Этапы разработки гибридной интеллектуальной обучающей среды для управления исследовательской деятельностью школьников в области математики

Проблема и цель. Поиск актуальных решений пересборки архитектуры современного образования, элементов новой системы посредством организации интеллектуальной среды обучения, адаптированной к исследовательской деятельности школьников по освоению сложного математического знания, составляет проблему исследования. Цель исследования – проиллюстрировать поэтапную разработку гибридной интеллектуальной обучающей среды, обеспечивающую управление исследовательской деятельностью школьников в области математики, с учетом современного опыта создания интеллектуальных обучающих систем.

Материалы и методы. В анкетировании приняли участие 52 педагога и 234 учащихся школ г. Москвы (Российская Федерация). Диагностические методики были направлены на получение данных о применении различных цифровых ресурсов и средств в повседневной учебной деятельности и уровне их интеллектуализации. Применялись методы описательной статистики (вариационные ряды, гистограммы, показатели меры центральной тенденции и разброса), а также $\chi^2$-критерий Пирсона.

Результаты исследования. Около 90% опрошенных преподавателей и 80% школьников высказались в пользу идеи внедрения интеллектуальных систем в процесс обучения, однако более 75% респондентов не могут привести примеры подобных систем и сред. Мнение обучаемых по внедрению цифровых инструментов в образовательный процесс значимо отличается от мнения их наставников ($\chi^2_{эмп}=33,4 > \chi^2_{кр(0,01)}=2,65$).

Представлены основные этапы проектирования интеллектуальной обучающей системы: разработка методологических положений для интеллектного управления образовательным процессом; определение персонализированных параметров научного потенциала, определяющих структуру учебно-исследовательского контента; разработка базы данных и знаний тематики проектной деятельности; выбор архитектуры и функционала гибридной нейронной сети.

Заключение. Авторские методологические и технологические решения предоставят ученным ориентир для проведения последующих исследований в области совершенствования высокотехнологичных форм электронного обучения, а педагогам – возможность изучить практические способы реализации персонализированного и адаптивного дистанционного обучения посредством автоматизированных интеллектуальных обучающих систем.

Ключевые слова: интеллектуальные системы, исследовательская деятельность, обучение математике, сложное знание

Problem and aim. The search for relevant solutions to the restructuring of the architecture of modern education, elements of a new system through the organization of an intellectual learning environment adapted to the research activities of schoolchildren on the development of complex mathematical knowledge is a research problem.

Materials and methods. 52 teachers and 234 students of schools in Moscow (Russian Federation) took part in the survey. Diagnostic methods were aimed at obtaining data on the use of various digital resources and tools in everyday learning activities and the level of their intellectualization. The methods of descriptive statistics were used (variation series, histograms, measures of central tendency and scatter), as well as Pearson’s χ²-test.

The results of the study. About 90% of the surveyed teachers and 80% of schoolchildren spoke in favor of the idea of introducing intelligent systems into the learning process, but more than 75% of respondents cannot give examples of such systems and environments. The opinion of trainees on the introduction of digital tools into the educational process differs significantly from the opinion of their mentors ($\chi^2_{\text{emp}} = 33,4 > \chi^2_{\text{cr} (0,01)} = 2,65$).

The main stages of designing an intelligent learning system are presented: the development of methodological provisions for the intelligent management of the educational process; determination of personalized parameters of scientific potential that determine the structure of educational and research content; development of a database and knowledge of the subject of project activities; choice of architecture and functionality of the hybrid neural network.

Conclusion. The author’s methodological and technological solutions will provide scientists with a reference point for further research in the field of improving high-tech forms of e-learning, and teachers will have the opportunity to explore practical ways to implement personalized and adaptive distance learning through automated intelligent systems.

Keywords: intelligent systems, research activities, teaching mathematics, complex knowledge

For Reference:
The COVID-19 pandemic has rapidly changed the nature of the educational process and exposed the shortcomings of education systems around the world. The pandemic has caused enormous damage to education: half of all countries have cut their education budgets, about 147 million students have missed the full-time education format.

Large-scale studies based on information from around the world on the organization of learning processes during the pandemic, conducted by international organizations such as The Directorate for Education and Skills, Organisation for Economic Co-operation and Development (OECD), the World Bank Group in Education, not only summarized statistics on the introduction of electronic educational resources, services and platforms from around the world during the pandemic, but also identified further prospects for digitalization and education reform. It was found that the introduction into the practice of teaching platforms, online services that provide intelligent management of educational and cognitive activities of trainees during the pandemic, was carried out mainly in foreign educational institutions. Among the most frequently implemented systems are: MATHia by Carnegie Learning, Yixue Education, Wayang Outpost, Century Tech, Math-u-See, Education Perfect, etc. At the same time, the total number of online resources implemented during the crisis was 72. The data were obtained from a sample formed on the basis of 99 countries and the volume of n=333 educational organizations [1; 2]. As you can see, the statistics of the introduction of intelligent systems in foreign countries also remains low, and is less than 10%.

For Russian education, this situation is fully confirmed by the study of open statistical reports and the global bibliometric analysis of scientific research by authors-developers of such projects [3; 4]. Among the most actively used electronic resources by students and teachers during the pandemic, we can single out: educational resources (Uchi.ru; Yaklass.ru; Infourok.ru; Resh.edu.ru, MASH); systems that pose themselves as integrated learning systems with structured content and the possibility of an individual approach to student learning (SkySmart.ru; Algoritmica.org; Physics.ru); resources that provide ready-made recordings of video tutorials, video lectures, lesson scenarios or fragments thereof (Education.yandex.ru; Foxford.ru; Interneturok.ru; Uchebnik.ru; Multiurok.ru; Nsportal.ru); resources for solving homework (gdz.ru; Sdamgia.ru; 4ege.ru ). Among the presented services and platforms, only the second group can be conditionally attributed to adaptive systems. With their sufficiently active functioning (the number of visits reached up to 7 million in October 2020), this amount of resources cannot be considered sufficient to provide and support educational institutions with high-quality adaptive intellectual systems.

Nevertheless, already today more than 130 countries have committed themselves to reboot their education systems and step up actions to overcome the unplanned learning crisis. About half of the countries have strategies to help schoolchildren catch up on lost knowledge. The issues of restarting education systems and intensifying actions to overcome the unplanned learning crisis were actively discussed at the UN Summit in September 2022 on the Transformation and Transformation of Education. The following key initiatives were identified at the summit:

1. The creation of the International Education Funding Mechanism (IFFEd) was announced on the initiative of the UN Secretary General and the UN Special Envoy for Global Education Gordon Brown;
2. UNESCO and UNICEF launched "Gateways to Public Digital Learning", a global multi-stakeholder initiative to create and strengthen inclusive platforms and content for digital learning. «The new Initiative will map, describe and analyze existing public platforms and content; help countries create and strengthen national platforms; identify and share best practices; and establish international norms and standards to guide the development of platforms in ways that advance national and international goals for education» [5].

Thus, the unplanned transition to a distance learning format has become a catalyst for the creation and implementation of more effective e-learning methods. Adaptive systems and learning environments based on artificial intelligence have become an actual technology of widely implemented electronic and mobile learning. E-learning has transformed into a high-tech form – s-learning, providing students with greater flexibility, efficiency, adaptation, engagement, motivation and feedback.

How effectively were these systems implemented during the pandemic? What is the dynamics of the use of intelligent environments in the real educational sector? What is the true status quo of learning systems using artificial intelligence? The formulated questions determined the problem of this study.

Intelligent learning systems are used in three directions:

• as learning systems implementing step-by-step learning actions based on a typical neural network architecture, including the following components: subject area, didactic model and student model; adaptive learning activity model; data collection; data analysis (Aero, ActiveMath, Algebra-Tutor, Cognitive Tutor, Geekie, etc.);
• in order to evaluate learning outcomes based on the implementation of expert systems with fuzzy logic and neural networks. The MATHia intelligent mathematics software, which provides individual support to students in order to gain new knowledge and their assessment, as well as widely available digital intelligent programs focused on assessing students' knowledge and used to support individual learning, should be included in the educational process: Dreambox Learning® Math (USA), Toppr (India) and Yixue (China);
• in the role of a research learning environment based on the methodology of constructivism. Research training using automated systems has been around for a long time (educational research environments – Fraction Lab, Betty’s Brain, Crystal Island), but these issues remain controversial. Critics of automated learning argue that due to the lack of clear instructions, and the fact that students must independently discover the principles of the subject area, these systems cause cognitive overload, lead to poor learning outcomes.

The last direction is less developed on the one hand, and the most in demand in the practice of digital learning using high-quality educational resources on the other hand. Analysis and revision of the basic principles and guidelines, scientific, methodological and technological approaches to improving the information and educational space in the context of the design and development of intelligent support systems and support for research activities.

In this paper, authors adhere to the following definition of the concept of "research activity": an active, creative process taking place in a condition of uncertainty, aimed at acquiring students subjectively new knowledge about the world around them through the application of the scientific method, as well as the formation of new personal structures (scientific thinking, scientific worldview, research experience).
In connection with the above, the purpose of the study was to illustrate the phased development of a hybrid intelligent learning environment that provides management of the research activities of schoolchildren in the field of mathematics, taking into account modern experience in creating intelligent learning systems.

Methodology

General Background of Research

The experimental base of the study was the State Budgetary Educational Institution of Moscow "School No. 1532" (Moscow), "Capital College of Service and Hospitality Industry" (Moscow), "Yelets State University named after I.A. Bunin. Training in the studied organizations is carried out according to the traditional methodology with the involvement of ICT. Students aged 15 to 18 took part in the search stage of the experiment. The sample of students \( n_1 = 234 \) consisted of high school students, colleges and institutes of secondary vocational education. The second group \( n_2 = 52 \) consisted of teachers and teachers of mathematics from these educational institutions aged 25 to 55 years.

When choosing the experimental groups, the dominant principle was the uniformity of group creation, which is important for the statistical processing of the study results. In particular:

1. For each age or class, an equal number of boys and girls were selected with an average level of performance in the academic subjects "Mathematics" and "Informatics";
2. The same motivational indicator was taken into account, expressed by interest in mathematics and computer science;
3. The choice of teachers of these subjects was carried out on the basis of the same rating (pedagogical knowledge and skills);

Instrument and Procedures

The methodology for identifying professional deficits among teachers in the direction of using artificial intelligence technologies in mathematical education was based on case testing technology aimed at identifying the level of formation of key competencies, such as: “The ability to form a rich information and educational environment by means of computer modeling, taking into account the requirements of the digital economy” and “Readiness to be included in the modern information and educational environment and to use automated intelligent learning systems for mastering subject material”, etc. A case test, as a form of assessment, is a set of input values, preconditions for performance, expected test results and postconditions for performance, designed to test compliance with a specific requirement, in our case, the ability and readiness to form and integrate modern intelligent EdTech into the educational process. Unlike traditional tests or questionnaires, case tests allow you to determine the professional and psychological characteristics of the respondent in the dynamics of his personal development, as well as assess his skills and abilities “in action”, and not just get a theoretical cut at the current time. For the proposed competencies, case testing allows you to determine how much a mathematics teacher knows the structural components of a rich information and educational environment and their hierarchy; stages, content and forms of computer modeling in solving educational and methodological problems of the selected subject area; features and characteristics of automated intelligent learning systems,
technologies and environments, the possibility of organizing the educational process with their application; is able to adapt modern technical achievements and priority end-to-end technologies (BigData and DLT, VR, AR and MR, artificial intelligence, elements of robotics, sensors, etc.) to the organization and operation of a rich information and educational environment; select and apply digital tools and services to solve specific educational problems; owns methods of analysis and critical evaluation of various theories, concepts, approaches to the formation of a rich information and educational environment; accessible digital teaching materials, tools and network services.

For students, questionnaires developed by the authors were used, focused on obtaining data on the use of various digital resources and tools in everyday educational activities, the level of their intellectualization and the desire to use them.

Results of the exploratory phase of the study

An easily predictable result was the receipt of data on the widespread use of digital technologies by teachers in everyday learning activities. Multimedia software that has become familiar, such as educational computer presentations, electronic encyclopedias and multimedia courses, is widely used. At the same time, 10% of respondents indicated awareness of the scope of intelligent learning systems in practice, which confirms the interest in the research problem and, at the same time, indicates a low distribution of these systems. Based on the results of the study, a diagram of the frequency of the use of various software digital tools by pedagogical workers was obtained (Fig. 1).

![Figure 1 Diagram of the frequency of use of intelligent computer learning systems tools in education](image-url)

It is interesting to note that students, somewhat differently than teachers, evaluate the ratio of types of intelligent computer training systems used by their mentors (Fig. 2).
Comparing two empirical distributions of the frequency of using digital resources in the educational process among teachers and students, one can establish a significant difference between these distributions using the Pearson criterion ($\chi^2_{\text{emp}} = 33.4 > \chi^2_{\text{cr}} (0.01) = 2.65$). Analyzing other data obtained during the experiment, we can conclude that the level of intellectualization, and as a result of individualization, of the EVT tools used in practice is insufficient. More than 75% of respondents cannot give examples of any ICOS. At the same time, about 90% of the teachers surveyed spoke in favor of the idea of individualization of education and supported the idea of introducing artificial intelligence systems at various levels of education. Similarly, more than 80% of students spoke in favor of individualizing their own learning, but only half of the students believe in the possibility of organizing many personalized pedagogical routes.

Thus, the analysis of the experiment confirmed the problem: the level of intellectualization, digital tools and resources used in practice is insufficient. However, there is a certain trend towards a qualitative improvement in the digitalization of the education sector, involving the latest achievements of science and technology in it, the need and readiness for further development and improvement of the applied pedagogical practices. Based on the foregoing, the study of the processes of development and integration of intelligent learning environments and systems into the system of studying mathematics in Russia confirms its feasibility and relevance.

**Literature review**

To build an effective research learning environment, it is necessary to establish optimal criteria for intellectualization. The broad technical and didactic capabilities of intelligent learning systems make it possible to construct their various classifications, each of which can be based on a variety of groups of criteria. The authors identified the following grounds:
1. Classification of intelligent learning systems by

**Intelligent learning systems with a classical structure** include a theoretical block, a control block, a knowledge base and a database. Adaptive management of educational and cognitive activity in such systems is carried out only according to the results of the current and final control, without taking into account the subject specifics of the discipline, as well as the level of initial training of the student and his psychological characteristics [6].

The second group consists of **intelligent learning systems with a subject-oriented structure**, containing blocks that take into account the subject specifics of the discipline (a block of practical tasks, laboratory work, etc.). Adaptive management of educational and cognitive activity is carried out on the basis of control results, as well as analysis of the current learning process [7].

The third group should include **intelligent learning systems with a personality-oriented structure**, in addition to the classical blocks, which also include a block for diagnosing the psychological characteristics of the student [8; 9]. In particular, the authors [36] have developed an intelligent learning system with a personality-oriented structure, characterized by the presence of a knowledge base for complex diagnostics and allowing adaptive management of educational and cognitive activity based on the results of psychological diagnostics and the initial level of training.

A higher level of adaptation can be provided by **intelligent learning systems with an agent-oriented structure**, allowing you to manage the learning process at all its stages. In systems of this type, a multi-agent approach is used, based on the functioning of a set of programs (agents) combined into certain groups to solve each specific learning task. The application of an agent-oriented approach in the process of forming the architecture of the educational environment provides support for competence-oriented learning technologies [10; 11].

The architecture of **integrated hybrid intelligent learning systems** is dominated by the main integrator module, which, depending on the set goal and the current conditions for finding a solution, selects certain intelligent modules for functioning. Examples of integrated hybrid systems are: the RAISON hybrid expert system, a hybrid intelligent system for creating robot movement plans.

2. Classification of intelligent learning systems by the mechanism of intellectualization

The first group includes intelligent learning environments operating **on the basis of expert systems**. These systems implement a dialogue between the user and the environment, providing an opportunity to explain the strategy for solving the problems of the studied subject area. The method of expert assessments allows you not to lay down a sequence of training steps beforehand, but to build it in the process of functioning of the training system. Based on the analysis of the student's answers to the test questions, as well as his personal characteristics, a competence-oriented model is formed. In the process of mapping the current model of the student to the reference model of the course, structural and parametric adaptation is performed, the individual training plan is adjusted. An example of a universal expert training system for a wide range of training courses is WITS (Whole-course Intelligent Tutoring System) – a system that simulates the expert opinions of a teacher [12].

**Training systems based on neural networks** are information structures consisting of the same type of elements (neurons) connected to each other in such a way that their functionality is similar to most of the functions of a biological neuron.

The paper [13] presents the architecture of an adaptive learning system that uses an artificial neural network to build a student model, establish relationships between various
modules of the curriculum, track progress in knowledge and predict student performance. The system selects educational elements of optimal complexity, personalized depending on the level of skills and speed of learning of students.

The paper [14] outlines the principles of the organization of a hybrid intellectual learning environment, integrating models based on production-type knowledge and neural network decision-making technologies. Java and Python are chosen as programming languages, developed respectively in the IntelliJ IDEA and VS Code environments.

Training systems based on genetic algorithms [15]. The essence of this type of algorithms is the parallel processing of a variety of alternative solutions and further concentration of the search on the most promising of them. This makes it possible to consider the possibility of using genetic algorithms to find the global extremum of a multi-extremal function when solving artificial intelligence problems.

3. Classification of intelligent learning systems by adaptation object

The function of adaptation in intelligent learning systems is to provide the learner with a personal educational space filled with educational content that "adapts" to his individual characteristics and provides the necessary information. As an example, we can consider the adaptive electronic learning resource developed by the authors, implemented on the basis of the Moodle learning management system [16]. The novelty of the proposed approach is the introduction of a three-stage system of adaptation of educational content: introductory adaptation (adaptation of the content of introductory materials of the discipline based on the initial level of students), current adaptation (adaptation of mathematical content based on the current effective actions of students), evaluative and corrective adaptation (adaptation of normative parameters of the level of assimilation of materials taking into account the achieved educational results).

Systems based on the adaptation of the order of provision of educational materials are the most difficult to implement, since they continuously collect data on the educational process (answers to tasks, number of attempts, use of interactive resources, etc.), analyze this data, and select the most relevant content. An example is the Knewton platform. It is worth noting that some intelligent learning systems use two objects at once for adaptation. For example, the MyLab student platform adapts learning materials based on the content and the order of materials provision, and the ALEKS platform adapts both learning tasks and the order of materials provision. ALEKS uses artificial intelligence to identify the level of readiness of the student at the current time in relation to each of the educational topics that he has to master. As a result, an individual trajectory of mastering educational materials is developed, and the transition to the next topic occurs only if the previous one is mastered. The domestic version of the intelligent learning system, which includes several adaptation mechanisms, was developed using a set of MathBridge tools [17]. The presented version is based on web technologies and provides adaptive learning of the basics of geometry, allowing you to dynamically generate mathematical problems adapted to the specific goals of the student, his preferences, abilities and knowledge.

4. Classification of intelligent learning systems by level of adaptability

In an intelligent learning system with the so-called "passive adaptivity", the main role is assigned to the student. Based on a set of rules and parameters, the student independently plans his movement according to the training material and the deadlines for completing tasks. In such systems, simple cause-and–effect "if-then" schemes are used.

An intelligent learning system with "active adaptability" itself determines the trajectory of the student's movement according to the educational material based on his answers to
test questions. Systems of this type include an adaptive version of the training course based on the SmartBook e-book from McGraw-Hill Education.

An intelligent learning system with "smart adaptability" builds a learning trajectory based on continuously received data about the student (psychological characteristics, preferences, success in mastering the material, etc.) Such a model is implemented using big data analytics in education Learning Analytics. As an example, Pearson MyLab courses are "personalized" using the Knewton algorithm, which use the analytics of learning content by students to build algorithms for adapting material to the needs of each user of the system.

5. Classification of intelligent learning systems by types of technologies for intellectual support of educational and cognitive activity

In modern training systems, various algorithms of intellectualization are used, which allow us to identify a number of fundamentally different technologies for supporting educational and cognitive activity: building a sequence of training courses; analyzing student responses; interactive support in solving problems; assistance in solving problems based on examples; adaptive hypermedia technologies. The purpose of the technology for sequencing the course of study is to provide the learner with the most appropriate, individually planned sequence of information blocks and training tasks (ELM-ART-II, AST, ADI, ART-Web, ACE, KBS-Hyperbook, DCG, SIETTE). Intelligent analysis of the learner's solutions deals with the learner's final answers to educational tasks (ELM-ART, Algebra, ADIS). The technology of interactive support in solving problems ensures the provision of intellectual assistance to the student at each stage of solving the problem instead of waiting for the final solution. A similar technology is implemented in ELM-ART, Algebra.

6. Classification of intelligent learning systems according to individual needs and learning styles

The creation of a profile of trainees is based on the processing of their input data to ensure the personalization of the learning process, automatically generated by the intelligent system. The personalization of the educational process was achieved in intelligent systems by identifying: cognitive characteristics (working memory capacity, inductive reasoning ability, associative learning skills) [18; 19]; affective states [20; 21]; personal characteristics [22]; consideration of emotional experience (interest in mathematics, expectation of success, self-efficacy) [23; 24]; learning dynamics [25]; learning styles [26]. However, the design of intelligent learning systems based on learning style models is recognized by the international community as dominant for e-learning. Adaptive systems based on the learning style are more productive, increase the student's academic performance, shorten the learning time and improve the student's academic achievements. Learning styles are an integral part of various types of learning systems, as well as the development of personalized adaptive learning systems combined with intelligent analysis technologies [27]. The article [28] proposes a new method using fuzzy sets to construct a series of fuzzy predictive models combining these variables for all dimensions according to the classical Felder-Silverman learning styles model [29].

The conducted clear classification of intelligent learning systems solves the problem of accumulation and systematization of knowledge about the existing variety of intelligent learning systems and intelligent methods in order to provide key parameters and data for the development of the author's modernization strategy and the development of the most effective intelligent learning system.
Results

The leading idea of the concept of a hybrid intellectual learning environment being developed is as follows: the key aspect of personal development in teaching mathematics is the development of complex knowledge based on the adaptation of modern achievements in science, vividly and meaningfully presented in applications to real life, the development of other sciences, high technologies and industries. The implementation of the concept involves the design of ordered, generalized, forming a single motivational and applied integrity of complexes of research tasks for the development of complex knowledge and the further inclusion of high school students in the study of the properties and characteristics of such generalized mathematical constructs as fractals, fuzzy sets, polyhedral surfaces, stochastic structures, etc.

The first stage of the development of an intelligent system for supporting the research activities of schoolchildren was the development of methodological provisions for the intellectual management of the educational process. The basic principles and guidelines for the design and development of intelligent learning systems were grouped and distributed in the context of the unity and mutual influence of the three components of the structure of the information and educational space: a set of digital educational platforms and technologies; digital interaction infrastructure in the context of the interactive triad "teacher - computer - learner" of the educational process; digital information and educational content. In the created structure of principles, it is necessary to indicate the principles of designing intelligent learning systems formulated by the authors for the first time: hybridity; fuzzification of the information flow; intelligibility of management; prismaticity; coherence; consistency of technologies and tool environments; verifiability and reproducibility; flexibility and adaptability of the organizational structure; resonance-wave effect; expertise of the system in the mode of support of research activities [30].

The second stage of the development of an intelligent quality management system and the success of mastering the research activities of schoolchildren was the definition of personalized parameters of scientific potential that determine the content of the structured educational content of the intellectual learning system [31]. These parameters were grouped into three clusters of psychological readiness for research activities of schoolchildren based on the following criteria: personal; activity; communicative; effective. The student's research activity is carried out in the logic of the sequential deployment of the levels of cognitive development and the growth of scientific potential. There are 4 levels with key characteristics and didactic support (databases of samples, standards and "problem areas" of modern scientific knowledge, databases of methodology for organizing design and research activities): search and reproductive (self-actualization), empirical (self-determination), theoretical (self-organization), creative (self-development of personality).

The third stage is pedagogical support and support of expert systems (development of a database and knowledge of the topics of project activities in the form of a hierarchical tree of subtasks of clusters of research tasks, instructions and rules for mastering research activities, detailed by the levels of growth of the student's scientific potential). At each level of the hierarchical tree, a database of logical continuation of the study of a particular block of the previous level is formed in accordance with the factors: the choice of parameters of scientific cognition (H), the state of perception modalities and preferences (M) and the
success of mastering the student’s research activity (K). Each variation of the generalized construct is the endpoint of a hierarchical tree of subtasks of clusters of research tasks arranged in logical chains and equipped with instructions (Ij), a bibliographic list of references (Rj) and an information support unit (Sj). An integral structural and logical model of the interdependence of the parameters of a homogeneous hybrid intelligent control system for the design and research activities of schoolchildren is presented in Figure 3.

Figure 3 Interdependence of control parameters design and research activities of schoolchildren

The final stage is the choice of the architecture, parameters and functionality of the neural network; the development of the Intelligent Learning System [32]. As the main method of training a neural network, training with a teacher was chosen, according to topology, a neural network is recurrent with hidden neurons. The proposed hybrid neural network is characterized by: the presence of an input layer of 9 linguistic variables and a universe of fuzzy variables determined by the diagnosis of each personality parameter; the presence of an output layer and three hidden layers of neurons (the input (output) vector consists of 9 neurons formalized according to 3 levels of 9 parameters of the initial (final) state of the quality and success of the research activity of schoolchildren); fuzzification of input variables and the choice of the sigmoidal activation function of neurons; a range of weights, threshold levels based on the selected activation function; classification of levels of success and quality of research activity of schoolchildren in the context of variability of the vector of parameters of the output layer and defuzzification of output variables; selection of the training sample and the learning process with the teacher by the method of error back propagation; collection and processing of feedback data on the levels of growth of scientific potential and parameters of the results of the dynamics of scientific thinking, communication and activity of schoolchildren.

Training of a multi-layer network includes the following stages:
1. Determination of the parameters of the input layer (9 normalized profiles of thinking (sign-symbolic, figurative-geometric, concrete-activity, information-computing, historical-genetic) [33; 34]. As a criterion of intellectualization, the authors use a
profile of thinking that characterizes the dominant ways of processing information, which are based on the types of thinking inherent in a given person and the level of creativity. In total, five neural networks are being built, while the technology of building a training sample remains identical for all.

2. Determination of indicators and weight coefficients of nine parameters of input layers. Diagnostics of the quality of respondents' research activities. A representative normal sample consists of 100-125 schoolchildren, distributed among 20-25 respondents for one neural network. Calculation of the mean, standard deviation, confidence interval, normalization, scaling.

3. Establishing the necessary conditions for matching confidence intervals for input and output samples.

4. Implementation of clustering and ordering of data in input and output samples by the K-means method, which determine the division of clusters into "weak", "medium" and "strong" respondents-schoolchildren. The criterion is the Manhattan distance between the vector of indicators of basic precedents and the zero of the nine-dimensional space (K = 3-5, a total of 27-45 basic precedents and responses to precedents (cluster mass centers) on 5 neural networks).

5. For each neural network on the hidden layer and for each precedent indicator, an increase (out of three variations of positive shifts) of possibilities with the number of precedent variants-2 equal to is determined by the method of expert systems 27 * 3 * 81 * 81;

6. Clustering and ordering of precedents-2 by the K-means method (K = 81 * 81) with the definition of 27 basic precedents-2 (three basic precedents for each indicator);

7. Similar dynamics and technology for the 2nd and 3rd hidden layer for 27 precedents-2, 3;

8. For the output layer, 27 responses vary according to the result of clustering the sample by 3 negative shifts with the effect of extrapolation for each of the 9 indicators (greater in terms of indicators than the sum of positive shifts for precedents 1, 2 and 3) and ordering by sample;

9. On all layers of the neural network (on each of the 5) for all samples and after the necessary ordering of the dynamics of the growth of the scientific potential "precedent-response" in each sample, their matrices of synaptic weights can be determined.

Thus, the training sample turns out to be uniquely composed of pairs (precedent-response) and it is possible to determine the matrices of synaptic coefficients for each neural network (j = 1, 2, ..., 5), which means that they can be used for a random respondent, taking into account the minimization of the Manhattan distance.

**Discussion**

The actualization of artificial intelligence for educational purposes contributed to the search for new theories, methods and algorithms in order to create a smarter and more intellectual technological educational product. This study proposes an author's solution for the use of a high-quality digital educational environment that complements and supports the educational process at school. This solution was developed as part of a global, multi-partner initiative to support countries in securing equitable access to digital learning resources. Own vision of the architecture, parameters and functionality of the intelligent learning
system will ensure the management of the project and research activities of each student in accordance with his personal preferences, intellectual abilities, ability and breadth of experience in mastering mathematics.

The proposed solution has a number of advantages over intelligent training systems developed earlier and analyzed by the authors в разделе «Literature review». Firstly, the presented intelligent system is focused not only on teaching the subject knowledge and skills, but also on the effective development of the student’s personality in the process of organizing and supporting project-based and research activities based on the functionality of the intelligent control. Moreover, the real result of the project-based and research activity of a school student related to the development of generalized constructs of complex knowledge may be the growth of their scientific potential, creativity and criticality of the personality. The results of our study are consistent with the data from the analyzed sources, however, intellectual systems based on obtaining an increase in the scientific potential of students were not previously considered in the scientific literature and practice.

Secondly, the authors propose the “zones of modern achievements in science” as the generalized constructs of complex knowledge for organizing and managing the project-based and research activities of schoolchildren using a hybrid neural network. Similar pedagogical support in the form of ground clusters of research tasks for a generalized construct of complex knowledge, instructions and rules for mastering the project-based and research activities detailed by the levels of growth of the student’s scientific potential was not previously considered. The results of this study expand the capabilities of existing educational research environments – Fraction Lab, Betty’s Brain, Crystal Island, which is of undoubted interest for science and is of practical importance for the study. The hybrid intellectual system developed and introduced into school practice for the first time for carrying out design and research activities of students and increasing the scientific potential for mastering complex knowledge in mathematics is of practical interest for the general education system. The use of such systems is becoming especially relevant in connection with the mass introduction of distance learning based on electronic learning environments and systems.

**Conclusion**

The article offers the author’s vision of the methodology, architecture, parameters and functionality of an intelligent learning system implemented to manage the research activities of each student in accordance with his personal preferences, intellectual capabilities and breadth of experience in mastering mathematics. The considered solution has a number of advantages in comparison with the intelligent training systems developed earlier and analyzed by the authors.

Firstly, the use of a hybrid paradigm in the design of intelligent research support systems allowed minimizing the risks of errors in tracing individual trajectories. The proposed architecture and system-technical approach have made it possible to increase the efficiency of using solutions based on artificial intelligence.

Secondly, the presented intellectual system is focused not only on teaching subject knowledge and skills, but also on the effective development of the student’s personality in the process of organizing and supporting research activities based on the implementation of the intellectual management functionality. The result of a student’s
research activity on the development of generalized constructs of complex knowledge can be the growth of his scientific potential, creativity and critical thinking. Improving the quality of mathematical education in the context of its digitalization is inextricably linked with the development of complex knowledge by schoolchildren and, as a result, the intensification of the developing effect.

Thirdly, as generalized constructs of complex knowledge for the organization and management of design and research activities of schoolchildren using a neural network, the authors propose such "zones of modern achievements in science" as fuzzy sets, elements of fractal geometry (including the Schwarz cylinder), complex numbers, random events, quantities and processes, etc. Such pedagogical support in the form of clusters of research tasks for a generalized construct of complex knowledge, instructions and rules for mastering research activities, detailed by the levels of growth of a student's scientific potential, has not been considered before.

Funding

The reported study was funded by RFBR, project number 19-29-14009

REFERENCES

Информация об авторах

Дворяткина Светлана Николаевна
(Российская Федерация, Елец)
Доцент; доктор педагогических наук; заведующий кафедрой математики и методики ее преподавания ФГБОУ ВО «Елецкий государственный университет им. И.А. Бунина»
E-mail: sobdvor@yelets.lipetsk.ru
ORCID ID: 0000-0001-7823-7751
Scopus Author ID: 57193775897

Жук Лариса Викторовна
(Российская Федерация, Елец)
Доцент; кандидат педагогических наук; доцент кафедры математики и методики ее преподавания
E-mail: krasnikovalarisa@yandex.ru
ORCID ID: 0000-0002-5054-882X

Смирнов Евгений Иванович
(Российская Федерация, Ярославль)
Профессор; доктор педагогических наук; заведующий кафедрой математического анализа, теории и методики обучения математике Ярославский государственный педагогический университет им. К. Д. Ушинского
E-mail: smiei@mail.ru
ORCID ID: 0000-0002-8780-7186
Scopus Author ID: 55734369900

Щербатых Сергей Викторович
(Россия, Елец)
Профессор; доктор педагогических наук; проректор по учебной работе, профессор кафедры математики и методики ее преподавания ФГБОУ ВО «Елецкий государственный университет им. И.А. Бунина»
E-mail: shcherserg@mail.ru
ORCID ID: 0000-0002-4870-8257
Scopus Author ID: 57196473659

Information about the authors

Svetlana N. Dvoryatkina
(Russian Federation, Yelets)
Associate Professor; Dr. Sci. (Educ.), Head of Mathematics and Methods of its Teaching Department
Bunin Yelets State University
E-mail: sobdvor@yelets.lipetsk.ru
ORCID ID: 0000-0001-7823-7751
Scopus Author ID: 57193775897

Larisa V. Zhuk
(Russian Federation, Yelets)
Associate Professor; Cand. Sci. (Educ.), Associate Professor of the Department of Mathematics and Teaching Methodology
Bunin Yelets State University
E-mail: krasnikovalarisa@yandex.ru
ORCID ID: 0000-0002-5054-882X

Eugeny I. Smirnov
(Russian Federation, Yaroslavl)
Professor; Dr. Sci. (Educ.), Head of Mathematical Analysis, Theory and Methods of Teaching Mathematics Department
Yaroslavl State Pedagogical University named after K. D. Ushinsky
E-mail: smiei@mail.ru
ORCID ID: 0000-0002-8780-7186
Scopus Author ID: 55734369900

Sergey V. Shcherbatykh
(Russia, Yelets)
Professor; Dr. Sci. (Educ.); Vice-Rector for Academic Affairs; Professor of the Department of Mathematics and Methods of its Teaching
Bunin Yelets State University
E-mail: shcherserg@mail.ru
ORCID ID: 0000-0002-4870-8257
Scopus Author ID: 57196473659