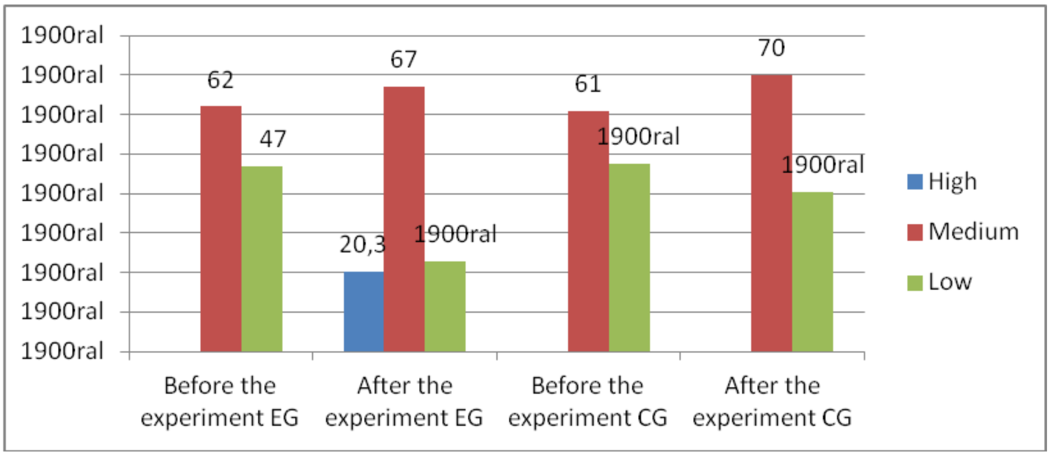

Figure 2. The summary of the changes in the pupils' knowledge of biology (before and after the experiment)

At the beginning of the experiment, the proportion of pupils with a low level of understanding in the experimental group was 47%. At the end of the experiment, this figure was estimated to be 22.8%. In EG, initially, 62% of the pupils showed a medium level of knowledge acquisition, but at the end of the experiment, this number changed to 67%. Moreover, none of the pupils showed a high level of knowledge acquisition at the outset; however, this figure reached 20.3% after the experiment.

Thus, we assessed the level of knowledge acquisition by the pupils involved in the experiment and determined that their knowledge had increased by the end of the experiment (Figure 3).

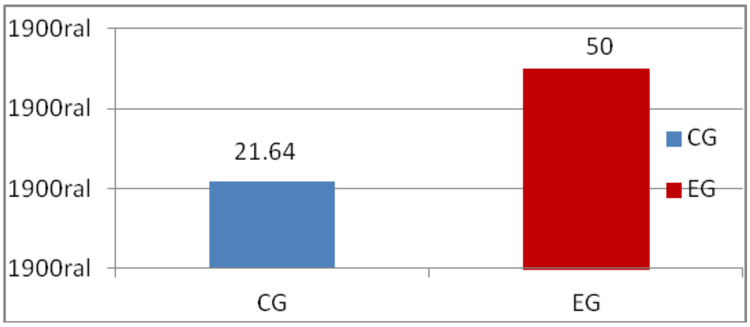

Figure 3. The levels of knowledge acquisition of the pupils participating in the experiment (EG – experimental group, CG – control group, after the experiment)

5. Conclusion

Following the subject "Biology", the possibilities of forming research and project activities by performing additional special project tasks and training programs are determined. Education is organized by integrating learning and research with integrated forms of learning.

We analyzed the data and verified it via statistical processing. We proved that the proposed methodology expands the theoretical knowledge of pupils and is also an effective tool for the formation of research skills. Besides, this methodology effectively increases the cognitive and creative abilities of pupils. In summary, the results of the expert analysis showed that the hypothesis of our research was correct.

From the works of several authors in the learning process, pupils independently find the problem, and independently solve the problem and check its correctness, evaluate it as the highest activity in the project method (Belwal, Belwal, Sufian, & Al Badi, 2020; Perez-Sanchez & Lopez-Jimenez, 2020; Chanpet, Chomsuwan, & Murphy, 2020).

The introduction of pupils to scientific and creative activities in natural Sciences, training along with scientific activities, and the formation of research skills was evaluated as the key to quality education (Muhibbuddin & Safrida, 2020; Briones et al., 2020; Cazorla-Montero, de Los Rios-Carmenado, & Pasten, 2019; Indorf, Weremijewicz, Janos, & Gaines, 2019).

In this regard, this research work has shown the importance of the relationship between educational and research activities of pupils.

6. Limitation and study forward

The use of modern methods of research in advancing biological knowledge, the development of innovative technologies, and scientific research methods will allow to increase the research competence of pupils, enhance their creative abilities, and deepen the quality of knowledge. The study results can be used in the work of teachers to perform research and project work at school and will be used in research activities in this area in the future.

The organization of project activities of pupils during extracurricular hours, implementation of educational and field practices were not covered. In the future, it is planned to organize work in these areas. Besides, it is planned to improve the evaluation system for project work in the future.

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