E-learning as a mean of forming students' mathematical competence in a research-oriented educational process

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Abstract. The article is devoted to the substantiation of approaches to the effective use of advantages and minimization of disadvantages and losses of e-learning as a mean of forming mathematical competence of students in the conditions of research-oriented educational process. As a result of the ascertaining experiment, e-learning has certain disadvantages besides its obvious advantages (adaptability, possibility of individualization, absence of geographical barriers, ensuring social equality, unlimited number of listeners, etc.). However, the nature of these drawbacks lies not as much in the plane of opportunity itself as in the ability to use them effectively. On the example of the e-learning course (ELC) "Mathematical Analysis" (Calculus) of Borys Grinchenko Kyiv University, which is developed on the basis of the Moodle platform, didactic and methodical approaches to content preparation and organization of activities in the ELC in mathematics are offered. Given the specifics of mathematics as a discipline, the possibility of using ELCs to support the traditional learning process with full-time learning is revealed, introducing a partially mixed (combined) model. It is emphasized that effective formation of mathematical competence of students by means of e-learning is possible only in the conditions of research-oriented educational environment with active and concerned participation of students and partnership interaction. The prospect of further research in the analysis of e-learning opportunities for the formation of students' mathematical competence, in particular, research and investigation tools, and the development of recommendations for the advanced training programs of teachers of mathematical disciplines of universities are outlined.

Keywords: e-learning, e-learning course, mathematical competence, research-oriented learning.

1 Introduction

Today's innovative society needs professionals of a new type who are able to act responsibly, actively and productively in the face of dynamic change, with a high degree of interdisciplinarity and adaptability, ready to learn quickly and effectively. This is why the EU Council and the European Parliament, as one of the key competences for lifelong learning, define mathematical competence as the ability to develop and apply mathematical thinking to solve problems in different situations and contexts, the willingness to trace cause and effect relationships, the ability to make and evaluate arguments, prove [1]. At the same time, the problems of our day require the specialists of mathematical competence not only in the above, general understanding, but also at the subject level, which is caused by the intensive development of the mathematical science itself, as well as the penetration of mathematics, its methods into other, non-mathematical, spheres. Training of such a specialist is possible only in the conditions of research-oriented teaching of mathematics (in particular inquiry-based learning), with active and concerned student's participation and partnership interaction. Obligatory components of such training are: asking questions, identifying problems, finding ways of solving, investigating, discussing, thinking about alternatives, rethinking and evaluating the result.

Recently, the effectiveness of mathematical training has been linked to the intensity of the implementation of various forms, methods and tools of e-learning in the educational process. Distance learning is a solid part of university education due to its advantages, including, among others, technological adaptability, the possibility of individualization (own pace and educational trajectory), lack of geographical barriers, ensuring social equality (access to training for persons with special needs, for example), unlimited number of listeners, etc. [18]

In modern scientific researches theoretical and methodological foundations of informatization of education have been revealed (Viacheslav V. Osadchyi [13], Liubov F. Panchenko [7], Serhiy O. Semerikov [6], Aleksander V. Spivakovsky [11], Vladyslav Ye. Velychko [2] etc.). The aforementioned scientific reconnaissance outlines the actual problems of the essential characteristics of informatization of education, components and structure of methodical systems of open education, information technologies of training, psychological and pedagogical substantiation of the nature of electronic educational resources [4], valeological aspects of the use of ICT, readiness of teachers and students to work in the system of open learning [9].

As practice shows, one of the most widespread innovative means of teaching mathematics is e-learning courses (ELCs) – complexes of educational-methodical materials created for the organization of individual and group study by students of mathematical disciplines using technologies of distance learning.

The use of ELCs in the study of mathematical disciplines has become the subject of research by a number of scholars. Thus, Andrii O. Vorokh [17] researched the structure of an e-learning course in descriptive geometry, Oksana V. Zaika [19] presented an electronic educational and methodological support for the course of projective geometry. Serhii A. Rakov [8] explored the process of forming mathematical competences of a mathematics teacher on the ground of a research approach in teaching using information technologies, etc.

Also noteworthy are the works [14; 15] aimed at improving the quality of the implementation of mathematical distance education using ELC. Thus, Oksana A. Zhernovnykova [22] considered the psychological aspects of the implementation of distance education technologies in the process of training future mathematics teachers, Kateryna V. Vlasenko et al. [16] presents the characteristics common to online courses, principles of providing a functioning and physical placement of online systems in webspace and make a conclusion about the expediency of promoting online courses, the purpose of which is to get mathematics teachers acquainted with the technical capabilities of creating educational content developed on Web 2.0 technology, Oksana M. Hlushak et al. [3] revealed the theoretical and methodological bases of using e-learning course “Analytical geometry” in the process of professional training of bachelors in computer science, etc.

There is a rich foreign practice of distance and blended higher mathematics teaching with the use of various packages and different platforms, a detailed review of which was given by Nataliia M. Kiianovska et al. [5]. Interesting and useful in the context of our research is the experience of the Latvian University of Agriculture on the organization of e-learning mathematics for students of engineering specialties. Didactic approaches to the construction of e-courses on the Moodle platform, grounded and tested by the academic staff of this university, allow to strengthen the practical orientation and professional direction of mathematical learning courses, which positively affects the quality of students’ mathematical preparation to the future professional activity [21].

Most researchers consider the use of ELCs to improve the quality of students’ mathematical training and the formation of their mathematical competence. At the same time, many years of experience in the use of the ELC also allow us to highlight a specific problem area related to various methodological, didactic, ethical, psychological and other aspects of e-learning.

2 The objective of research

The aim of the article is substantiation of approaches to the effective use of the advantages and minimize the disadvantages and losses of e-learning as a mean of forming the mathematical competence of students in the context of a research-oriented educational process.

3 Research methodology

The achievement of the goal of the research was facilitated by the use of a set of appropriate methods: analysis of scientific literature in order to establish the state of elaboration of the problem under study, determination of the categorical and conceptual apparatus of the research; synthesis, generalization, systematization for theoretical substantiation of approaches to minimizing the disadvantages of e-learning as a mean of forming students’ mathematical competence; empirical: diagnostic (talk, survey, testing) to track the dynamics of e-learning implementation; ascertaining experiment to prove the advantages and disadvantages of e-learning as a mean of forming students’ mathematical competence; mathematical methods (Pearson’s) for assessing students’ perceptions of e-learning courses.

The research was carried out within the framework of the “Partnership for Teaching and Teaching Mathematics at the University” (PLATINUM) program of the EU

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4 Results and discussion

The guideline in our research is the Regulation on the ELC in the Borys Grinchenko Kyiv University [10]. This provision sets out the basic requirements for the ELCs, the compliance of which should contribute to the achievement of the learning outcomes declared in the work program of the discipline. These include:

- structured teaching materials;
- adherence to the logical sequence of study of the discipline;
- a clear timetable for the implementation of the curriculum;
- system of interactive interaction between teacher and student, students among themselves;
- high quality of the offered educational materials, resources;
- system of control and evaluation of all types of student's educational activity.

In Fig. 1 a fragment of the title page of the ELC for mathematical analysis is shown.

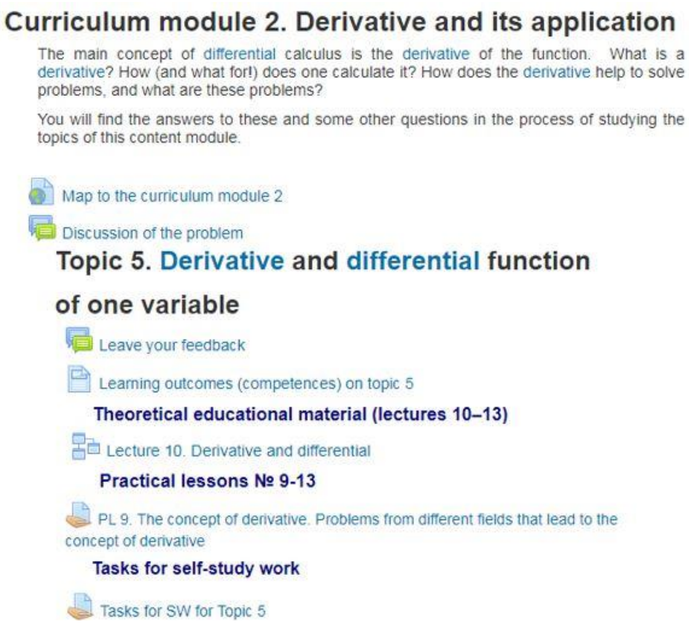


Fig. 1. Fragment of the cover page of the ELC "Mathematical Analysis"

This fragment illustrates the structure of teaching and didactic materials, in particular, the curriculum module “Derivative and its application”. Here is a brief motivational appeal to students, a map (diagram) of the module, a forum “Discuss the problem”, outlined the structure of the first topic of this module “Derivative and differential function of one variable”, consisting of four lectures and five practical sessions. Independent work assignments are also suggested, and the learning outcomes to be achieved as a result of learning of the topic are determined. It is worth noting that ELC was created in Ukrainian, and a part of the course was translated into English for the article.

To find out the real state of implementation of ELC in the educational process and their usefulness for forming mathematical competence of students, we conducted an ascertaining experiment during March – May 2019. The basis of the experiment was the Faculty of Information Technology and Management of Borys Grinchenko Kyiv University (BGKU). A total of 155 Mathematics, Computer Science, Finance, Banking and Insurance students and Management students took part in the survey. In addition, 25 teachers were involved in the experiment as experts.

A benchmark for the student survey was taken “The Perception Questionnaire” ELC in higher mathematics in the Moodle system, conducted at University Kebangsaan in Malaysia [20]. “The Perception Questionnaire” contained 20 indicators grouped into 4 groups: a) Usefulness; b) Computer Self-Efficacy; c) Simplicity; d) General Attitude. Rating scale – four-point (from 1 to 4); the higher the score, the more positive the perception.

Our students were asked to evaluate the ELC generally on the same four scores and on the same four-point scale. The results of the questionnaire are shown in the Table 1.

Table 1. Results of a survey of students’ perceptions of ELC

No	Indicator	Rating students BGKU	Rating students Malaysia
1.	Usefulness of ELC (how much it helps me in learning, makes learning more effective, improves success; enhances material understanding, facilitates material perception, and alike)	2.09	3.76
2.	Computer Self-Efficacy (whether there is access to the content, can I use all the elements and resources of the ELC without further explanation, or can I fix the problems on my own if they arise during the use of the ELC)	3.26	3.48
3.	Simplicity in use (whether there is a convenient interface, whether it's easy to communicate with the teacher, students, report on tasks, ask questions, etc.)	3.02	3.38
4.	General Attitude (how do they find using the ELC: interesting, exciting to learn in such a way, other positive emotional feelings or not interesting, boring and other negative feelings)	2.84	3.71

We compared the statistics obtained using Pearson’s criteria χ^2**.** It is established that for the number of degrees of freedom $\nu = 1$ the empirical value of the criterion $\chi^2_{emp} = 2.424$. The critical value of the criterion, $\chi^2_{cr} = \begin{cases} 7.815, & p \leq 0.05, \\ 11.345, & p \leq 0.01 \end{cases}$’ $\chi^2_{emp} < \chi^2_{cr}$, that is, in total, the differences between these distributions (the views of

Ukrainian and Malaysian students on the problem of using ELCs in the educational process) are not statistically significant. At the same time, comparing the survey results of our and Malaysian students clearly shows that the biggest differences are in assessing the usefulness of the ELC and the overall emotional perception. This suggests that our ELCs, for the most part, do not provide interactive learning and do not create positive internal motivation for students, that is, they do not justify the philosophy of the Moodle educational environment – the pedagogy of social constructivism, which involves active, research-based learning in partnership interaction [12].

In addition, the survey revealed that the vast majority of students have the following problems in studying mathematics disciplines using ELC:

- lack of (or limited) personal communication between the teacher and the student, and stated interaction in theory is poorly implemented in practice;
- insufficient interest of students themselves, especially junior students, in mastering mathematical knowledge independently due to poor mathematical preparation and lack of general educational skills;
- the inability to practice the mathematical knowledge obtained with further discussion of possible errors;
- health problems (such as vision defects) that prevent you from working at your computer for a long time;
- most of the lectures of the ELC are presented in the form of boring textual information with a minimal number of examples, graphics and videos, and without any feedback.

Expert teachers also outline a number of problems in the use of ELC in teaching mathematics:

- only in the teaching audience does the teacher feel how students understand the material (by their questions, answers, emotions, etc.), which allows to make corrective changes in the course of study (to emphasize the students on a certain theoretical or practical aspect, to give additional explanations, to pay additional explanations, certain subtleties of proof, etc.);
- students who are used to communicate in a virtual environment often have poorly formed communication skills, which leads to seclusion, uncertainty, fear of communication. Students lack experience in public speaking, discussion, formulation, and finding answers to study tasks;
- the problem of identifying students' personalities when performing tasks, for example, tests, homework assignments, etc. is also relevant.

Teachers of mathematical subjects also point out the difficulties associated with the creation of the ELC. In particular, the development of mathematical content (lectures, assignments, test questions, glossary articles, etc.) requires a large number of formulas, and Moodle does not support formula editor in Word; so, you have to save and paste formulas or type in LaTeX. But formulas in the form of pictures are non-editable. In addition, they require a large amount of memory, which significantly slows down the download of training material when working with Moodle. And not everyone knows

LaTeX. This circumstance also complicates communication in the ELC "student – teacher", "student – student", in particular, the exchange of information containing mathematical texts.

Without going into the technical issues of creating and working with the ELC structural units in Moodle, we will focus on content preparation issues (filling lectures, practical tasks, tests, etc.) and selecting activities to effectively take advantage of and minimize the losses of computer learning compared to traditional.

As known, the didactic purpose of the lecture on mathematics is to introduce students to the scientific problem, to reveal the main issues of the topic, to solve the problem, justify the method, focusing on the most difficult (problematic, contradictory) points, the possibility of applying theoretical knowledge, and preparing students for further self-work. Properly organized lecture makes passive learning impossible.

Virtual lecture (in e-course) is deprived of this important factor – direct communication of the lecturer with students, in which the lecturer has the opportunity to conduct a "Socratic dialogue", ask questions, prompt the listeners to answer and formulate questions, oppose, stimulate imaginary experimentation, encourages and provokes discussion, give students the opportunity to make mistakes "safely", to choose their own way, even if it is a dead end, to formulate hypotheses, to draw conclusions, and most importantly – to be able to respond to answers, considerations, students' questions in time, to make necessary corrections in their explanations, if necessary, to improvise.

Let's illustrate by examples of lectures of the author's e-learning course on mathematical analysis in Moodle environment [3] – how it is possible to compensate the direct "live" communication of the lecturer with the students, implementing the principle of interactivity, in the e-learning course.

It is suggested to use the "Book" resource or the "Lesson" activity to create an e-learning course in Moodle. The "Book" module allows the teacher to create multi-page resources in book format, from chapters and subdivisions. Books can contain content in the form of text, pictures or media files. However, a lecture in the "Book" format does not stimulate the student to research and search activity, does not create conditions for interactive interaction of the student with the teacher, but rather similar to a regular paper book, which the student passively reads. Therefore, this resource is barely suitable for lecture. It should be used to summarize a particular topic (concepts, theorems, formulas, methods, etc.), or to create a reference book. It is best to use the "Lesson" activity to design the lecture. The "Lesson" module not only provides some theoretical material, but also predicting the student's activity and feedback (interaction) and the possibility of providing the student with the necessary assistance in the process of its development.

To do this, at first, all lecture material should be broken down into short, meaningful blocks; after each of them, ask questions (or tasks) to test understanding of the theoretical material presented. Depending on the answer to the question (task), the student goes to the next page (if the answer is correct) or (if the answer is incorrect) goes back to the previous page; the commentary on his incorrect answer explains the essence of the error or a hint or pointing to the relevant theoretical material whose ignorance led to the error. In such a way, the teacher is able to monitor the entire process of the student's development of the lecture, providing the necessary assistance at each stage. The student will give a lecture to the end, if he will correctly answer all the questions due to the course, that is, if he will actively work (analyze, compare, argue, prove, ask questions, express hypotheses, etc.), and not just passively read the text.

Secondly, the presentation of the material (proof of the theorem, for example) should be in the form of an imaginary dialogue (the author asks the question and answers himself), so that the student has the feeling that he is thinking. While giving a lecture, a student should see an example of a research-based way of knowing and learn from this example to ask the question: Why? And what if ...? What are the restrictions? How to find out? and so on (Fig. 2) Similarly, the presentation should be interspersed with the objections (by the imaginary opponent) and the answers to those objections.

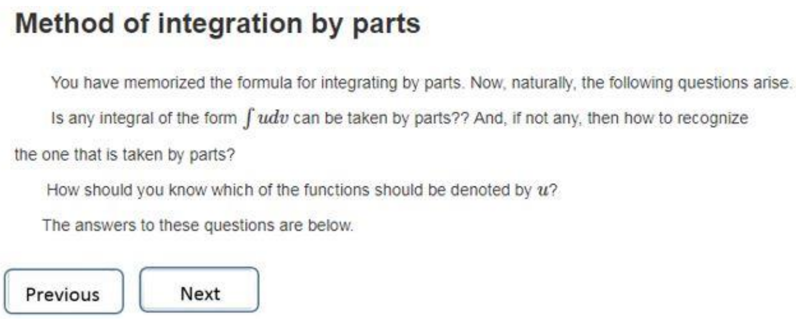


Fig. 2. A fragment of a lecture with questions

Thirdly. Just like in a real lecture, the course author does not rush to report the finished fact, but encourages the student to experiment (real, using a certain resource, such as Go-lab, GeoGebra or imaginary) and formulate a hypothesis, as well as describe (as if he is conducting) this experiment either formulates a hypothesis or prompts the student to do so (Fig. 3).

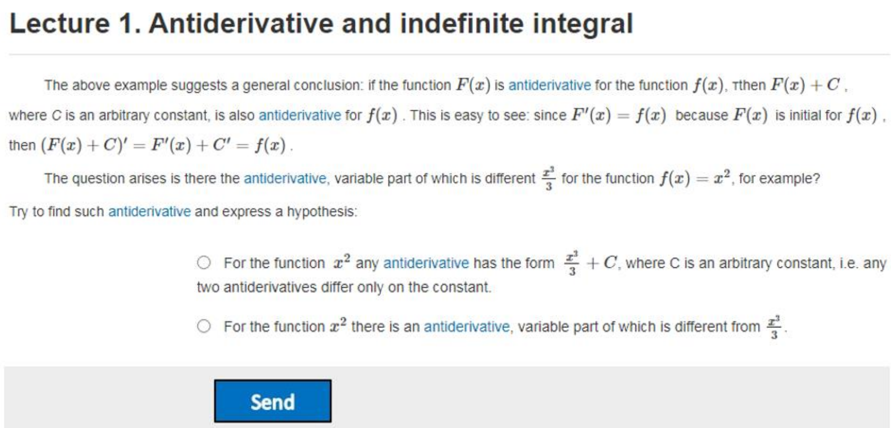


Fig. 3. Fragment of the lecture with the task of expressing a hypothesis

Fourth. Remembering that on an e-lecture the teacher does not see the student and cannot visually evaluate how closely he or she listens to and understands the material, the ELC author should find an opportunity to encourage the reader to make a conscious perception of the virtual lecture. For this purpose, one should ask from time to time questions such as: “What follows from this condition?”, “What are these restrictions?”, “Where is the condition of the theorem used?” etc. For example, after a fragment of a lecture on mathematical analysis of integration by the method of substituting a variable, where the integral $\int \sqrt{a^2 - x^2}dx$ is calculated by substitution $x = a\sin t$, $t \in \left[-\frac{\pi}{2}, \frac{\pi}{2}\right]$, students are asked to indicate where the condition $t \in \left[-\frac{\pi}{2}, \frac{\pi}{2}\right]$ is used in the above considerations (Fig. 4).

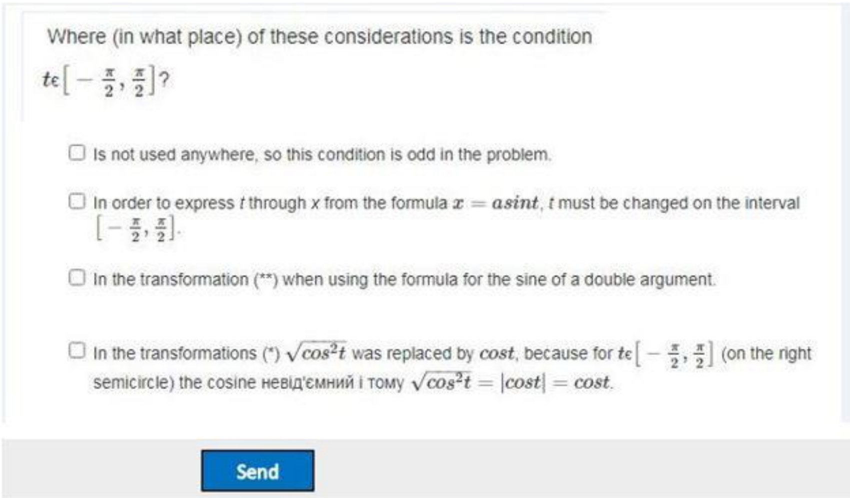


Fig. 4. A fragment of a lecture on the theme: “Integration methods” with a test task

Fifth. Preference is given to open-ended test tasks; when designing a test task, it is necessary to program (predict) errors in order to be able to adjust the student’s educational trajectory.

And finally, the language of presentation should not be a stationery book, but “live”, personalized, close to direct communication during the face-to-face lecture.

Here is an example of a fragment of lecture 4: “The concept of the limit of the numerical sequence” in the form of “live” dialogue, during which the student is induced to an imaginary experiment and thus summed up the definition of a new (for the student) concept:

“Previously, we have already formed on a sensory level the concept of convergent sequence and the limit of sequence. So, observing the behavior of the sequence $x_n = \frac{1}{n}$ members, we notice that they accumulate around the point 0. Mathematicians say that the specified sequence tends to 0 or that it has limit of 0.

Let’s try now to give a rigorous mathematical definition of this concept.

What does "members of the sequence accumulate, thicken near the point" mean?

Obviously, they are approaching this point anyway close; that is, differ from this number arbitrarily little. Well, let's take, for example, the sequence of $x_n = \frac{1}{n}$. Its members accumulate at zero. Let's imagine that on a number line of the monitor the flashlight lights up every second at a coordinate point $x_1 = 1$, $x_2 = \frac{1}{2}$, $x_3 = \frac{1}{3}$ etc, approaching, as was already mentioned, to point 0. We want to stop this movement. To do this, lets surround the point 0 with barriers: $\pm\frac{1}{10}$. Does this stop the members of the sequence from closing to zero? Obviously not. Already on the eleventh second, the next (eleventh) member of the sequence, followed by all the following, will overcome the barrier (the flashlights will be lighting up one after the other on the left of our barrier, ignorantly approaching zero).

What if point 0 is surrounded by new barriers: $\pm\frac{1}{100}$? Will we stop the movement of the members of the sequence? Obviously not. Already the 101st member, followed by all the following, will overcome our new barrier.

What if we are building these barriers not close enough around zero?

Not really. No matter how tight we surround the barrier point 0, we will not be able to "protect" it from the "invasion" of the members of the sequence. Right?

Therefore, it is quite logical to have the following definition of the convergent sequence.

Definition. It is said that the sequence x_n "tends to" a or that number a is limit of sequence x_n if **all** the members of a sequence **starting with some** get in **any** circle of point a".

Since mathematical competence means the ability to act, it is obvious that its formation is possible only in the process of active search and research activities (and it manifests itself in the actual behavior of the individual in a particular situation). An organic and tested field for such activities is mathematical problems.

In the structure of mathematical disciplines, much of the study time is devoted to practical classes, where, in particular, the ability and practical application of theoretical knowledge are formed in the process of solving problems. Virtual (distance) training of any practical skill is ineffective. Therefore, in our practice, we use ELC in the Moodle system to support the traditional full-time learning process by implementing a partially blended (combined) model.

However, the limited ability of the ELC to undertake a practical training can and should be transformed into an advantage. The fact is that during practical class, there is no time to think long about the task, and most non-reproductive tasks require slow thinking. Therefore, in a practical auditorium class, it is advisable to unleash mainly training exercises on the direct learning of concepts, theorems, standard problems, the acquisition of certain mathematical methods and techniques. Non-standard tasks and tasks for modeling real processes, creative tasks to find a solution, analysis, research of the result, etc., which create favorable conditions for engaging higher levels of cognitive processes, but require more time to solve, the same "slow thinking", it is better to offer for work outside the auditorium. A productive idea, the right or optimal solution, is most often born of discussion, debate. And the platform for such communication in the ELC is forum and chat.

Mathematical solving of applied problems inevitably raises the problem of adequately understanding of the content of a real problem to translate it into a mathematical language and then interpreting the mathematical result in the context of a real problem. A glossary auto-linking filter, created by a mathematics teacher in conjunction with a particular subject teacher or practitioner, helps solve this problem effectively. The idea is borrowed from [21]. The glossary contains terms, laws, descriptions of processes, etc. of a specific discipline or industry that may not be known or misinterpreted by mathematics students, as well as students of other specialties, because they study higher mathematics in junior courses and do not yet have sufficient knowledge in their subject industry.

Another type of activity that can be used effectively for students to accomplish specific tasks is to work on collaborative projects is the wiki. Wiki allows participants to add and edit a set of web pages, both editable by all members and modified only by their wiki. The history of previous versions of each page in the wiki is saved with a list of changes made by each participant. And it is very convenient, because it allows the teacher to track the trajectory of each student in the process of completing the task and, if necessary, to respond in a timely manner. Examples of the use of wiki in the ELC are students' creation of short notes, directories of theoretical material in preparation for practical classes (Figs. 5, 6) and the implementation of a collective project for the development of dynamic models to problems of projective geometry in the GeoGebra system [2; 1].

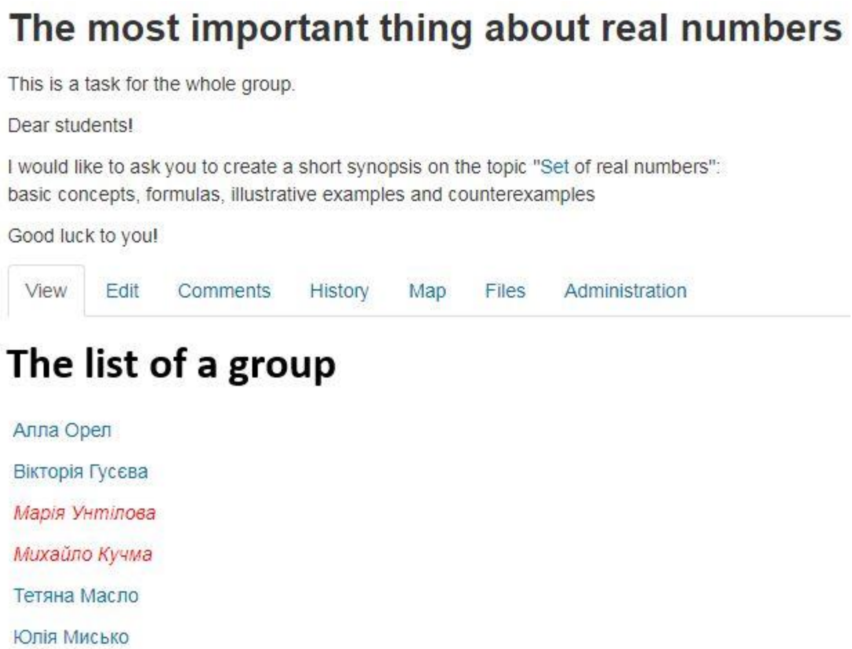
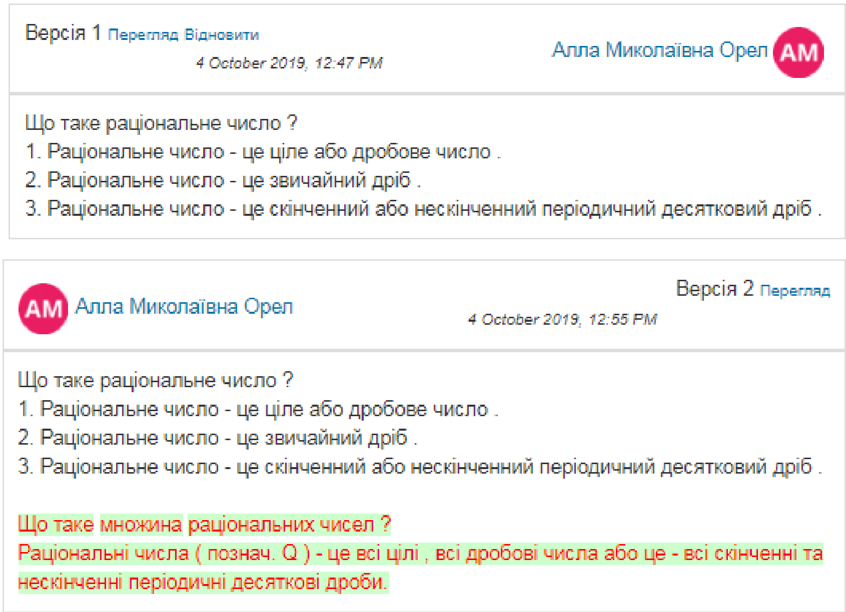


Fig. 5. A task for a group of students to create a short note on the topic "Set of real numbers"

In fig. 6, in particular, we see two versions of the wiki page about rational numbers, created by student A. O. The first version (where three different interpretations of the rational number are given, fig. 6a), she complements the definition of the set of rational numbers (second version, fig. 6b).



(a)

(b)

Fig. 6. History of creation of a Wiki by the student A. O.

An important element of any training is the diagnosis and monitoring of results. Since e-learning is dominated by automated proficiency testing, testing is the most common form of assessment and evaluation. With quick feedback, the test can be an important tool for students to evaluate their own performance and help them become more successful. Properly selected test provides the necessary information for the teacher on the degree of mastering the educational material by students.

The effectiveness of knowledge control by testing is determined by the quality of the test tasks. Moodle has powerful tools for creating quizzes with different types of questions. To assess the level of mathematical knowledge and the ability to apply it in practice, which is an indispensable indicator of mathematical competence, the most appropriate are tests of the open type, with a freely constructed answer (Fig. 7).

In test tasks with choices, there is a temptation simply to guess the answer. And, even if you exclude guessing, there is a big difference between finding the right answer and formulating it yourself. For example, if an open-ended problem proposes to find the root of an equation, then the student will need to solve the equation; if the answer to this problem is one of the correct ones, then the student can find it directly in the equation. Obviously, in the second version, we will not have any information about whether the student has methods of solving certain types of equations.

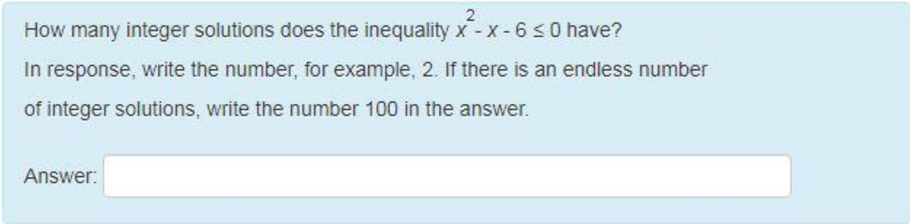


Fig. 7. Test of an open type

In addition, developing a test that meets the criteria of validity requires specific expertise in the field of testology. And to a greater extent this applies to tests with closed test questions. As a rule, the ELC author/teacher does not have such special knowledge. Therefore, often a set of questions with the choice of one or more correct answers, similar in appearance to the test, isn't in fact a test and doesn't give an adequate information about the knowledge neither to the student nor to the teacher.

Finally, it should be remembered when designing test tasks, that the answer to any reproductive question is easy to find in the Internet today. Therefore, it makes no sense to ask such questions in control tests.

5 Conclusions

1. As a result of the analysis of the scientific literature, it is found that the effectiveness of forming mathematical competence of students is related to the intensity of implementation of various forms, methods and means of e-learning in the educational process. The conducted research also proves that e-learning, besides the obvious advantages (adaptability, possibility of individualization, absence of geographical barriers, ensuring social equality, unlimited number of listeners, etc.) also has certain disadvantages. However, the nature of these shortcomings lies not so much in the plane of opportunity itself as in the ability to use them effectively.
2. The results of the ascertaining experiment indicated students' willingness to use ELC – on the one hand, and low assessment of their usefulness, and not quite positive general emotional perception – on the other. This leads to the assumption of poor quality and, therefore, the inefficiency of the majority of ELCs, which do not provide interactive learning and do not create positive internal motivation for students, i.e. do not justify the philosophy of the educational environment Moodle – pedagogy of social constructivism and active, research-oriented learning in partnership interaction).
3. Considering that effective formation of students' mathematical competence is possible only in the conditions of research-oriented learning with active and concerned student participation and partnership interaction, didactic and methodical approaches to content preparation and organization of activities in ELC in mathematics are proposed. Also, given the specifics of mathematics as a discipline, it is proposed to use the ELC to support the traditional learning process with a full-time form of education, introducing a partially mixed (combined) model.

The prospect of further research is seen in a more detailed analysis of e-learning opportunities for the formation of students' mathematical competence, in particular, research and development tools, and the development of recommendations for advanced training programs for teachers of mathematical disciplines of universities.

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