Adaptive e-course in Mathematics in LMS Moodle: Design and Implementation Problems

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Abstract

The article presents a model of adaptive teaching of mathematics for students with different levels of subject training in mathematics. The design features of this model are: taking into account the principles of the didactic subsystem of the personalized digital model of teaching school mathematics; building a system of conceptual didactic foundations for the design of adaptive learning. The principles of the didactic subsystem of the personalized digital model of teaching school mathematics made it possible to more effectively organize blended learning, in particular, the design of electronic courses for students with different levels of training. The conceptual basis of adaptive learning is B. Bloom's taxonomy of educational goals and V.P. Bespalko. These theories made it possible to identify the stages of student preparation, to determine the conditions for organizing educational content, to develop a system of adaptive testing, to organize a bank of questions of various levels of difficulty. The implementation of adaptive learning was carried out at the Institute of Mathematics and Mechanics. N.I. Lobachevskii Kazan Federal University (Kazan, Russia) in the first half of 2021. Results were obtained that prove the effectiveness of the adaptive learning model for students with different levels of training.

Keywords

Adaptive Learning, Math Teaching, E-Course, LMS Moodle, Personal Learning Path, Math Upgrading

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1. Introduction

At this stage of digitalization of education in the world, one of the urgent areas is the creation of technologies for the personalization of education. In educational practice, there is experience in the design and implementation of adaptive technologies that provide personalization in distance or blended learning. Digital educational platforms have been created that provide adaptation in the process of organizing individual trajectories at various stages of training [1–6].

Adaptive learning is a technology that provides a personalized experience using digital technologies. The level of individualization in existing adaptive learning technologies depends on the learning model itself and its technical implementation [7]. Developers of adaptive technologies take into account various grounds for their design: the psychological portrait of the student, the level of training at each stage of training, the dynamics of learning, the wishes of the student, etc. [8–11]. The effectiveness of adaptive learning has been proven in many studies [12–14]. For example, in [10], the effectiveness of the implementation of the adaptation of the e-course to the previous knowledge of students using the Learning Management System (LMS) is shown.

Feedback is a key component of adaptive learning in a learning environment. It allows learners to measure their learning progress and helps educators personalize learning content according to learners' needs and profiles. The study [15] examines various options for the implementation of feedback using computer learning environments. The review focuses on 20 different implementations

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of feedback in a computerized learning environment, ranging from multimedia networked intelligent learning systems, interactive intelligent learning systems, networked intelligent e-learning systems, adaptive hypermedia systems, and adaptive learning environments.

Let's consider the possibilities of constructing a feedback system in adaptive learning.

1. An automated feedback system based on adaptive formative testing is proposed [11]. The software allows the intelligent system to determine the most appropriate individual feedback based on the results of a test constructed according to Bloom's cognitive levels.

2. A platform based on semantic models for obtaining information about users and feedback was proposed by [9]. Semantic models enable interaction and reuse of assessment and learning resources. This system takes into account the difficulty level of each question in the self-assessment test to decide what type of individual feedback a student needs. This process provides accurate information about the student's level based on the results of their own participation in the assessment.

3. In [16], the authors propose a structure for the automatic generation of adaptive feedback from the metadata of elements. The generated feedback can be converted to human readable format; at the same time, it can also be used by intelligent learning systems to support adaptive navigation.

4. In [14], several personalized feedback frameworks are proposed that adapt different types of feedback based on student characteristics and / or characteristics of assessment questions. The frameworks are interdisciplinary, ignore the characteristics of the assessment question, and are either hardcoded or automatically generate feedback types from a limited set of items created by a subject matter expert. We are also interested in this study because the authors propose a system that they call the Ontology-based Personalized Feedback Generator (OntoPeFeGe). This approach offers automatic generation of questions and tasks. The questions have different characteristics, in particular, they are aimed at assessing the knowledge and skills of students at different levels in accordance with Bloom's taxonomy. Each question is associated with different types of feedback, which range from checking the student's answers to providing them with more detailed information related to the answer. The feedback automatically generated in OntoPeFeGe is personalized using an algorithm. It is based on rules that take into account the personal characteristics of students and the characteristics of the assessment questions.

Optimal choices for creating automated eLearning courses are template-based open-ended question systems such as OntoPeFeGe, Preg, METEOR and CorrectWriting [17], which provide answers until the correct one is received, and can also find and communicate information li about the different types of errors. This approach takes more time to create questions, but less time to manage learning in courses after they have started.

An important issue in the implementation of adaptive learning is the availability of design technology for any teacher who is developing an e-course on his own. One of the most popular eLearning management systems is LMS Moodle. In the study [13], an attempt was made to solve the problem of implementing an integrated adaptive mechanism for managing the learning process of students on the Moodle platform. A model has been developed that can be combined with the Moodle platform to provide students with adapted content according to their educational level. The opportunity for teachers to manage the mechanism of teaching their students in the context of inverted learning is offered. The model was tested by implementing the Smart Adaptive Management for Flipped Learning (SAM-FL) plugin. The proposed model is based on several hierarchical agents that provide modularity in the development of course content and test thresholds. The model was assessed objectively by comparing the students 'output levels with the initial conditions, and subjectively - by assessing the quality of the students' experience. The results obtained showed the effectiveness of the model in terms of the level of development of students.

The above studies are devoted to the organization of adaptive learning with a developed feedback system and its automation. An important stage in the organization of adaptive learning, in our opinion, is taking into account the theoretical foundations of didactics for highlighting the stages of student training, organizing a system of multi-level issues and their implementation in teaching. We present such a systematic approach in our study.

2. Design and implementation of adaptive teaching in mathematics

Designing adaptive learning should involve several steps.

1. Analysis of the conditions, taking into account which the training will be implemented.
2. Identification of the fundamental foundations of the organization of adaptive learning.
3. Building a model of adaptive learning.

The final stages of adaptive learning are the implementation of the adaptive learning model and the analysis of the results.

2.1. Conditions for designing adaptive learning

We have set ourselves the challenge of designing adaptive learning in a mathematics course that satisfies a number of conditions.

• Short course duration (1 semester). At this stage, most of the proposed adaptive learning takes a long period of time. Our task was to build an adaptive learning model for a shorter period, for example, within the framework of studying one topic.

• A small group of students (no more than 30).

• The design of the e-course is carried out in LMS Moodle. It is one of the most popular eLearning management systems with a wide range of extensible tools.

• Within the group of students, there are large differences in the level of required subject training. In this case, adaptive e-learning is most in demand. In particular, the group of students in which the adaptive course was tested includes: 1) students of the Russian Federation who entered on a competitive basis (tuition is paid by the state), 2) students of the Russian Federation who study on a contract basis; 3) students from other countries who study on a paid basis, but do not have the same level of subject training due to training in another school system, and have certain language difficulties.

• Students have the opportunity to make an independent choice to achieve personal results. Due to the different level of subject training, each student, through self-assessment in the process of adaptive learning, can set realistic goals for achieving subject results.

• Personalization of training for each student. An adaptive learning system should help everyone choose the level at which the required quality of training will be provided and move to the next level when certain results are achieved.

• Strength of the basic level of training by detailed elimination of gaps in the subject training of each student. The transition to a higher level of training (at the level of understanding individual definitions, methods of action, etc.) is possible provided the strength of the previous stage of training is ensured.

• Implementation of adaptive learning is possible in both mixed and distance formats. In a constantly changing environment, the teacher must painlessly transfer adaptive learning from a blended learning format to distance learning and vice versa.

Designing an electronic course in these conditions allows you to build an adaptive learning model that can be successfully used by any teacher working in Moodle.

2.2. Fundamental approaches to adaptive learning design

At this stage, an interdisciplinary team of researchers is developing a personalized digital model for teaching school mathematics (hereinafter referred to as the P-model). The P-model is based on the ontology of school mathematics $\text{OntoMath}^{\text{Edu}}$ [18]. Adaptive learning is the leading form of teaching organization in the implementation of the P-model in teaching high school students. The P-Model consists of four subsystems: ontological, didactic, computing resources and management. To implement the didactic subsystem, the following principles of organizing training in a mixed or distance format were developed, and on their basis, the design of individual courses was carried out [19]:

• the principle of ensuring the quality of educational content;
• the principle of openness to ensure interconnection with the external Internet space;
• the principle of granularity of educational material (breaking the material into micro-fragments);
• the principle of free assembly of various educational material within a single course;
• the principle of independence in the individualization of the educational space;
• the principle of collaboration between trainees and teachers to solve educational problems using course tools;
• the principle of course gamification and active visualization of educational material;
• the principle of interoperability [18].

The fundamental foundations of adaptive learning design are also B. Bloom's taxonomy for setting educational goals in the design of classes [20] and the theory of learning levels by V.P. Bespalko for the classification of educational tasks and test questions of the electronic course [21]. They were used to generate test questions based on the OntoMath^{Edu} ontology [22], design a bank of questions [23], and so on.

B. Bloom's taxonomy allows you to consistently build the goals of subject training of students from the level of "knowledge" to the level of "assessment". Theory of assimilation levels V.P. Bespalko allows you to create a scientifically grounded multi-level system of test questions that ensure the goals of subject training. Examples of matching goals for B. Bloom's taxonomy and test questions for V.P. Bespalko are given in Table 1.

Table 1

Correspondence of educational goals and levels of assimilation in the formation of a bank of questions of an adaptive course on the topic "The concepts of equations and inequalities"

No	Test Question	Classification by educational objectives	Classification by the level of assimilation	Moodle question type
1	Is 2 the root of the equation $-8x^2 + 10x = -12$?	knowledge	Pupil	true or false
2	Which expressions are equations? a. $x^4 + 2x - 7 = x^2$ b. $2 = 2$ c. $y = 2x + 5$ d. $4x + 2x - x + 2 = 6x - x + 2 = 5x + 2$	understanding	Pupil	multiple choice
3	Solve the equation $-4x + 5 = 7$	application	algorithmic	computed response
4	It is known that $a - b - c = 9$ and $a^2 + b^2 + c^2 = 323$. Find the meaning of the expression $bc - ab - ac$	analysis, synthesis	heuristic	short answer

Let us note an important theoretical aspect of V.P. Bespalko, who substantiated that the quality of a trainee's preparation at a certain level of assimilation is ensured, subject to passing the corresponding test with a score of more than 71%. The author showed that only in this case the student can proceed to the next stage of training.

These fundamental foundations formed the basis for the development of an electronic course and the organization of blended learning for a group of 1st year students (14 students) of the Pedagogical Education Department of the Institute of Mathematics and Mechanics named after N.I. Lobachevskii Kazan Federal University (Kazan, Russia).

2.3.Designing an adaptive learning model in LMS Moodle

When organizing adaptive education for students with different levels of training, it is necessary to divide the training materials into two parts, providing basic and advanced levels of training for students.

The basic level of training is a necessary part of training, providing educational goals at the level of "knowledge – understanding – application – analysis – synthesis". Without mastering the basic level, the student will not be able to study these concepts at a higher level of difficulty, will not be able to pass the training course.

Subject-In-depth training materials provide analysis-synthesis-assessment objectives. Mastering this level of training allows the student to apply for a higher assessment of his achievements.

In our course, we have divided the course into two parts:

1. The basic level is provided by the materials of the electronic course "Adaptive course: Equations and inequalities" [24] (hereinafter – the basic course). This course introduces the basic concepts of a basic school mathematics course.

2. The advanced level is provided by the materials of the electronic course "Elementary Mathematics: Equations and Inequalities with a Parameter" [25] (hereinafter referred to as the Advanced Course). It presents the concepts of a profile course in school mathematics, their generalizations, various ways of solving one problem, more complex reasoning.

The student is recommended to start studying the materials of the second year when passing the adaptive tests in the first year on the relevant topic by more than 71%. The teaching materials for all courses are in the public domain, but the limitations presented in the recommendation system do not allow the student to pass control materials or tests if the previous tests have not been successfully passed.

The interaction of the basic and advanced parts of the training course is organized as follows. The e-courses are organized around the same topics. Having passed the topic of the basic adaptive course, you can proceed to the study of the corresponding questions in the second in-depth course. For example, in the basic course, the topic "The concepts of equations and inequalities" is developed in the section of the advanced course with the topic "The concepts of equations and inequalities with a parameter. Solving Linear Equations with a Parameter". A feature of the basic course is a detailed study of each concept using a different presentation of educational material (text, video) and a system of tests for self-examination. The study of the basic course materials is optional if the proof test has been passed successfully.

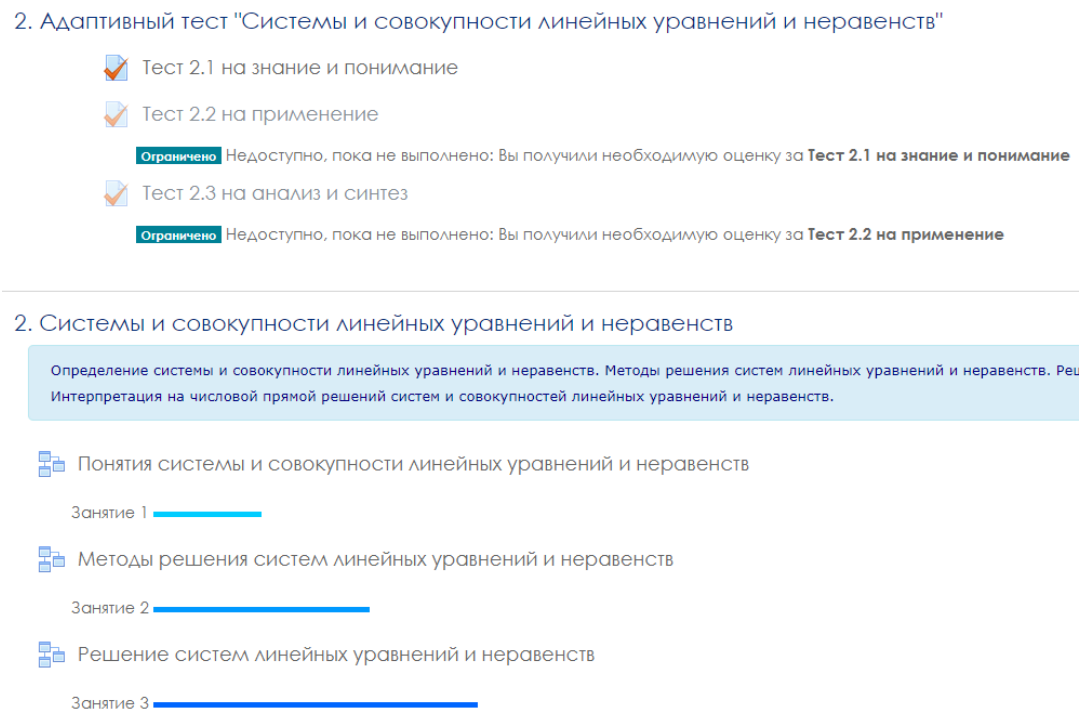

Figure 1: Organization of the system of adaptive testing and training sessions on the topic “Systems and sets of linear equations and inequalities” in the basic electronic course

Consider the system of organizing educational materials in a basic adaptive course. Table 2 shows that any topic is divided into three levels according to educational goals. Each of these levels corresponds to certain systems of test questions: “Test 2.1 – Lesson 1”, “Test 2.2 – Lesson 2”, “Test 2.3 – Lesson 3” (Figure 1).

Table 2

Designing a theoretical block, related test questions in accordance with theoretical foundations in the course "Adaptive course" Equations and Inequalities ""

№	Theoretical module component name	Educational goals (B. Bloom)	Levels of relevant test questions (V.P. Bespalko)
1	Lesson 1. Basic concepts of the topic, definitions	knowledge, understanding	pupil
2	Lesson 2. Solving the simplest problems	Application	algorithmic
3	Lesson 3. Solving problems of a higher level of difficulty	analysis, synthesis	heuristic

Personalization of learning is provided at several key points:

• within each lesson (the “Lecture” element of LMS Moodle presents various paths for passing training materials and tests for self-examination);

• within each thematic module (a student may not study some classes if he has successfully passed the test);

• in the control testing system (several attempts, recommendations for further course completion, testing at a convenient time for the student);

• in the continuity of basic and advanced courses.

The implementation of the adaptive approach in each lesson can be carried out in different ways, which are shown in Figure 2.

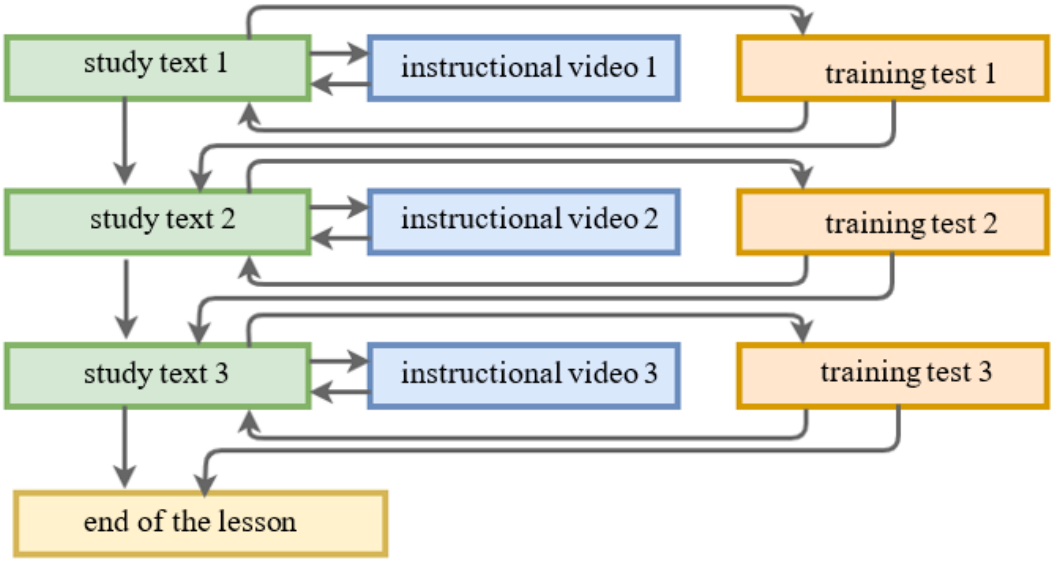

Figure 2: Possible trajectories of learning in the lesson of the basic e-course

For example, the trajectory of movement along a given element of the course may be as follows: "Training text 1" – "Training text 2" – "Practice test 2" – "Training text 3" – "Training video 3" – "Training text 3" – "Practice Test 2 – Instructional Video 3 – Instructional Text 3 – End of Session. The choice of movement is determined by the student himself on the page with the educational text of the "Lecture" element. Figure 3 shows the page on which the student is offered transitions: "Instructional video" (alternative to the text of the lecture or additional video materials), "Check yourself!" (3-5 questions for self-examination), "The next theoretical module" (transition to the next page of the educational text).

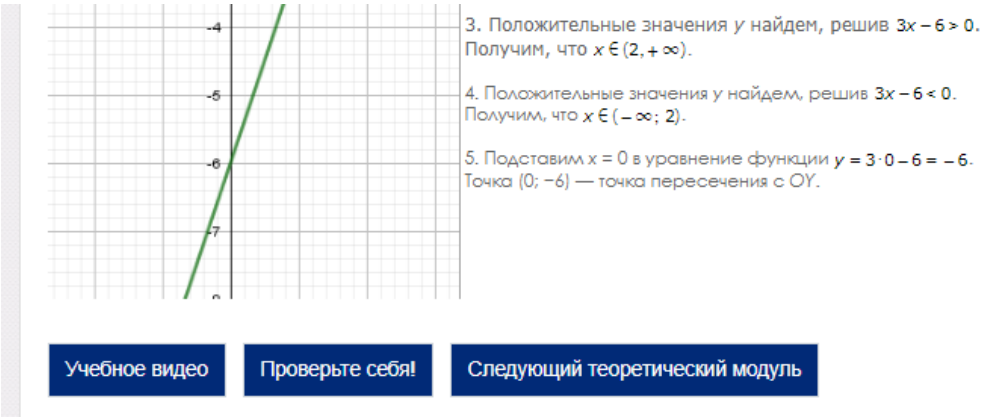

Figure 3: Page of the element "Lecture" in the lesson of the basic e-course in LMS Moodle

Before and after completing the lesson, the student can undergo adapted testing. At this stage, the testing system for each topic is represented by three tests, interconnected by the system of restrictions proposed in Moodle (Figure 1). A student cannot pass a subsequent test if the previous test fails (more than 71%). After passing the first test, depending on the results, recommendations are offered either to carefully study the materials of the corresponding lesson, or in case of a positive assessment, the opportunity to pass the next test.

An important issue in the design of electronic courses is the design of a bank of questions. The question bank has its own category for each activity. The occupation category, in turn, contains categories with the same type of questions. Any question from the question bank can be characterized by content, level of assimilation, educational goals. For example, in Figure 4, consider the category

“A2-2 (5) * (yes / no) Correspondence of the system solution and the graphic image”. Already by the name of this category, we can determine that this question has:

• (A2-2) – educational goals “application-analysis-synthesis”, the type of question by the level of assimilation – heuristic;

• (yes / no) – type of questions in Moodle;

• the content of the question is aimed at checking the understanding of the relationship between the analytical solution of the system of inequalities with the features of the graphic image on the coordinate plane.

The tests themselves were formed by random questions from the selected categories. Thanks to this construction, many variants of the same test were created. This allowed students to be given multiple attempts to pass the same control test.

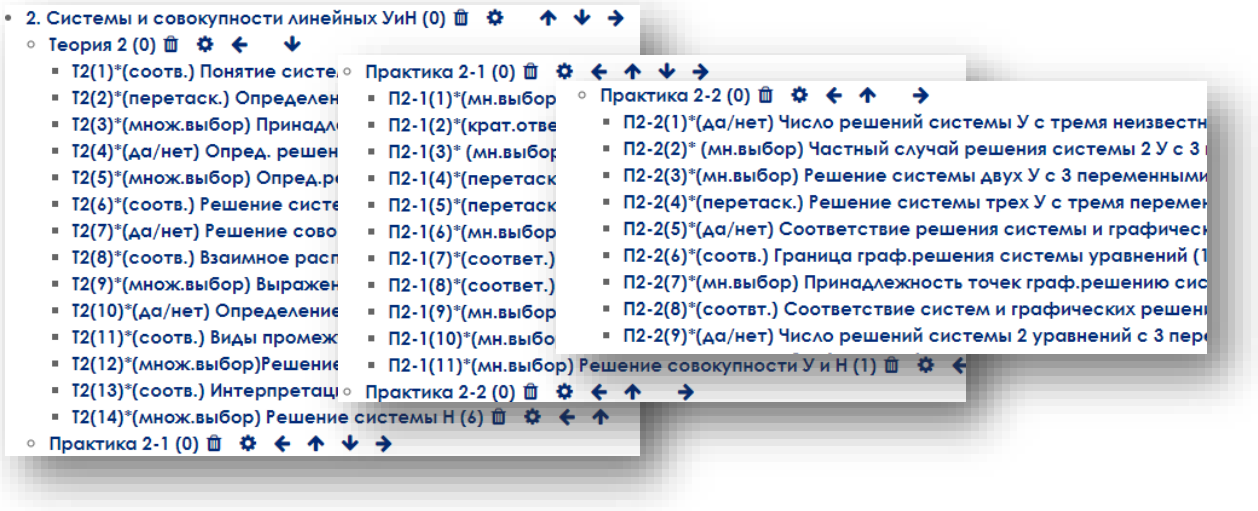

Figure 4: Bank of questions to the test system on the topic “Systems and sets of equations and inequalities” of the basic electronic course in LMS Moodle

2.4. Results and conclusions

The system of adaptive learning developed by us was implemented when teaching the course “Elementary Mathematics (Equations and Inequalities)” to 1st year students from February to May 2021. The training system was useful to the students and aroused their genuine interest. Various learning paths were implemented while ensuring the required quality of training in the subject.

The most prepared students, as a rule, experienced difficulties in passing the third test in the test system aimed at realizing the goals of “analysis-synthesis”. They began to study theory, take tests for self-examination. By closing the gaps in the basic training of students, the in-depth classroom teaching of the curriculum was more productive. Less prepared students repeatedly immersed themselves in the study of educational materials, which significantly raised the level of their subject training.

This model of adaptive learning is planned to be implemented in an electronic course based on the OntoMath^{Edu} ontology on planimetry for high school students [26-28]. This course assumes the use of a recommendation system, automatic generation of certain types of questions [22], the use of semi-automatic text markup for communication with external resources through ontology, and so on.

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