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Adaptive system of web-based teaching

Abstract. The study deals with the creation of an adaptive system of web-based teaching. The principles put into the concept of such a system development are formulated. The structure of the system which includes the educational content model, the user model, the adaptation model, and the learning outcomes assessment model is presented in the article. Within the framework of the proposed system an adaptive e-learning course of a mathematical discipline has been developed and implemented into educational process. It is proved that successful mastering the course contributes to mathematical competence development of the students.

Key words and phrases: web-based teaching, adaptive e-learning course, personalisation, mathematics teaching, competence-based approach.

2010 *Mathematics Subject Classification*: 97U50; 97D60, 97D70

Introduction

Nowadays global educational system is greatly influenced by rapid advancement of information and communication technology. Traditional educational technologies are being replaced by e-learning. Thus, Russian Federation Government Programme titled "Advancement of Education" points out the necessity of implementing of modern digital educational environment as a priority project, including the sphere of higher education [1]. Active use of e-learning courses in teaching modern "digital generation" living in the world of electronic culture is an integral part of education which concerns all university disciplines including mathematical ones [2].

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It should be noted, however, that the implementation of web-based teaching is a challenging task from pedagogical and technical aspects. In particular, it is caused by the fact that the methodology for e-learning still stays in its infancy. In addition, the actual participation of the teacher in e-learning process, unlike traditional educational process, is not required. We suppose that the function of student individual characteristics accounting, normally performed by the teacher, can be fulfilled by an adaptive e-learning course.

Basing on the definition of the "electronic learning resource" stated in the Russian Federation National Standard [3], we understand the adaptive e-learning course of a discipline as a learning resource presented in electronic digital form which includes a structure and a content area and provides for the possibility of adaptation depending on student individual characteristics. The use of adaptive e-learning courses in educational process allows personalising learning and increasing its effectiveness. We should point out that personalisation provision in e-learning is a global trend in modern education.

The purpose of this article is to create an adaptive system of web-based teaching, to describe its structure and components as well as the principles of its development.

In the frame of the proposed adaptive system an adaptive e-learning course (AELC) of a mathematical discipline running on Moodle learning management system (LMS) is created. The question of mathematical competence development when mastering such a course is under study.

1. Literature Review

The development of information technology and the active use of the Internet contributed to the appearance of web-based educational systems in the middle of the 1990s [4–6]. One of few examples of an adaptive intelligent web-based system used for teaching mathematics is ActiveMath [7]. It should be mentioned, however, that the existing adaptive web-based educational systems usually constitute commercial products and are seldom used for teaching particular subjects at school or university.

The development of e-learning in educational institutions moves towards creating e-learning courses based on learning management systems, which provide ample opportunities for both teachers and students [5]. To be more precise, teachers use LMS to develop educational content, tests and other assessments, to interact with students and to organise the learning process, including the use of active learning methods. As for students, LMS gives them the opportunity to interact with each other and with the teacher, to organise group work as well as to monitor their progress while studying the course.

No sooner had first web-based learning systems appeared than understanding of the fact that such systems must have the property of adaptiveness came. The review [4] identifies five main technologies used in adaptive educational systems: adaptive presentation, adaptive navigation support, curriculum sequencing, intelligent analysis of student's solutions, and interactive problem solving support.

In the 2000s, due to Semantic Web technology there appeared a possibility of effective interaction between web-based educational systems. In particular, this technology is used in educational content development and allows achieving adaptivity and flexibility in learning [8–10].

In their turn, adaptive educational resources contribute to personalisation of the learning process, which makes it more effective [11, 12].

The design of adaptive educational systems taking student learning styles into account constitutes a significant trend of e-learning development [13–15].

Currently, the so-called massive open online courses (MOOCs) are becoming widespread, however, the realisation of the adaptive approach in MOOCs is so far at the stage of discussion [16–18].

Over the past few years the leading Russian universities have been working upon the projects on development and implementation of electronic learning resources, including adaptive ones, into educational process [19–22].

However, there is no coherent concept of web-based teaching at the moment. Consequently, the creation of the adaptive system of web-based teaching as well as principles of its development has become topical.

2. Materials and Methods

As a pedagogical basis for creating the adaptive system of web-based teaching we use the poliparadigmal approach which is defined as an open and consistent cluster of approaches to teaching, the integrated use of which has synergistic effect [23, 24]. The competence-based approach takes the leading position in this cluster. The contextual, interdisciplinary, discipline-based and information technology approaches as well as fundamentalisation continue the hierarchy of approaches by their didactic potential.

We also follow the didactic principles of modern higher education. In particular, the system of web-based teaching includes a set of organisational and pedagogical conditions contributing for student to acquire knowledge and experience, to develop the skills which result in developing competence required for his or her professional activities [2, 25].

When designing educational content, the strategy of microlearning is used, which consists in structuring the whole course material in small chunks [26–28].

We use modern approaches and methods of teaching mathematics in the creation of the adaptive e-learning course of a mathematical discipline in the frame of the proposed adaptive system [29–31].

Structuring of the AELC learning material is proposed to be performed on the basis of hierarchical semantic model of the educational content which is represented as a concept tree. The use of the hierarchy of concepts allows visualising the logical structure of the educational content, determining the sequence of studying the material, and exercising control over the results of course mastering.

Moodle open learning management system is chosen to be the software environment for creation of the AELC. This system has gained a widespread use and offers rich functionality which allows developing e-learning courses and resources, implementing web-based adaptive teaching, adaptive testing mechanisms and techniques, and building individual educational trajectories. The following features of Moodle LMS can be referred to as its advantages: possibility of expanding the system by means of additional modules, transferability of Moodle-developed e-resource components to other platforms, which all support its interoperability.

The empirical base of the study are meant to be the learning results and the results of the questionnaire for the first year students majoring in Information Technology at Siberian Federal University who studied Discreet Mathematics discipline with the use of the adaptive e-learning course and without it.

3. Results of the Study

We propose the concept of adaptive web-based teaching relying on the following principles:

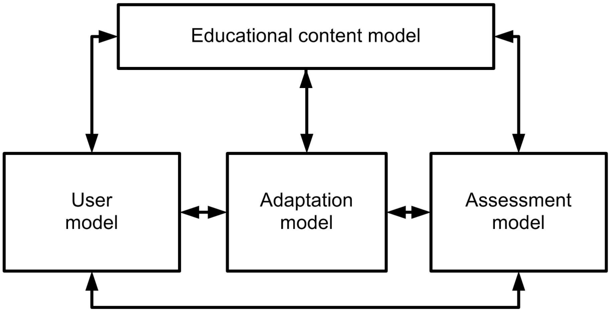

Figure 1. Structural scheme of the adaptive system of web-based teaching

- personalisation of the learning process, which allows students to build an individual educational trajectory and to create a personal space of educational materials;
- variability — educational content has various forms of presentation;
- education periodicity — automatic return to the studied topic content represented in a different form;
- filling gaps in knowledge and skills gained earlier;
- motivational and intellectual involvement of students into the learning process;
- aiming at the achievement of learning outcomes;
- integrity — formation of cohesive comprehension of a discipline by students;
- relevance — educational content should be relevant for students and correlate with the context of their future professional activities;
- the teacher's role is redesigned from a knowledge broadcaster to the organiser and the coordinator of the learning process who provides advice for students.

These principles are implemented in the creation of the adaptive system of web-based teaching which consists of the educational content model, the user model, the adaptation model, and the assessment model for assessing learning outcomes (Figure 1).

When building the *educational content model*, we use the approach based on the integration of the methods of Voishvillo's logical-and-gnoseological concept analysis [**32**] with graph theory methods. At the first stage we identify all the concepts of the subject area.

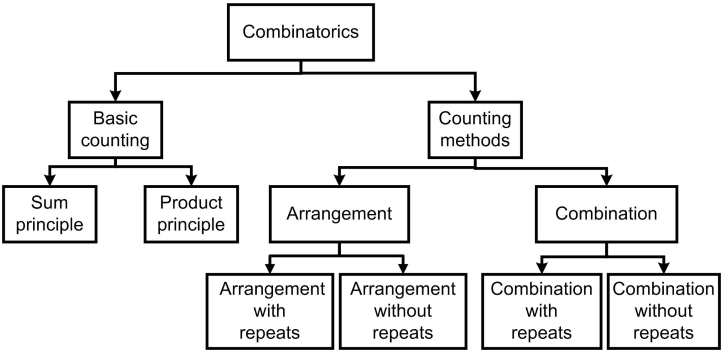

Figure 2. Fragment of the concept tree for Discreet Mathematics discipline

For example, the process of structuring the educational material in the Combinatorics section of the Discrete Mathematics discipline is carried out as follows: the general *fundamental concept* of "combinatorics" is introduced first. Further, it is concretised by establishing interrelations between its elements that act as the *basic concepts*: "counting methods" and "basic counting". Each of them corresponds to a fragment of educational material explaining this concept. Basic concepts are specified through establishing interrelationships with smaller *key concepts* in accordance with the *principle of uniting small structural units into large ones*. Thus, the basic concept of "counting methods" includes the key concepts "arrangement" and "combination". Finally, the essence of key concepts is shown with the help of *specific concepts*: "arrangement without repeats", "arrangement with repeats", "combination without repeats" and "combination with repeats".

Consequently, the subject area is formalised as a complex system of fundamental, basic, key, and specific concepts.

Each concept is characterised by its content and volume which are determined by reference to the conditions of necessity and sufficiency for learning outcomes achievement and development of the pieces of competence mentioned in international, professional, and state educational standards of the relevant educational level [33].

At the next stage all the concepts are arranged in a hierarchical structure — a *concept tree* or a collection of concept trees (Figure 2).

The concept tree is used as the basis for identifying the smallest chunks of theoretical material which we call *terms*. A term implies a sequence

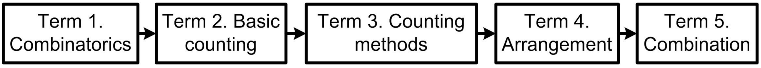

FIGURE 3. Fragment of the term sequence for Discreet Mathematics discipline

of semantic facts and procedural rules which have logical completeness [20, 34]. Each term constitutes a fragment of the concept tree.

Using the strategy of microlearning we define the following criteria to include concepts into terms:

- volume limitation — each term contains no more than five concepts of the tree; in case the concept has large volume, it can be allocated to a specific term;
- completeness — when developing the term, we follow the principle of uniting small structural units into large ones, that is, the term is formed of the concept and the smaller concepts associated with it;
- testability — the level of knowledge and comprehension of all the concepts within the term can be tested.

The amount of terms depends on the workload of the discipline. For example, in the process of structuring the educational content for the Mathematical Logic and Algorithm Theory discipline with a workload of 108 academic hours, the number of terms amounted to 21, and we formed 32 terms for the Discrete Mathematics discipline, which has a workload of 180 academic hours.

The terms are studied sequentially: from the fundamental concepts to the basic ones and then from the key concepts to the specific ones. It allows correlating the concepts of the term with their place in the overall subject area of the discipline and contributes to the formation of its cohesive comprehension. A fragment of the sequence of terms for Discrete Mathematics discipline is presented in Figure 3. In the terminology of graph theory, the study of the course material is carried out in a sequence corresponding to the method of *Depth-First Traversal.*

At the final stage the terms are distributed into academic weeks, which determine the normative rate of learning.

To sum up, the educational content is structured as a sequence of terms studied in a certain order covering the whole course material.

The *user model* of the adaptive system of web-based teaching contains information about students which is necessary to adapt the educational content to their individual characteristics and to control learning process in e-learning environment.

Student individual characteristics are described with the help of two groups of parameters. The first group includes a student learning style and his or her learning results for each term. The second one includes the results of monitoring the learning process of the student: current position in the course; time spent on studying each term and doing assignments; number of effective loggings in the system, those that allow the teacher to control the student's activity in e-learning environment.

In such a way the user model allows taking the individual characteristics of the student into account as well as the need for personal support from the teacher.

The *adaptation model* of the system of web-based teaching includes an automated navigation system and the adaptation of educational content accounting for the individual characteristics of the student. Each term, test or assignment has certain settings which are provided by the capabilities of the LMS.

To adapt the educational content, each term is provided in three different versions, which differ in the level of detail and the form of presenting: text, graphics, tables, audio and video materials, and interactive resources. Based on the experimental data, it has been found out that three versions of each term are sufficient for mastering the discipline material and achieving required learning outcomes.

For example, presentation of the term of a mathematical discipline is connected with the level of mathematical competence development. Thus, the term presentation in the *version of the first level* is aimed at developing skills of independence and initiativity, uses problem-based approach to teaching, encourages students to create problem solving algorithms, to integrate knowledge, and to prove the consistency of obtained results. The content of the term in the *version of the second (basic) level*, along with the theoretical material, includes the examples of solving typical problems as well as the problems which, to some extent, go beyond the scope of typical ones and require integration of different mathematical methods and knowledge. The presentation of the term in the *version of the third level* is based on the expansion of the basic level materials by means of a detailed

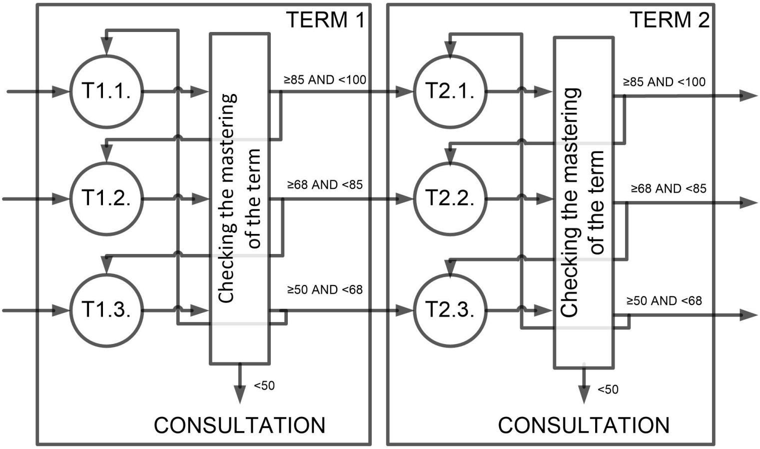

Figure 4. Term navigation

description of mathematical objects and their properties, and thorough explanation of problem solutions using standard formulas, procedures and known algorithms.

When studying the current term, the student has access to the educational material in the version corresponding to his or her current parameters in the user model. The choice of the first term version is made based on the results of the placement test. Namely, the students who have got low scores have access to the version of the third level, the students with middle scores – to the version of the second level, and the students with high scores – to the version of the first level.

After studying the term material an automatic redirection to the test is performed. If the score reaches a pass mark at the first attempt, this allows the student to proceed to the next term. However, the student may decide to improve his or her progress. The different version of the term material becomes available, and the student can be retested one more time after having studied it. If both attempts are unsuccessful, the student has to ask for the teacher's advice. The detailed algorithm for automatic redirection from one term to another is presented in Figure 4.

The learning process organised in this way ensures the formation of an individual educational trajectory for each student as well as a personal space of educational materials.

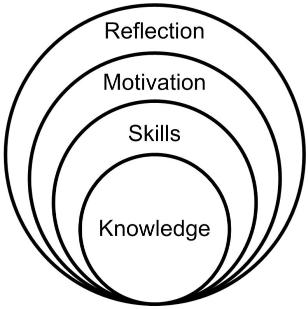

Figure 5. Subject competence structure

The *assessment model* of the adaptive system is intended to determine the level of subject competence development of the student by assessing all its components which are presented in Figure 5.

The following testing and assessing materials were developed:

- a placement test to assess prior knowledge and determine the students individual characteristics and their level of readiness to study the discipline;
- tests on terms to assess the level of knowledge and comprehension of the current material;
- tasks for independent practice with answer keys;
- tests-simulators;
- progress tests for each module of the discipline;
- applied and professionally oriented problems to determine student readiness to use the acquired knowledge and skills in the future profession;
- a final test.

The process of learning outcomes assessment is automated and it starts with evaluation of the assimilation of the therm material (knowledge component of the competence). The process is fulfilled by performing tests on terms.

The ability to operate with concepts (skill component of the competence) is checked with the help of the progress tests for each module of the discipline. The level of skill development is confirmed with tests-simulators performed during the limited period of time.

Applied and professionally oriented problems are used to assess the motivational component of the subject competence. The solution of such problems allows determining if the student is ready to use the acquired knowledge and skills in the future profession.

To assess the reflective component two attempts are provided in all tests on terms. After taking the test for the first time the student receives an immediate response on his or her solution. If there are any mistakes, the student can think them over and has the opportunity to have the second attempt after studying the material presented in a different version.

After assessing all the components, we can make the conclusion concerning the level of subject competence development of the student being taught in the e-learning environment.

To sum up, the developed adaptive system consisting of the educational content model, the user model, the adaptation model and the assessment model, all interrelated to each other, allows implementing the adaptive web-based teaching and assessing the level of subject competence development of students.

In the process of adaptive learning implementation the teacher (or a group of teachers) functions as the developer of educational content and the organiser and coordinator of the learning process. Besides, the teacher provides advice for students and performs students' activity control. The latter is fulfilled through messages including those determining the normative rate of study, gamification elements, progress indicators for tasks completeness and achievement ratings, which contribute to increasing the motivation for learning.

One of the most important aspects of the organisation of web-based teaching is the student-student and student-teacher communication being provided in both online and offline ways: forums, chats and means of feedback in the elements of the e-learning course.

The adaptive e-learning course (AELC) running on Moodle LMS was developed basing on the adaptive system proposed for Discrete Mathematics discipline. It was successfully implemented into the educational process of first year engineering students majoring in Information Technology at Siberian Federal University.

Technical implementation of the mechanisms of educational content adaptation is carried out using the settings of access to the components of the e-learning course, which are based on the current test results as well as

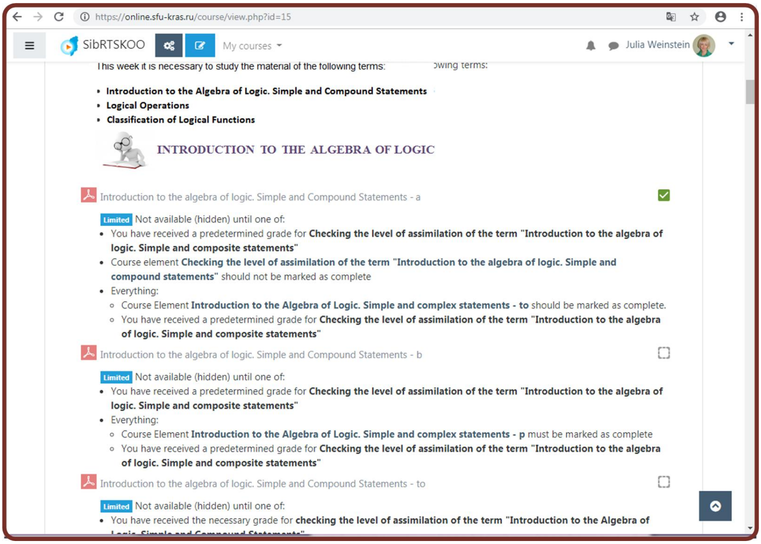

FIGURE 6. AELC interface as viewed by teacher-developer

tracking the completion of the course elements. The layout of the AELC fragment for the teacher-developer is presented in Figure 6.

At the beginning of the study all the materials are hidden from the student, becoming available only in the process of the study. For example, according to the results of the placement test, one of the versions of the first term is available to the student. After studying the term material the student gets access to the test on this term to determine the level of his or her assimilation of the material. Next, based on the test results the access to the next term is opened, or another version of the current term becomes available (Figure 7).

To evaluate the efficiency of the AELC use in the mastering of the discipline, we compared the mathematical training level of the students in the control group (116 students) and the experimental group (118 students) before the onset of studying and at the end of it. The comparison was made with the use of Mann–Whitney U test. Namely, we compared the results shown by the students of both groups in a placement test and a final test. Under the null hypothesis H_0, point distributions in the control group and the experimental group are equal. The alternative hypothesis H_1 is that the scores in the experimental group are greater.

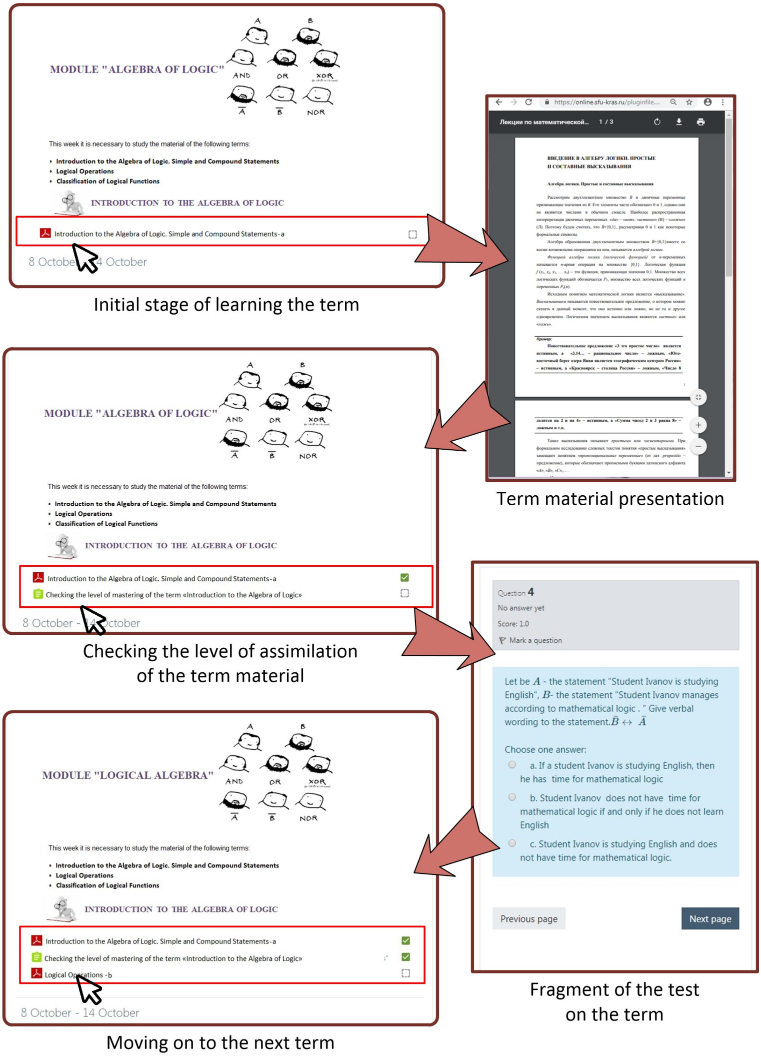

FIGURE 7. AELC interface as viewed by student

The results of the placement test revealed that $U_{\text{emp}} = 139$ and $U_{\text{cr}} = 81$ at the significance level of $\alpha = 0,05$. As $U_{\text{cr}} < U_{\text{emp}}$ hypothesis H_0 is accepted with a probability of 0.95, that is, there was no significant difference in mathematical training level at the onset of the discipline studying between the students of the control group and the experimental group.

Processing the final test results we received $U_{\text{emp}} = 67.5$. As $U_{\text{cr}} > U_{\text{emp}}$ we accept hypothesis H_1 and can assert with a probability of 0.95 that the students of the experimental group have got better results. Thus, the implementation of the adaptive e-learning course in the educational process contributed to the rise of the level of mathematical competence development.

4. Discussion and Conclusion

In this article a unique structure of the adaptive system of web-based teaching is described. The scientific novelty of the study consists in structuring the educational content as a hierarchy of terms, original methods and algorithms of adapting learning material, and the learning outcomes assessment model which provides for the assessment of the level of subject competence development. The proposed approach to building the educational content model is based on the integration and development of the methods of logical-and-gnoseological concept analysis with graph theory methods.

A number of advantages were revealed for both teachers and students during the implementation of the adaptive e-learning course into educational process. Namely, the use of the AELC enables the student to build an individual educational trajectory, to form a personal space of educational materials which correspond to his or her individual characteristics, to organise a flexible learning schedule with constant self-monitoring of learning results, and to improve the quality of the acquired knowledge and skills. A questionnaire among students showed that use of the AELC contributed to the formation of cohesive comprehension of the discipline, increased motivation for study the course and minimised psycho-emotional stress.

Basing on the studying experience with the AELC the students mentioned the following positive factors: an opportunity of studying the material delivered in a user-friendly form; boosting the efficiency of classroom work caused by the fact that students attend classes being familiar with the theoretical material; an opportunity to practise at any convenient time and at the individual pace. Alongside with that, some students admitted having had difficulties managing their own learning.

AELC implementation has made it possible for teachers to reduce the volume of broadcast educational material and routine processing of learning results. Although AELC development is rather laborious and time-consuming, its use in educational process has led to the reduction in the classroom workload of teachers and the release of the hours that can be used for their professional growth.

At the present moment, within the framework of the proposed system several adaptive e-learning courses of various disciplines have been developed and successfully implemented at Siberian Federal University. This fact allows us to make a conclusion that the considered system is universally applicable and can serve as a basis for organising adaptive web-based teaching not only for Mathematics but also for other disciplines in institutions of secondary, higher and further education.

We suppose that the implementation of adaptive e-learning courses into educational process has a good potential for organising learning within the framework of blended learning model, as AELCs allow organising student individual work, learning theoretical material as well as acquiring certain procedural abilities and skills, which gives an opportunity to reduce classroom hours significantly.

Materials of this study are of interest for both teachers who develop electronic educational resources and managers of educational institutions interested in implementing such resources into educational process. We see further development of adaptive web-based teaching in creation and use of adaptive MOOCs.

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