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USING MOODLE FOR INQUIRY-BASED LEARNING IN MATHEMATICS

Mariia Astafieva[1], Oksana Hlushak[2], Kateryna Hruzdova[3], & Volodymyr Proshkin[4]
Borys Grinchenko Kyiv University, Bulvarno-Kudriavska St. 18/2, Kyiv, Ukraine
[1] m.astafieva@kubg.edu.ua, https://orcid.org/0000-0002-2198-4614
[2] o.hlushak@kubg.edu.ua, https://orcid.org/0000-0001-9849-1140
[3] kihruzdova.fitm23m@kubg.edu.ua, https://orcid.org/0000-0002-2747-3364
[4] v.proshkin@kubg.edu.ua, https://orcid.org/0000-0002-9785-0612

Abstract: *The scientific article aims to explore the possibilities of using the Moodle platform to implement a research-oriented approach to teaching mathematics based on students' questions and active engagement – Inquiry based learning in mathematics (IBLM). The article analyses the results of a survey of students, which was conducted in order to identify the difficulties faced by students during distance learning of mathematics. Problems encountered by students in learning mathematics online are identified, along with ways to overcome them. The opportunities provided by the Moodle platform to support active and research-oriented mathematics learning are highlighted, in particular, the creation of a favourable learning environment where students can explore mathematical concepts, formulate questions and solve problems at different levels of Inquiry based learning. The article provides examples of mathematics tasks developed on the Moodle platform aimed at teaching distance at different levels of inquiry, including structured, guided and open. Special emphasis is placed on the development of an individual approach to teaching mathematics that takes into account the level of students in Inquiry-Based Learning IBL. Thus, the article contributes to the understanding of the possibilities of using the Moodle platform for the implementation of IBL in the study of mathematics.*

Keywords: Moodle; distance learning of mathematics; Inquiry based learning in mathematics (IBLM)

INTRODUCTION

The leading methodology of modern education is active, research-oriented learning, which is designed to form key competences necessary for the culture of democracy (Competences for democratic culture). One of the effective strategies for achieving

this goal is Inquiry based learning (IBL). This strategy develops students' critical thinking and creative potential, engaging them in active work on their own research and problem solving.
In today's digital world, where information communication technologies are at the center of attention, educational platforms are becoming indispensable tools for implementing the IBL approach. One of such platforms that is gaining more and more popularity in teaching mathematics is Moodle. Moodle is an open learning management system that helps create a stimulating learning environment where students become active participants in the process of learning and research, which is what Inquiry-based learning consists in.
In this article, we will examine the use of Moodle to implement an IBL approach to mathematics education. We will explore how Moodle can become a powerful tool for stimulating students' independence and activity in the process of learning mathematics. We will also consider examples of specific Moodle tools and functionality that contribute to the implementation of the IBL approach.

1. ANALYSIS OF CURRENT RESEARCH

The importance of IBL in mathematics learning as a pedagogical technique that encourages students to explore, hypothesize, discover, prove, collaborate and communicate is revealed in (Capaldi, 2015; Dorier, & Maass, 2020). Calleja, J. distinguished four features of IBL in the mathematics class: mathematical tasks, collaborative learning, purposeful questioning, student agency and responsibility, led teacher's role and conditions for IBL (Calleja, 2016). The effectiveness of using IBL in the process of learning mathematics has been proven in many studies, for example (Karamustafaoğlu, & Pektaş, 2023; Nunaki et al., 2019; Pedersen, & Haavold, 2023).
The use of digital technologies in teaching mathematics is the subject of modern scientific research, for example Clark-Wilson, Robutti, & Thomas (2020), Hillmayr et al. (2020), Astafieva et al. (2019). Researchers pay special attention to the development of an educational environment for teaching mathematics on the Moodle platform (Darmayanti, Baiduri, & Inganah, 2022). Aspects of using digital mobile technologies to support IBL are described in (Becker et al., 2020). However, the use of Moodle for the implementation of the IBL strategy in mathematics education has not been sufficiently investigated. This opens up prospects for further scientific research.
The analysis of scientific sources allowed us to formulate the research question:
What are the possibilities of using Moodle to implement the IBL approach in teaching mathematics?

2. MATERIALS AND METHODS

Theoretical – analysis, systematization and generalization of scientific and methodical literature to clarify the essence of IBL, its levels, and the possibility of adapting IBLM for the formation and development of mathematical thinking of schoolchildren, definition of the conceptual and categorical research apparatus; generalization of progressive ideas and existing shortcomings in modern secondary education to justify ways of use Moodle for inquiry based learning in mathematics; empirical: a pedagogical experiment to determine the effectiveness of using inquiry-based learning in the process of teaching mathematics, as well as a survey to find out the difficulties that arise when learning mathematics in an online format and the effectiveness of use Moodle for Inquiry-Based Learning in Mathematics. The research was carried out within the scope of the scientific topic "Mathematical methods and digital technologies in education, science, technology" (state registration number: 0121U111924) of the Department of Mathematics and Physics of Borys Grinchenko Kyiv University.

3. MAIN RESULTS

3.1. Survey

A survey of 37 students majoring in "Mathematics" of Borys Grinchenko Kyiv University (BGKU) from 2019 to 2022 and 10 students of the online school "New Generation" in 2022, regarding the difficulties that arise when studying mathematics in an online format showed that these difficulties are practically the same and can be summarized as follows:

A. Lack of direct interaction with the teacher, which:

- deprives the student of the opportunity to immediately receive immediate answers to questions or additional explanations when learning new mathematical concepts or solving problems. This often leads to a decrease in motivation or even a loss of it when students encounter challenges without knowing how to overcome them.
- prevents deprives the teacher of promptly diagnosing the cause of the mistake made by the student and conducting work on correcting knowledge in a timely manner, which, as a result, negatively affects the student's conceptual understanding of mathematical concepts, facts, methods, significantly increases the time for their assimilation and forms a stereotype about the complexity and incomprehensibility of mathematics.

B. Lack of teamwork. Even when teamwork is organized online (synchronously or asynchronously), it is ineffective, since the teacher does not correct the course of the discussion, and if the discussion is "stuck", then most often no one can "unblock" it, steer it towards generating new, productive ideas. The task remains unsolved, faith in one's own strength is lost.

C. Lack of self-discipline and the ability to independently organize and rationally allocate time ("… in the classroom I focus on work, I don't get distracted, but I can't do this during distance learning").

D. Technical problems: It is not uncommon to experience problems with technical facilities such as computers, software, or power and Internet connections, which is particularly common during and as a result of Russian missile strikes. This results in interruptions in learning, stress and inconvenience in completing tasks.

There are reasons to assume that not only the successful choice of a distance education platform, appropriate digital tools, but also the Inquiry based learning (IBL) strategy can significantly minimize the difficulties of online mathematics learning, as it involves students in research, active search and construction of knowledge, stimulating interest and motivation. IBL provides communication and interaction between the teacher-student and students among themselves, which reduces the feeling of isolation in the online environment, and various online platforms are an ideal place for discussions, joint problem solving, and teamwork. In addition, IBL encourages flexible individual learning, aiding in better time management and mitigating self-discipline issues.

3.2. Pedagogical strategy of Inquiry-Based Learning (IBL) and its implementation in the training of future mathematics teachers

The IBL approach, initiated in the 60s of the last century by Joseph Schwab, is actively developed (at all levels of education) and researched. This is evidenced by numerous publications, for example (Goodchild, Fuglestad, and Jaworski, 2013; Laursen, & Rasmussen, 2019; Manoli et al., 2015) and the implementation of a number of international projects. In one of these projects, namely, Erasmus + KA2 "Partnership for Learning and Teaching in University Mathematics" (PLATINUM), teachers of the Department of Mathematics and Physics of the Borys Grinchenko Kyiv University participated. The project developed methods and tools of IBL in mathematics higher education at the theoretical and practical levels. The results of the project are accumulated in a collective monograph (Gómez Chacón, Hochmuth, Jaworski, Rebenda, Ruge, & Thomas, 2021).

Inquiry based learning in mathematics (IBLM) is based on a paradigm in which students are encouraged to work in the same style as professional mathematicians: observe, experiment, notice properties and regularities, ask questions and look for mathematical, scientific ways to answer them, express hypotheses, make generalizations, interpret and critically evaluate solutions, communicate effectively in the process of searching, presenting, discussing ways and results. Within such a paradigm, the teacher is a partner (tutor, facilitator) of joint activities with schoolchildren. IBL requires a fundamentally different model of organizing the educational process, when the teacher organizes pedagogical support for the student's self-learning, effectively directs the trajectory of his search and research activity, which leads to the acquisition of new (for the student) knowledge. An inherent feature of IBL is the student's active participation and responsibility for acquiring (constructing) knowledge. With a series of purposeful inquiry-questions, the teacher (or student) directs progress towards the formulation of the hypothesis, supporting and encouraging discussion, reflection, and mutual assistance.

According to (Zion and Mendelovici, 2012), three levels of IBL organization of students on the way to new knowledge are distinguished: structured, guided and open Inquiry. We characterize the activity of the teacher and students in the implementation of IBML at each of these levels as follows.

Level I. Structured Inquiry

The teacher formulates a research question (problem, problem statement), briefly describes the procedure (solution idea), and students, implementing the proposed procedure or idea, come to the answer (get the result). The stages of the solution, intermediate conclusions or results, explain and argue.

Level II. Guided Inquiry

The teacher only formulates a research question or problem. Students independently analyse a known or new problem, formulate hypotheses regarding the idea of a solution or result, choose a method, procedure, tools to find an answer to the question, present and justify their choices and the result obtained, formulate certain conclusions (whether the solution is unique, whether it is sensitive to minor changes in parameters, whether it has interesting partial cases; whether the chosen method is rational, what are its "pros" and "cons", what are other possible solutions).

Level III. Open Inquiry

Students independently formulate a research question or problem, look for a research method or solution, develop and implement the appropriate procedure, choose the necessary tools and present their results and conclusions. The teacher, depending on the situation, acts as a consultant, partner, team member, tutor, facilitator or opponent. Depending on the level of readiness of the students and their previous experience in search and research activities, the teacher implements one or another level of Inquiry. It is obvious that one should start with the first and second levels, gradually moving to the third level, at which the research work of students most completely repeats the work of scientists, except for the example of solving simpler (for a scientist, but not for a student) problems.

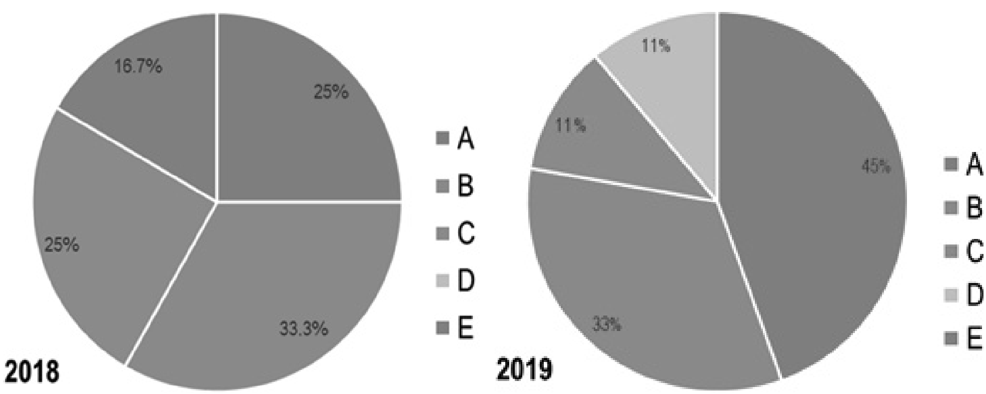


Figure 1. Results of exams on mathematical analysis of first-year students in 2018 (12 students) and 2019 (9 students) years of admission, respectively (A, B, C, D, E – ECTS grades)

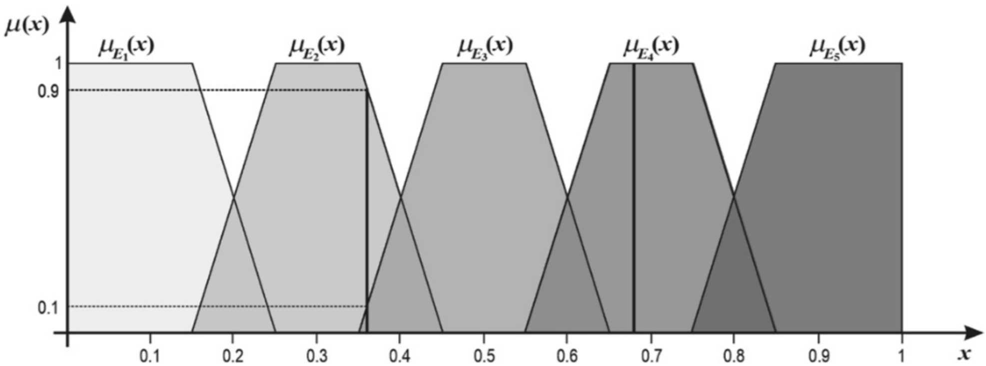
Source: Own work.

IBLM pedagogical strategy tools (existing and developed by participants of the PLATINUM (Partnership for Learning and Teaching in University Mathematics) Project) were tested at Borys Grinchenko Kyiv University when teaching mathematical analysis in the "Mathematics" specialty (teacher Mariia Astafieva) and confirmed their effectiveness in forming conceptual mathematical knowledge and mathematical competence in general in students – future school teachers of mathematics (Inquiry in University Mathematics Teaching and Learning, 2021, pp. 327–348). This is evidenced by the comparative results of the exams of two academic groups of students of the 2018 and 2019 years of admission, in the second of which the IBLM strategy was implemented (Figure 1, (Inquiry in University Mathematics Teaching and Learning, 2021, pp. 346)).

3.3. Adaptation of IBLM for the formation and development of mathematical thinking of schoolchildren

The positive results of the approbation (within the PLATINUM Project) of IBL in the educational process of mathematics students of the university prompted the adaptation of the mentioned strategy to school mathematics education. This idea was implemented in 2021 in the mathematics education of fifth-grade students of the I–III Degrees Specialized School № 129 in Kyiv (teacher – Kateryna Hruzdiova). We proceeded from the thesis that the cognitive basis and cognitive component of mathematical competence is mathematical thinking, the best field for the formation and development of which is mathematical problems.

We assumed that the use of tools and techniques of IBLM, the competent construction of assistance by the teacher in the form of a system of questions makes it possible to use the developmental potential of the task to the maximum. We changed some problems from the textbook or prepared new mathematical problems from all topics of mathematics of the 5th grade, the solution of which would resemble the work of a mathematical scientist (from experiment, observation to the formulation and testing of a hypothesis), developed pedagogical support for this process in the IBL style, and conducted a pedagogical experiment described in (Astafieva and Hruzdova, 2021). The results of the experiment confirmed our assumption. Diagnostic testing of the level of formation of mathematical thinking in experimental and control classes (30 students in each) showed a significant advantage (from 22% to 39%) of the results of the experimental class in all parameters that characterize mathematical thinking (Astafieva and Hruzdova, 2021). Determination of the level of mathematical thinking in two groups of test takers, carried out using the methods of the theory of fuzzy sets (Zadeh, 1978), showed a sufficient level of mathematical thinking of students of the experimental class (the indicator 0.68 is contained in the term E4, which characterizes a sufficient level), and the level of mathematical thinking of students of the control class (0.36) is in the transition zone from elementary (E2) to middle (E3) levels, and the value of the belonging functions indicates a higher degree (0.9) of belonging to the zone of the elementary level (Figure 2, (Astafieva and Hruzdova, 2021)).



F i g u r e 2. Terms of the linguistic variable "Mathematical thinking"

S o u r c e: Own work.

3.4. Using Moodle for IBLM in a distance format

The prevailing circumstances in Ukraine, including the pandemic and Russia's military aggression, have necessitated the shift of the educational process to a distance format. New distance schools are being established, and one such institution, the "New Generation" distance school, was founded at Borys Grinchenko Kyiv University during the 2022–2023 academic year. Drawing from our positive experience with IBLM in face-to-face education, we have implemented this strategy in the "New Generation" distance school using the Moodle platform. The choice of this platform for IBLM is primarily due to its capacity to actively engage students in the educational process, stimulate their independent search and research work, offer divers options for differentiated learning, both group and individual work, facilitate effective interaction between the teacher and students and among students themselves, and allow for monitoring the progress of students to enable timely adjustments to the educational process. For effective IBLM, it is necessary that the educational strategy of the teacher and the activities of students correspond to one or another level of Inquiry (structured, guided or open). Therefore, all students should be divided into groups based on their readiness for research-oriented learning. It is obvious that the composition of such groups is dynamic and the teacher's goal is to ensure that students gradually move to a higher level. The tests used avoid closed-type tasks that only require the selection of a single correct answer from multiple choices, because such tasks do not provide information about the student's analytical skills, research abilities, or overall mathematical thinking. Instead, tests often involve 'short answer' or 'essay' tasks. Here are some examples of using Moodle tools to implement the IBLM strategy.

Example 1. Lesson

"Lesson" is convenient to use for learning new material or solving a problem. The structure of a lesson on the same topic is different for different levels of Inquiry. Figures 3 and 4 show the "Lesson" diagrams for Structured and Guided Inquiry, respectively. A screenshot of the collapsed view of the lesson on the topic "Condition of perpendicularity of vectors" for the "structured inquiry" level can be seen in Figure 5.

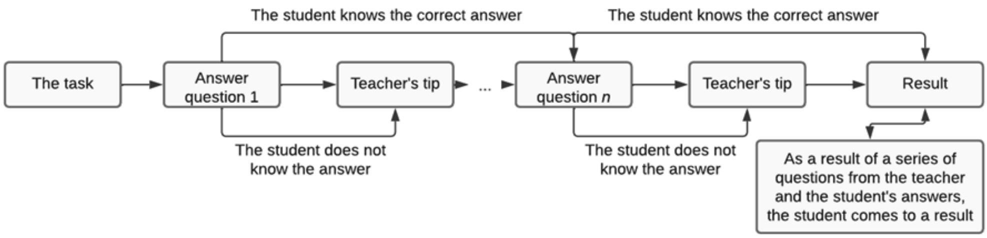


Figure 3. Lesson structure for structured inquiry

Source: Own work.

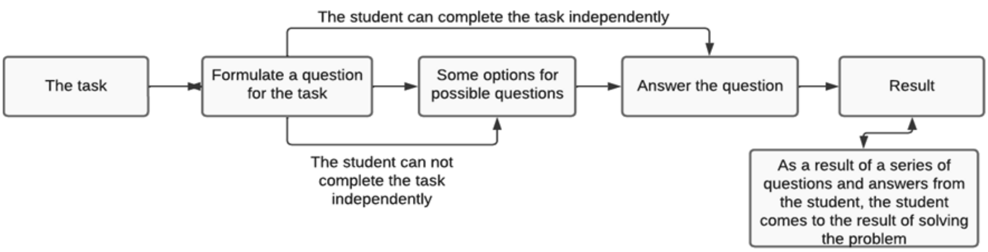


Figure 4. Lesson structure for guided inquiry

Source: Own work.

The condition of perpendicularity of vectors

Preview | Edit | Reports | Grade essays

Collapsed | Expanded

Page title	Page type	Jumps
What vectors are called perpendicular?	Multichoice	Next page Perpendicularity of vectors Perpendicularity of vectors
What is the angle between perpendicular vectors?	Short answer	Next page The angle between the vectors
Choose the option of the scalar product of vectors if the vectors are perpendicular	Multichoice	Next page Scalar product of vectors Scalar product of vectors
What is the numerical value of the scalar product of perpendicular vectors?	Short answer	Next page The value of trigonometric functions of some arguments
Make a conclusion: formulate a proven statement using the construction "If..., then..."	Multichoice	Next page Correct answer with explanation Correct answer with explanation Correct answer with explanation
Formulate a statement inverse to the proven one	Multichoice	Next page Inverse statements Inverse statements Inverse statements
Make a conclusion about the correctness of the inverse statement by going through the chain of reasoning in reverse order	Content	Next page The condition of product equality is zero.
Formulate, if possible, the criterion for perpendicularity of vectors	Multichoice	End of lesson Necessary, sufficient, necessary and sufficient conditions Necessary, sufficient, necessary and sufficient conditions

Figure 5. Collapsed view of the lesson on the topic: "Condition of perpendicularity of vectors" in Moodle

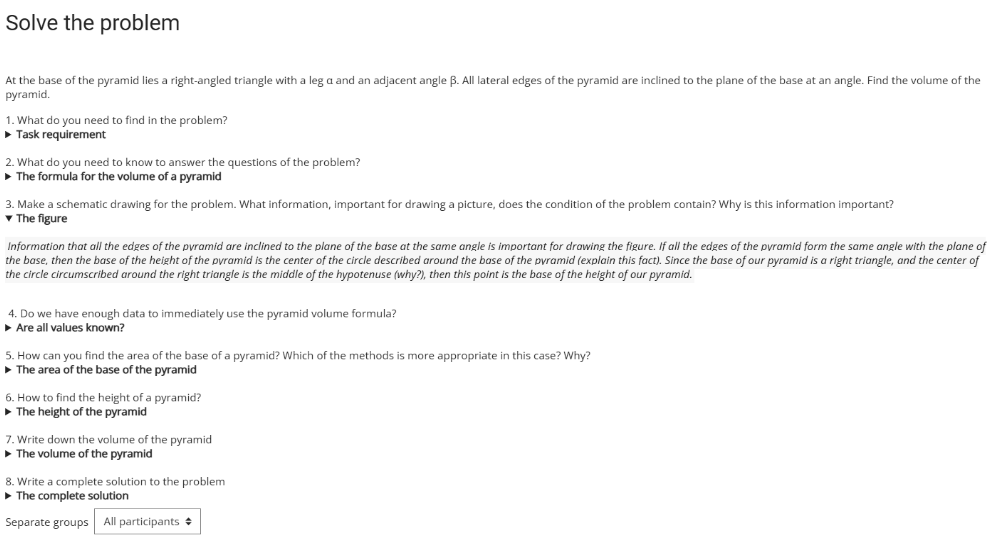
Source: Own work.

Example 2. The forum

In the forum there is a task: "*At the base of the pyramid is a triangle with sides a, b, c. The side edges of the pyramid are equal to each other and have a length of l.* A. Generate the question (requirement) of the task. B. Offer answers to questions formulated by your classmates. C. Discuss, evaluate questions and answers and solutions".

The effectiveness of using the forum for teaching students to ask mathematical questions, to formulate a problem, that is, to work at the third (open) level of Inquiry, is evidenced by the questions and tasks proposed by students: from the simplest (what is the height / volume / area of the side (full) surface of the pyramid? why are the flat angles of the trihedral angle at the top of the pyramid equal? what angles form the side edges of the pyramid with its base?) to the more interesting (what are the dihedral angles of the pyramid equal to? what is the radius of the sphere circumscribed around the pyramid? what is the volume and surface area of the cone circumscribed around the pyramid equal? why are the volume and surface area of the cone inscribed in the pyramid equal?), and even complex (what is the radius of the sphere inscribed in the pyramid? express the desired radius through the volume and the full surface of the pyramid; find the ratio of the volume of the cone circumscribed around the pyramid to the volume of the pyramid, write down the corresponding formula through the perimeter of the base of the pyramid and the length of the circle of the base of the cone). It is also important that all students asked their questions, each according to their level of conceptual understanding and knowledge of the topic "Pyramid".

Example 3. Hidden text



Solve the problem

At the base of the pyramid lies a right-angled triangle with a leg α and an adjacent angle β. All lateral edges of the pyramid are inclined to the plane of the base at an angle. Find the volume of the pyramid.

1. What do you need to find in the problem?
▶ **Task requirement**

2. What do you need to know to answer the questions of the problem?
▶ **The formula for the volume of a pyramid**

3. Make a schematic drawing for the problem. What information, important for drawing a picture, does the condition of the problem contain? Why is this information important?
▼ **The figure**

Information that all the edges of the pyramid are inclined to the plane of the base at the same angle is important for drawing the figure. If all the edges of the pyramid form the same angle with the plane of the base, then the base of the height of the pyramid is the center of the circle described around the base of the pyramid (explain this fact). Since the base of our pyramid is a right triangle, and the center of the circle circumscribed around the right triangle is the middle of the hypotenuse (why?), then this point is the base of the height of our pyramid.

4. Do we have enough data to immediately use the pyramid volume formula?
▶ **Are all values known?**

5. How can you find the area of the base of a pyramid? Which of the methods is more appropriate in this case? Why?
▶ **The area of the base of the pyramid**

6. How to find the height of a pyramid?
▶ **The height of the pyramid**

7. Write down the volume of the pyramid
▶ **The volume of the pyramid**

8. Write a complete solution to the problem
▶ **The complete solution**

Separate groups | All participants ⬍

Figure 6. An example of a task in Moodle with hidden text

Source: Own work.

In order to differentiate the pedagogical support of students' search and research work in the conditions of distance learning (when the teacher does not have direct contact with the student and therefore cannot immediately provide him with the necessary help), it is useful to initially hide part of the text on the page of the educational material with the possibility of accessing it as needed. Moodle allows you to do this in HTML editing mode. In Figure 6, we see a task to solve a stereometry problem, in which pedagogical support in IBL style is provided by hidden text. Completion of this task is not evaluated, which encourages the student to be honest with himself and use the hidden text rationally in order to prepare for the independent solution "for evaluation" of a similar problem.

4. DISCUSSION

Here is some feedback from teachers and students about the usefulness of Moodle tools in implementing IBL in online mathematics education.

Teacher 1. Forums in Moodle allow students to express their ideas, ask questions, share their research, collaborate and learn from each other. Hidden text tasks stimulate curiosity and help students actively explore the material on their own, searching for answers to questions. A wiki allows us to create collaborative projects and research, which develops collaborative and creative thinking skills.

Teacher 2. We use quizzes in Moodle as an effective way to assess student knowledge. Moodle allows us to create different types of questions, but we prefer open-ended test tasks, in particular, "write the answer as a number". Automatic grading helps you save time when reviewing tests. In addition, Moodle has the ability to provide feedback and statistics about student responses, which helps us understand which aspects of the material need more attention.

Student 1. Moodle has been a real lifesaver for me when learning mathematics. It was very difficult to study online without it. Because when you read a textbook and something is unclear or when you have to solve a problem and you don't know where to start, then everything remains unstudied and unsolved, because there is no one to ask. The Moodle Forum provides an opportunity to discuss complex issues with my classmates and receive answers from our teacher. This allows me to better understand the material and get support when I need it. However, it turned out that asking the right question, explaining exactly what you do not understand, what the problem is, is also a difficult task. Also, using the Forum encourages learning to ask questions.

Student 2. Moodle is a very comfortable educational environment for me. I can go through the material at my own pace and refer to it at any time convenient for me. Also, the Forum allows me to discuss issues with my classmates. It is very interesting to see how the same problem (most often – geometric) can be solved in many different ways. In the Forum, we often arrange a kind of competition – who can find more ways, and whose way is the most rational, the most beautiful. It is important that in all our discussions the teacher is "invisibly" present, who at the right moment, when the discussion has reached a "dead end", will lead out of it, help to see the error.

Student 3. The use of hidden text in "lessons" and "tasks" allows me to independently solve problems and check my answers, or at a certain stage to use a hint if difficulties arise. This tool helps me to better understand and apply mathematics, and it also encourages me to try my hand at solving problems myself, because you know that there is always an opportunity to use help.

Student 4. The Forum allows me not only to get answers to questions, but also to help other students who have difficulties. It gives me confidence. I also feel that we are a team, a community where mutual help and support are valued.

Student 5. Self-tests help me a lot to study. I like to get results and feedback instantly. It helps me quickly identify my mistakes and weaknesses, which gives me the opportunity to improve my knowledge and thus better prepare for the knowledge test.

Although the given student feedback does not contain any mention of IBL, but only that Moodle helps them in online mathematics learning, in fact, these feedbacks show that the use of the Moodle platform and its interactive tools helps to support the principles of Inquiry-based learning in the process of online mathematics learning, promoting the active participation of students in their search and research activities, supporting interactivity and interaction between participants in the educational process, developing creativity and the ability to alternative thinking, fostering independence and self-discipline.

CONCLUSION

1. A survey of students and schoolchildren confirmed that the online format of learning mathematics is accompanied by certain difficulties, such as the lack of direct interaction with the teacher, lack of teamwork, lack of self-discipline and the ability to independently organize and rationally allocate time, as well as technical problems.
2. Using the IBL strategy can be an effective solution to these difficulties because, as confirmed by the experiment of teaching students and schoolchildren in the classroom, IBL involves students in active search and construction of knowledge, stimulates their interest and motivation, and also promotes interaction between students and teachers.
3. The use of the Moodle platform contributes to the effective implementation of the IBL strategy at different levels of inquiry (structured, guided and open) in distance learning of mathematics. Moodle allows teachers to effectively organize both group and individual work, interact with students and monitor their progress, and also promotes active involvement of students in research activities.
4. According to feedback from teachers and students, Moodle tools effectively support the IBL principles in online mathematics learning, encouraging active participation of students in search and research activities, fostering their creativity and ability for creative thinking, and promoting interaction and interactivity in the educational process.

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