DESIGN AND IMPLEMENTATION OF A PERSONALIZED DIGITAL LEARNING MODEL

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Abstract

This work is devoted to the development of a personalized digital model of teaching school mathematics (hereinafter P-model) at the distance education site of Kazan Federal University (KFU), Russia. When developing this model, we drew on the experience of applying digital technologies in educational practice in different countries.

The main principle of developing the P-model is the principle of emergent stratification. According to this principle, multi-level, different, but interrelated subsystems are developed such as a subsystem of computing resources, an ontological subsystem, a didactic subsystem and a management subsystem. These systems ensure the creation of the digital area of the student's activity.

The design of the P-model and its application by users is based on a system of principles. It contains three groups: the principles of the organization of the P-model, the principles of the student's activity, and the principles of the teacher's activity. The first group of principles highlights granularity of educational material, openness of the P-model, quality assurance of educational material, free collection of educational material, independence in the individualization of the educational space, collaboration, gamification and active visualization, and interoperability of the P-model. The principles of the student's activity within the P-model include individual integration, level differentiation of training, personification and openness. Among the principles of the teacher's activity, we should note the availability of modifications, authorship, cooperation, transposability, and ensuring the individualization of training.

One of the results of designing the P-model is an intelligent recommendation system. The development of this system is based on the OntoMathEdu ontology of school mathematics, developed by the authors. The novelty of the proposed approach consists in the integration of both mathematical and methodological conceptualization.

The principles of the P-model are the basis for the implementation of an electronic course on planimetry for schoolchildren at the distance education site of KFU. This course actively uses the OntoMathEdu ontology as an intellectual knowledge base, providing differentiation, personification and openness in learning. Differentiation and personification are provided by a system of didactic relations that allow taking into account the level of training of the student, who can independently regulate their needs in training and receive appropriate methodological recommendations. To organize this process, we offer automatic recommendations and suggestions – what additional material one needs to study, what tasks one needs to solve to form the required skills. The principle of openness is provided by linking the ontology with external training resources, using a system of linked open data.

Designing a learning environment based on the principles of the P-model allows one to implement a model of self-regulated learning that meets the high standards of modern education.

Keywords: Digital learning environment, personalization, ontology, OntoMathEdu.

1 INTRODUCTION

The actual problem of digitalization of education is the creation and effective functioning of a digital educational environment. Currently, there is significant experience in the use of digital technologies in the world educational practice. An analysis of existing e-learning models and statistical data on learning outcomes over the past 20 years show the need of improving the quality of e-learning [1]. One of the ways of improving the quality of e-learning is the development of fundamentally new dynamic models of e-learning, built on the principles of digital learning theory [2]. “Traditional” e-learning models are also evolving to support the user opportunities and such models become the component part of a complex ecosystem focused on learning and knowledge management at the institutional and personal levels [3].

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Both university teachers and school teachers are in need of new e-learning models. The existing practice of using distance and e-learning in educational institutions does not have the expected effect in the Russian educational community opinion [4]. The contradiction between the need for scientifically and practically grounded digitalization of school and university education and the lack of effective models that provide a low-cost, massive, continuous and integrated educational process, which is adequate to the real challenges of the time, is becoming increasingly apparent [5]. The entire world educational community faces this contradiction. Over the past decade, e-learning technologies have reached a high level, but there remains both a low level of student motivation and their dissatisfaction with learning because of the course content quality and the low level of information competencies of the teachers [6].

Researchers and practitioners have proposed many approaches to existing e-learning challenges. For instance, the work of Savenye [7] discusses the planning, developing, implementing and evaluating a distance web course and its effective using. Brazilian scientists [8] have developed the conceptual foundation of new teaching materials in mathematics for distance learning of students. This approach considers the problem of qualitatively different semiotic means of mathematics embedded in full-time and distance learning and also the development of induced thinking in both forms of learning. Scholars from the Netherlands [9] have studied the course design as the most important methodological component of any educational course. The study [10] identified the types of pre-training profiles. These types have been shown to be associated with the achievement of learning goals. A bottom-up approach provides a more detailed view of the cognitive, emotional, and social aspects of perceived learning as it has been shown in the study on learning theory by Blau et al. [11]. Other studies are underway to build learning concepts in the new digital realities. The digitalization process reveals specific problems in teaching methods in different subject areas.

In mathematics education, difficulties arise associated with the digitization of educational content, which is characterized by a high level of symbolism of the mathematical language, and, consequently, with the development of mathematical search engines [12], with the organization of feedback (for example, in the form of chatbots). In this regard, special applications and programs are needed for the preparation and processing of mathematical content. There are some problems that are associated with the development of subject intelligent systems for direct control of the electronic course and the creation of personalized learning trajectories [13], [14].

To solve the above-mentioned problems the authors of this paper are designing a personalized digital educational platform for distance education at Kazan Federal University, Russia. This digital learning environment is being developed based on the ontology approach. The core of this approach is the new OntoMathEdu mathematical ontology [15]. The ontological approach makes it possible to formalize the content of school mathematics. We also are developing intelligent recommendation systems (hereinafter referred to as IRS), which are used in electronic courses. As a pilot, we are creating a distance course on planimetry for schoolchildren and students (future math teachers).

From a technical point of view, it is necessary to develop an algorithm that will help most accurately predict the optimal learning paths for the user with broad opportunities to implement the emerging wishes of users. Psychological factors must be taken into account when organizing the user-system interaction. Communication should be configured in such a way that the user can trust the system's recommendations and was satisfied with his decisions based on these recommendations. Kutyatin [16] highlighted knowledge-based collaborative filtering systems among the main algorithms used by the IRS.

A review of the main directions of development and use of IRS in education was carried out by Carrera Rivera et al. [17]. One approach is related to the presentation of personalized recommendations in e-learning as web models with consulting for personalized training programs [18]. One of the key challenges is using artificial intelligence techniques to improve the personalization of academic choices, as most of the existing recommendations do not take into account differences in student profile and their characteristics. This task, in turn, requires the creation of large personalized data collections and using machine learning techniques for data processing. It is important to assess the accuracy and efficiency of forecasting personal recommendations. When implementing and constructing IRS, some studies are testing the system to ensure the most accurate forecasting using performance metrics such as recall and accuracy for improving the IRS model. The IRS was used to identify students with learning disabilities [19]. The goal of the IRS was to find areas and performance indicators in which students should improve their knowledge and identify students with low academic performance. Another area is the use of the IRS in educational activities such as recommendations of resources, courses, and different activities [20]. The article [21] presents a recommendation system with a collective intelligence that offers academic resources on the Internet, including educational videos, non-fiction books, and all useful materials for research.

The goal of our research is developing a personalized digital model of teaching school mathematics (hereinafter the P-model) in the general education system using artificial intelligence technologies. We are developing the IRS using the OntoMathEdu ontology created by authors earlier.

2 METHODOLOGY

2.1 Personalized Digital Model Structure

The architecture of the P-Model is designed based on the principle of emergent stratification of information systems for the digitalization of the economy [22]. On based that principle one develops multi-level, different, and interconnected subsystems that ensure the creation of a digital sphere of the student's activity.

The developed P-Model consists of four following subsystems: 1) ontological one, 2) didactic one, 3) system of computing resources and 4) management system.

The first subsystem allows representing the content of the school math course by the system of concepts of the OntoMathEdu ontology [23].

The second subsystem allows designing a didactic dynamic personalized model of teaching mathematics using the OntoMathEdu ecosystem [24]. Also, this system requires the development of principles for organizing training and the choice of didactic training models such as mixed model, self-regulating model, etc.

The subsystem of computing resources is a system of technical solutions in math teaching based on the electronic course in LMS Moodle. The main functions of this subsystem support high-level programming of the electronic course, the development of the applications with using the ontology.

The management subsystem is used for the development of a system for assessing the process and learning outcomes based on the P-Model. The main functions of this subsystem support building assessment using the digital footprint of users, organizing psychological and pedagogical research and constructing methods for upgrading the course.

The content of the P-Model ontological subsystem includes a combination of mathematical and methodological conceptualization of concepts. The objects of a complex representation of a mathematical concept are axioms, mathematical concepts, definitions, theorems, formulas. The ontology includes concepts, definitions, general concepts, species concepts, alternative definitions, synonyms, visualizations, related theorems, history, concept development, applications, typical tasks. The ontology contains recommendatory links to external educational Internet resources.

2.2 Principles of P-model development

The development of the P-model is based on the following system of principles [25].

1 The principle of ensuring the quality of educational content. This principle aims to regulate mechanisms for monitoring the quality of educational content, including test information, drawings, animation, video, and others. It is necessary to take into account the age of the students, their educational learning needs, and also copyrights of the course developers.

2 The principle of openness to ensure relationships with the external Internet space. This principle demands from the creators of the course to include links to external resources to provide different approaches to studying the educational material. It allows students to get new opportunities for high-quality teaching.

3 The principle of granularity of educational material is associated with breaking the material into micro-fragments. This principle is becoming more and more popular in the design of educational courses, for example, the YaKlass platform works according to this principle [26]. If you compare the material of the math textbook and the educational content of the "Yaklass" platform, you can see significant differences. The advantage of the "Yaklass" digital educational resource is the division of educational material into logical blocks with rich illustrations.

4 The principle of free assembly of various educational material within a single course provides the ability to collect and combine various educational content (diagrams, slides, interactive lectures, workbooks, wikis, etc.) in one course.

5 The principle of independence in the individualization of the educational space provides an opportunity for students to create their own personal educational space (saving important materials or links in their notebook, having a journal with teachers' assessments and comments, saving information on participating in working groups, recording personal achievements in the portfolio, etc.).

6 The principle of cooperation between trainees and teachers to solve educational problems using course tools ensures the creation and functioning of working groups of students or joint groups of teachers and students

7 The principle of course gamification and active visualization of educational material. There are different types of gamification. Structural gamification is of particular interest. In this case for the current quantitative assessment of the results at the training stages one can use the points in the rating of the trainees. Active visualization is aimed to create useful visual content for specific educational goals for solving educational problems.

8 The principle of interoperability is necessary for interaction with other systems without access restrictions.

2.3 Development of an electronic course based on an ontological approach

The new electronic distance course for students in grades 9-11 is being designed in accordance with the above principles that underlie the organization of the P-Model. The complex of principles of the student's activity on the electronic course include the following ones: 1) the principle of individual integration; 2) level differentiation of learning; 3) personification; 4) openness. The complex of principles of teacher activity include the following ones: 1) availability of modifications; 2) authorship; 3) cooperation; 4) transposability; 5) individualization of training.

We consider the taxonomy of educational goals of B. Bloom [23], the theory of the development of geometric thinking by van Hiele [27] and the theory of the levels of assimilation of material by V.P. Bespalko [28] as a psychological and pedagogical basis for choosing educational goals, organizing the structure of the course, building a sequence of teaching materials and developing test systems. These psychological and pedagogical foundations were tested earlier in the implementation of the electronic course of plane geometry for future mathematics teachers [29]. Thus, van Hiele's theory is used as for organizing classrooms and as for developing an electronic course.

The e-course is loaded on the Moodle educational platform and opens up wide opportunities for both students in the study of the discipline and for the teacher in tracking and evaluating the learning outcomes of each course participant. The use of this resource began in January 2013 but the state of the resource has been constantly improved. The first conceptual idea was the organization of blended learning because of there is small teaching hours for teaching plane geometry and, in most cases, because of the low level of training of students in this section of elementary mathematics. Thus, the quality of students' independent work and the mechanisms for tracking its results have become very important. In 2012, a SPOC course (Small Private Online Course) was designed with an “inverted lecture” learning model based on the taxonomy of B. Bloom’s learning objectives. As a result, the time freed up due to the primary comprehension of the new learning material by students (knowledge-understanding-application) became used to develop higher educational goals in the classroom (analysis-synthesis-assessment).

The Bespalko' theory of the levels of assimilation of material [28] was the ground for the classification of educational tasks and tests. The bank of questions in LMS Moodle is organized in accordance with the classification of learning levels.

3 RESULTS

An important trend in e-learning is the development of intelligent systems to support personal personalized learning models. The paper [30] discusses two interactive visualization tools for learning management systems aimed at improving learning and teaching in online courses. The first tool was developed at the Intelligent Information Systems Laboratory (IISLab) at Tampere University of Technology (TUT). This tool is used to analyze trainees' activity based on automatically recorded data from the user's log and to build interactive visualizations. These data provides valuable information about the learning process and student participation in the training course. A second tool, developed at Unitelma Sapienza University, extends the navigation and search functionality of the LMS discussion forum using a thematic paradigm. This tool analyzes the content of the forum and automatically identifies new topics for discussion. These new topics then are included in thematic navigation structure and an interactive search graph. Both tools were developed as plugins for LMS Moodle, but their processes and analysis methods can be adapted to any LMS.

In our opinion, when developing a personalized digital learning model used in a mixed format, one should focus on developing an electronic resource. The digital educational environment itself within the curriculum should stimulate the student to maximize involvement in the subject. This can be facilitated by various methodological techniques and means (gamification, creation of conditions for individual and group creativity, the choice of alternative ways of solving educational problems, etc.).

The e-course is designed to become a system of opportunities for the student. The student can get acquainted with the information in alternative ways (interactive lectures, short video clips, links to external resources, etc.). Student can constantly test his knowledge and skills and also he can improve his results by completing an additional task, re-passing the test. He can deep his knowledge of the subject studying additional interesting materials, recommendations for training on external resources, etc.

The electronic course, on the one hand, provides students with the necessary basic level of subject training, on the other hand, it becomes a creative subject laboratory. The electronic course has confidence and clarity in management, flexibility, and variability [31].

3.1 Implementing a personalized digital learning model

3.1.1 Intelligent knowledge base for teaching

The originality of the proposed approach is integration as a single model such components as OntoMathEdu math educational ontology; semantic technologies; verification model of educational levels of users. The knowledge about user educational levels allows designing and adjusting the difficulty levels of the studied mathematical concepts.

Because of its educational purposes the OntoMathEdu ontology contains not only mathematical facts about the concepts presented in it, but also information about using these concepts in the educational process [14], [32].

Information about using the concept in the educational process is expressed in ontology with help of two main relations:

1 Prerequisite relation. It is a didactic relation, that is, a prerequisite is anything that you need to know or understand first before attempting to learn or understand something new. Concept A is a prerequisite to concept B if, in order to learn B, you must first to learn A.

2 The relationship between the concept and the educational level to which the concept belongs.

3.1.2 The system of didactic relations in ensuring the differentiation and personalization of learning

To implement the principles of consistency and continuity in the study of concepts in the field of geometry, we introduced the concept of educational level and applied it as property to ontology concepts. This property is necessary to organize personalized learning for each student's strengths, needs, skills and level of math training. We can take into account different types of users using OntoMathEdu ontology. The lower the mathematical experience of the user, the more intelligibly and accessible information should be presented for him. The user can independently choose the level of difficulty for studying a given mathematical unit. We develop a recommender system on the basis of this approach.

The educational level of an ontology is a set of concepts of the OntoMathEdu ontology that have certain values of the "educational level" property. The values of this property are defined the school grade. For example, in a Russian school there are grade 7, grade 8, grade 9, profile class 8, profile class 9, additional grade. There are also concepts in the ontology that are not assigned the “educational level” property. Among them, we defined the concepts that using for a more accurate formalization of domain. For example, the "limited part of the plane" concept is necessary in the ontology for combination of geometric figures that have the areas calculated in plane geometry. Such concepts do not have the "educational level" property.

We distinguish the educational levels of training of students using the "educational level" property in the ontology. For example, the group of concepts with the values <grade 7, grade 8, and 8 profile math class> of the "educational level" property allows selecting concepts corresponding to the level of student training who graduated from the 8 profile math class. This is a new approach in designing an individual digital trajectory for school math learning.

3.1.3 Application of the principles of organization of the P-model for designing e-courses

The results of designing a course in accordance with the above conceptual ideas for organizing blended learning have shown their effectiveness in various applications.

Increasing the level of geometric thinking was demonstrated by students in the 2018-2019 academic years [33] and increasing the level of activity and cognitive mental states were detected in the 2017-2018 academic years [34]. Now we are improving the course of plane geometry for students in grades 9-11 of the school. We conducted inquiry among students about applying the technologies of flipped learning, blended learning, management, and self-management of learning [35]. 108 students took part in this inquiry. The analysis of results showed that the overwhelming majority of students are ready to using blended learning. The blended learning format allows involving students who are learned distantly, in didactic communication and to apply effective pedagogical technologies, and also to increase the motivation of students. Within the framework of blended learning, it is possible to implement the principle of "learning in cooperation", joint learning activities, which are considered by modern didactics as one of the main strategies of learning in general and distance learning.

The results obtained showed the relevance and effectiveness of using e-course for teaching in a mixed format with the intelligent OntoMathEdu ontology [23]. The OntoMathEdu ontology allows automatically generating simple questions, and in the future, it will allow developing different recommendation systems with maximally personalizing the training of each student.

For distance learning, there are opportunities to replace the classroom activity of blended learning with a new activity in a distance format. At this stage, we are developing the model of an adaptive course with interactive elements such as three-level interactive lectures (in accordance with Bloom's taxonomy) and multi-level interactive workshops (in accordance with the classification of Bespalko's assimilation levels).

4 CONCLUSIONS

Training on a personalized digital educational platform in both mixed and distance formats, with independent study of educational materials presented in the e-course, and classroom training with a built-in computer experiment (both in lectures and in laboratory classes), excludes the possibility of an experimental and theoretical gap. The difference between this technique and the traditional way of presenting material by giving lectures and then solving problems is that students are active participants in the learning process, in this case, the teacher does not give knowledge in ready form, but he plays the role of a coordinator in the learning process.

The use of the ontological approach in the construction of recommendation systems in education is very promising and ultimately allows to contribute to new achievements in the field of digital education.

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