С. Н. Дворяткина, Л. В. Жук, Е. И. Смирнов, С. В. Щербатых

Дидактическая модель развития исследовательской деятельности школьников в гибридной интеллектуальной обучающей среде

Введение. Проблема разработки и внедрения интеллектуальных цифровых технологий в систему обучения предметным областям знаний с целью самоорганизации личности, понимания и осмысления сложного математического знания как принципа развития личности на основе индивидуализации обучения, установления персонифицированной и компьютеризированной обратной связи когнитивных и оценочных процессов является актуальной и далеко не решенной. В данном проблемном поле актуализируются вопросы организации исследовательской деятельности обучаемых в процессе адаптации современных достижений в науке к школьной математике посредством интеллектуального управления.

Материалы и методы. Для выявления новых тенденций в развитии концепта «исследовательская деятельность» использованы методы теоретико-методологического анализа, анализа математической, психолого-педагогической, технической литературы, методы систематизации имеющегося опыта по проблеме исследования. Изучены возможности методов интеллектуального управления, проектирования гибридной интеллектуальной обучающей среды для создания модели исследовательской деятельности.

Результаты исследования. Разработана дидактическая модель исследовательской деятельности на основе использования гибридных интеллектуальных систем в ходе адаптации современных достижений науки с проявлением эффектов самоорганизации личности. Структурообразующим модулем построения модели явилась авторская концепция интеллектуального управления образовательным процессом в условиях гибридной интеллектуальной обучающей среды. Сформулирована и обоснована система принципов, рассматриваемая в контексте единства и взаимного влияния трех составляющих структуры информационно-образовательного пространства: совокупности цифровых образовательных платформ и технологий; инфраструктуры цифрового взаимодействия в контексте интерактивной триады «педагог – компьютер – обучающийся» образовательного процесса; цифрового информационного и образовательного контента. В ходе освоения сложного знания через историогенез и спектр его приложений выстроены технологические конструкты кластеров фундирования компонентов обобщенной структуры в направлении построения индивидуальных образовательных траекторий школьников с использованием гибридных нейронных сетей, составляющих содержательный компонент модели развития исследовательской деятельности.

Заключение. Результаты исследования имеют практическую ценность, так как выступают методологической основой создания программного комплекса, реализующего функционал гибридной интеллектуальной системы развития исследовательской деятельности обучающихся на основе разработанных принципов и структурных компонентов с использованием экспертных систем и нечеткого моделирования.

Ключевые слова: обучение математике, исследовательская деятельность, интеллектуальное управление

Ссылка для цитирования:

Дворяткина С. Н., Жук Л. В., Смирнов Е. И., Щербатых С. В. Дидактическая модель развития исследовательской деятельности школьников в гибридной интеллектуальной обучающей среде // Перспективы науки и образования. 2021. № 2 (50). С. 278-292. doi: 10.32744/pse.2021.2.19

S. N. DVORYATKINA, L. V. ZHUK, E. I. SMIRNOV, S. V. SHCHERBATYKH

Didactic model of development of research activities of schoolchildren in a hybrid intellectual learning environment

Introduction. The problem of developing and implementing intelligent digital technologies in the system of teaching subject areas of knowledge for the purpose of self-organization of the individual, understanding and comprehending complex mathematical knowledge as a principle of personal development based on individualization of learning, establishing personalized and computerized feedback of cognitive and evaluative processes is relevant and far from solved. In this problem field, the issues of organizing the research activities of students in the process of adapting modern achievements in science to school mathematics through intellectual management are updated.

Materials and methods. To identify new trends in the development of the concept of "research activity", methods of theoretical and methodological analysis (comparative, retrospective, modeling), analysis of mathematical, psychological, pedagogical, technical literature, methods of systematization of existing experience on the research problem were used. The possibilities of methods of intelligent management, design of a hybrid intellectual learning environment for creating a model of research activity are studied.

The results of the study. A didactic model of research activity is developed based on the use of hybrid intelligent systems in the course of adapting modern scientific achievements with the manifestation of the effects of self-organization of the individual. The author's concept of intelligent management of the educational process in a hybrid intellectual learning environment was the structure-forming module of the model construction. The system of principles considered in the context of the unity and mutual influence of the three components of the structure of the information and educational space is formulated and justified: a set of digital educational platforms and technologies; digital interaction infrastructure in the context of the interactive triad "teacher-computer-student" of the educational process; digital information and educational content. In the course of mastering complex knowledge through historiogenesis and the range of its applications, technological constructs of clusters of foundation components of the generalized structure are built in the direction of building individual educational trajectories of schoolchildren using hybrid neural networks that make up the content component of the research activity development model.

Conclusion. The results of the study are of practical value, as they serve as a methodological basis for creating a software package that implements the functionality of a hybrid intelligent system for developing students' research activities based on the developed principles and structural components using expert systems and fuzzy modeling.

Keywords: teaching mathematics, research activities, intelligent management

For Reference:

Dvoryatkina, S. N., Zhuk, L. V., Smirnov, E. I., & Shcherbatykh, S. V. (2021). Didactic model of development of research activities of schoolchildren in a hybrid intellectual learning environment. *Perspektivy nauki i obrazovania – Perspectives of Science and Education*, 50 (2), 278-292. doi: 10.32744/pse.2021.2.19

Introduction

1 Relevance of the study

The key determinants of the current stage of development of science, technology, economy, socio-cultural processes are uncertainty, variability of the surrounding world, the multiplicity of trends in its development, generated by the influence of random factors. The instability of competencies in demand in the labor market, dynamically changing personal preferences of subjects of the educational process actualize trends towards the development of the motivational sphere of the individual, the expansion of its metacognitive experience, the formation of cognitive independence. In the new educational paradigm, the emphasis is focused on the processes of self-actualization and self-realization of the student, mastering metasubject competencies against the background of the deployment of adequate pedagogical conditions, subject content, means, forms and technologies of training. The indicated trends in modern education determine the formation of an integral system of research activities of schoolchildren based on the integration of educational, scientific and practical components of the learning process as one of the key tasks.

The solution of this problem is possible through the use of adaptive training systems (ATS), which recently undergo significant transformation, becoming a complex integrated organizational and technical environment, based on analytical and heuristic models that take into account the randomness of external influences, heterogeneous a priori incompleteness of knowledge, uncertainty of goals of the system formed competencies, thus allowing to implement non-formalized and semi-structured tasks of management of cognitive activity of trainees. A promising direction in the development of the processes of personalization of learning, the formation of personal identity is the development of training systems based on methods and technologies of artificial intelligence.

2 Literature review

In the works [9; 26], the historical line of ATS design was traced, methodological and humanitarian aspects of the impact of artificial intelligence technologies on the transformation of education and society were described, foreign and domestic experience of implementing intelligent digital technologies in the general education system was analyzed, in particular, the principles of building and functioning of intelligent systems of teaching mathematics were studied. The development of hybrid learning environments based on neural networks and expert systems with fuzzy logic is identified as one of the main trends in the digital transformation of the education system. Specific features of hybrid environments that distinguish them from previously used automated learning systems in educational practice are the presence of an intelligent interface, a self-learning adaptive system, as well as a set of synergetic features – fuzzy goals and institutional boundaries; chaotic and fluctuating behavior of the environment; weak formalizability and non-standard situations; the importance of small impacts, etc. The presence of these features makes it possible to consider the development of mathematics by students in a hybrid learning environment as an intellectual process that allows you to design and implement individual educational routes of students with the leading role of supporting intelligent and expert systems in solving and researching multi-stage mathematical and information tasks that form generalized constructs of complex knowledge structures and procedures.

The work [6] reveals the essence of managing the cognitive activity of students in the conditions of hybridity, interactivity and adaptability of methods of teaching mathematics as a mechanism that provides systematic support, control and correction of the process and result of mastering the material in a rich information and educational environment. At the same time, it is necessary to take into account the dependence on the educational style and individual psychological characteristics of students, the level of training, the formation of self-organization skills in design and research activities, the interactive methods and means of mastering mathematics used. We are talking about *intellectual management of students' research activities*, by which we mean the use of the functionality of a hybrid intellectual system in conditions of openness to external influences and factors, as well as the synthesis of mathematical and computer modeling in order to update the personalized feedback of creative cognitive processes of mastering mathematics of complex knowledge.

A sensitive period for the manifestation of synergetic effects in teaching mathematics, the actualization of self-organization processes is high school, since this age period is characterized by intellectual readiness to master multi-stage abstractions of complex knowledge, communication in a coherent field of interaction of subjects of the educational process. In addition, significant achievements in mathematical science (fractal geometry, the theory of chaos and catastrophes, the theory of coding and encryption, the theory of generalized functions) and its applications give a powerful motivational charge to the study of mathematical disciplines, the development of theoretical thinking, the complementarity of its logical and intuitive components, the ability to highlight the main thing, generalize, model. These studies should be reflected in the programs of school mathematics education, creating a rich information and educational environment with a high potential for the personal development of students. Understanding and solving a series of specific problems of mathematics as integrative centers of relevant information that require the use of a complex of mathematical methods and information technologies will contribute to the development of intellectual thinking operations (analogies, associations, modeling, concretization, abstraction, generalization, etc.) in older students, which are the basis of universal educational actions.

In the psychological and pedagogical literature, the materials of productive research on the problems of development and organization of research activities of students are widely presented. Methodological and theoretical foundations for the development of research activities in the educational process are considered in the works of N. V. Bordovskaya [2], Kennedy Baker [11] (content, purpose, functions of educational and research activities); G. V. Makotrova [13], A. O. Karpov [10] (psychological foundations of the research approach to learning); M. V. Klarin [12] (characteristic features of research activities in the education system); Of great interest are the works devoted to the study of the organization of educational and research activities in the teaching of individual disciplines-mathematics (V. A. Dalinger [5], E. I. Smirnov [20; 21], D. M. Rishor [16]), physics (V. A. Kotlyarov, V. A. Belyanin, N. S. Purysheva [1]), chemistry and biology (E. Yu. Kravtsova, D. Isaev, A. Sobolev, M. Pak [8]), humanities (A.V. Leontovich, A. C. Obukhov [14] and others), which consider specific methods of organizing educational and research work both in the classroom and outside of school, comprehensively examines its impact on the development of students' creative abilities.

A clear differentiation of the concepts of research activity and educational research activity is of fundamental importance. Research activity is an individual scientific knowledge aimed at revealing external and internal connections, properties, laws, relations between

objects and phenomena of the surrounding reality, while educational and research activity involves the development of the student's personality in the process of his interaction with the teacher. Thus, in science, the subject is a scientist, in education-a student under the guidance of a teacher.

The presence of two subjects of educational and research activity determines the duality of its goals. The external, object-oriented goal of the student is to gain new knowledge about the world around them through research, while the external goal of the teacher is to educate the student in the context of developing his research qualities. The goals of the internal plan, aimed at oneself as a subject of activity, on the part of the student are the desire to acquire new personal qualities (scientific thinking, scientific outlook, research position, research experience), on the part of the teacher – the desire, using research activity as an educational technology, to increase the effectiveness of the educational process. The line of demarcation separating educational and research activities is the nature of the novelty of the result obtained: if in science, as a result of the application of a set of research actions, an absolutely new knowledge with objective novelty arises, then in the process of educational research, students receive subjectively new knowledge.

The scientific method-a set of rules and principles adopted all over the world, which consists of the sensory perception of facts and their theoretical understanding based on strict logic-acts as a means of determining the algorithm of both research and educational research activities. The method of scientific knowledge as a tool for discovering the objective laws of reality was created as a result of the efforts of many generations of scientists and is objective, independent of the subject of activity. The subjective means of research activity are the innate and acquired abilities of the student, his activity, knowledge and experience, divergent and convergent thinking, logic, search activity.

Based on the analysis of the nature of teaching and research activities will adhere to the following definition of the concept: *educational research activity – active, conscious and creative process that takes place in limbo, aimed at getting students subjectively new knowledge on the part of the surrounding world through the application of the scientific method under the guidance of a teacher, as well as new capacities and structures (scientific thinking, scientific Outlook, experience, research activities)*. Thus, educational and research activity is considered as an independent search form of educational work, which is a complex of subject-subject interactions of participants in the educational process, aimed at the active development of theoretical and empirical methods of scientific knowledge by students and the formation of their research competencies.

Under the *development of research activities of schoolchildren in a hybrid intellectual learning environment*, we will understand the totality of quantitative and qualitative changes in its structure, which are expressed in an increase in the level of formation of research competencies. These can be such parameters of research activity as: the level of scientific training, motivation, organization, perseverance and responsibility, creative self-development and self-realization [18], critical thinking, independence, teamwork, intercultural interaction [4], actions in conditions of uncertainty, self-improvement, the need for intellectual activity [12], collection, study and processing of information, problem analysis, practical significance of the project, self-assessment (objectivity) [3], technological readiness to search, self-assessment of personal growth, creative independence [13], etc.

The ultimate attractor of students' research activity should be a *database of modern achievements in science* (elements of fractal geometry, the theory of encoding and

encryption of information, fuzzy sets and fuzzy logic, generalized functions, cellular automata, etc.).

The comparative analysis of foreign and Russian literature related to this topic, as well as all the above, has determined:

- *research problem*: what are the theoretical and methodological foundations and didactic mechanisms for the development of research activities of schoolchildren in a hybrid intellectual learning environment?
- *the purpose of the study* — is to build a didactic model for the development of students' research activities in a hybrid intellectual environment that provides assistance and support for planning, organizing and intelligently managing the process of mastering mathematics during the deployment of individual educational trajectories.

Methodology

The basis for constructing the Concept of a didactic model for the development of research activities of senior schoolchildren in teaching mathematics in a hybrid intellectual environment was the synergetic and fractal approaches. The establishment of the fractal structure of pedagogical phenomena and objects (mathematical knowledge, educational content, educational element) made it possible to apply the fractal methodology and its principles in the phase of analysis, selection and structuring of educational material as a knowledge base based on the identification of hierarchies and characteristics of fuzzy modeling. Fractal methods as a means of modeling and analyzing complex, nonlinear processes allowed us to create heuristically productive, predictable in their development hybrid models with unique properties: they were used to detect and simulate both linear and nonlinear educational effects. At the same time, the implementation of the process of improving the efficiency of educational systems is possible on the basis of updating the synergetic approach. This is especially true for mathematical education, which has a huge potential for actualizing the processes of self-organization in research activities and the positive manifestation of synergistic effects in different directions using intelligent systems.

The theoretical and methodological basis of the model is also the integration of several scientific approaches: system-genetic, environmental, integrative and competence-based. All this provided the necessary depth of study of the main aspects of the problem and the tasks set, allowed us to identify new patterns of research activity and parameters of its quality using intelligent systems. To identify new trends in the development of the concept of "research activity", methods of theoretical and methodological analysis (comparative, retrospective, modeling), analysis of mathematical, psychological, pedagogical, technical literature, methods of systematization of existing experience on the research problem were used.

The possibilities of methods of intellectual management, design of hybrid intellectual learning environment in the context of the unity and mutual influence of the three components of the structure of the information and educational space for creating a model of research activity are studied. In particular, the possibilities of neural network algorithms for optimizing system parameters using high-parallel and cascade learning are studied. The effectiveness of the use of the artificial neural network method for the development of an intelligent learning system is justified.

Results

When developing a didactic model of development of research activity (RA) high school students in math training in hybrid intelligent environment was chosen the modular design of the individual model components – methodological, substantive, procedural and diagnostic, the unity of which provides the design of a scientifically-managed process for the development of research competencies.

The block of goal-setting of the RA development model is determined by the purpose and objectives of the study. Considering the priority of the personal-oriented goal of mathematical education of schoolchildren – the development of research competencies, the formation of readiness for activity in a continuously changing information environment, for successful socialization in modern society, we see the possibility of achieving this goal through solving a group of problems:

subject-content: the development of techniques for adapting generalized scientific knowledge to the processes of mathematical activity of students; the development of the ability to carry out mathematical and computer modeling of applied problems; the formation of the ability to apply classical and modern mathematical methods in practice, choosing the most effective ones;

personal development: ensuring a high level of educational motivation of schoolchildren through visual modeling, concretization of the essence of generalized constructs of complex knowledge, establishing relationships between mathematics and other fields of science; development of divergent thinking and creative independence; formation of productive and creative mathematical skills in the course of solving non-standard and problematic problems; development of skills of independent research work, skills of applying modern information technologies to solving mathematical problems; development of adaptation skills in social communications;

general cultural: the formation of a scientific worldview, mathematical culture as one of the main components of the general culture of the individual, stimulating cognitive activity and independence of students, ultimately, ensuring the harmonious development of their personality through an increase in intellectual and creative level.

The methodological basis of the didactic model of RA development is the concept of intellectual management of the educational process in a hybrid intellectual learning environment, which is based on the following key idea: the most important aspect of the phenomenon of synergetic effects and personality development in teaching mathematics is the development of complex knowledge based on the adaptation of modern achievements in science using a hybrid intellectual system.

The fundamental factor that ensures the implementation of the concept is the unity and interrelation of the following methodological approaches:

- *system-genetic*, focused on the study of trends in the development of the student in dynamics and the systematic organization of his activities in solving research problems, the basic characteristic of which is the development of a reflexive orientation with the implementation of the transition from theoretical knowledge to practical action. The basic provisions of the approach are to establish the historical foundations of the formation and development of a complex mathematical object or procedure, the causes and conditions of their occurrence, and the personalities who have made a significant contribution;

- *vector-contextual*, providing the development of research activities in a three-dimensional educational space (personal-adaptive, content-based and procedural) through the systematic use of the applied context;

- *competence*, based on the establishment of the need to form a holistic integrative quality as a result of teaching mathematics, invariants of universal competencies that allow you to successfully solve educational problems in conditions of uncertainty, build and implement promising lines of intellectual, cultural, and professional development;

- *environmental*, in which the innovative educational environment is considered as the main condition and means of educational activities aimed at the development of the student's RA;

- *synergetic*, based on the mechanisms of interdisciplinary interaction of diverse areas of scientific knowledge in terms of methods of cognition, forms, means in order to change both the methodological system itself and the individual in the process of mathematical education, where the RA acts as a synergistic effect of learning;

- *integrative*, understood as a set of different components of the developing environment that ensure the implementation of basic (school) and professional training with the activation and integration of binary opposition, expressed in a special structuring of activities, methods, concepts, principles, means, forms of training, as well as several areas of knowledge.

- *fractal*, considering all pedagogical phenomena and objects with an emphasis on quantitative and qualitative assessment of their structures, which have a complex hierarchical organization of any dimension, describing the self-organization of mathematical activity, modeling its self-development in the direction of the development of funding spirals as integral integrating mechanisms;

- *conventional*, which means machine learning methods based on formalism and statistical analysis, while computational approaches mean iterative development and training based on empirical data.

- *computational*, involving iterative development and training based on empirical data.

System design principles and development of intelligent tutoring system is considered in the context of unity and mutual influence of the three components of structure of educational space.

The principles of designing an ITS (intellectual training system), as *a set of digital platforms and technologies*, are: *hybridity* – the use of information processing modules based on fuzzy logic algorithms and sets, as well as modules that use a neural network; *management intelligence* (integration of artificial intelligence methods and management theory), the principle is based on the symbiosis of mathematical and computer modeling of the content and hierarchies of knowledge and procedures, interactive intellectual training and evaluation activities in information environments in which the functions of expert systems, fuzzy logic, artificial neural networks and genetic algorithms are integrated; *prismaticity* – the return of the information response from the trainee (with a controlled and set system sampling rate), followed by decomposition into a spectrum of key components (analysis of the logic of solving the task by the trainee); *unity of educational and technological logic* – continuity and consistency of algorithms for building a local educational space and algorithms for digitalization of its stages (processes) as part of the ITS; *openness of the system* – the freedom to expand the ITS with new digital technologies while preserving the main functional algorithms, including taking into account the possibility of connecting external systems, mutual data exchange between various structural elements of the ITS; *coherence* (coordinated action of different principles and effective feedback)

is expressed in the integrity of the content of education and the underlying structure of internal and external links of a complex system or object; *consistency of technologies and tool environments* is a synergy of technologies that provides the expansion of service capabilities of platforms, including the creation of conditions through computer tools for formal and non-formal training.

The principles of the *digital interaction infrastructure in the context of the interactive triad "teacher-computer-student"* are: *flexibility and adaptability of the organizational structure*, which is responsible for the implementation of various options for building an individual educational strategy, depending on the personal characteristics and capabilities of the student; *resonance-wave effect* the *principle* implies a system-controlled frequency, intensity and contextual emphasis on the impact of information on the student in order to intensify the perception of educational material; *signs of expert system in maintenance mode research activities* are manifested in the activation of algorithms for transition to the highly specialized subject areas and intensify the use of heuristic databases; *motivational-synergistic effect* – the lack of educational dead-end routes, creation of situation of success and sustained motivation for learning, leading to self-organization and creative activity of the student and immersively perception of the material being studied as a unified system of knowledge; *fuzzification of the information flow* is performed during its transition to the tasks of the middle and upper levels of gradation of educational material with subsequent dispatching of input data from the student; visibility of personal assessment — providing and stating the evaluation of the results of the student's activity in the form of a simplified interface; *consistency, variability and integrity of the ITS* – the content, methodological, technological integrity of the educational process in the continuity of all levels of education.

Design principles of ITS *as a totality of digital information and educational content* are: *information richness of the educational environment* – oriented didactic redundancy, resource opportunities when selecting items of content of educational material and levels of its development for quality solutions to educational problems; *individualization and personalization of educational routes* — is based on establishing and maintaining a dynamic system of rapid feedback and corrective action ITS, according to individual characteristics and needs of the student; *fractality* – allows to present educational elements of a subject area in the form of fractal models and to provide on this basis identification of essence of objects and procedures of research of "problem zones" or integrity of reflection of local attractors of a complex system (knowledge and procedures) in processes of assessment of quality of educational process depending on depth of interpenetration and intersection of growing and multiplying fractal structures; *transdisciplinarity*, which provides solutions to complex problems of interaction between natural science and humanitarian cultures, as a constructive dialogue of various scientific fields, as a form of interaction of disciplines for understanding the phenomenon of complexity of systems, and creating a new intellectual space; *reliability and quality of information*.

The content component of the model of development of research activity includes the development of students' funding chains of research practice-oriented tasks for the development of complex knowledge [17] by means of mathematical and computer modeling. The principle and technology of the foundation of personal experience (E. Husserl, V. D. Shadrikov, E. I. Smirnov, etc.) is the basis for the adaptation of modern achievements in science, acting as an effective mechanism for managing the project and research activities of schoolchildren, updating the integrative links between science and school. In the process of solving a complex of multi-stage mathematical and information tasks, high school students

are involved in the study of new mathematical properties and characteristics of generalized constructs: fractal objects, mathematical models of instability of solutions of nonlinear dynamical systems, means of encoding and encrypting information, cellular automata, fuzzy sets, carry out computer modeling of polyhedral surfaces, stochastic structures on strange attractors, etc.

Let us illustrate by example the construction of a funding chain of the content of research activities of schoolchildren in the form of multi-stage mathematical tasks, which actualizes the essence of one of the generalized constructs of complex knowledge – fractal geometry.

Example. *Variations of the generalized construct "Fractal geometry of Mandelbrot and Julie" sets in the form of a chain of research problems:*

- historiogenesis and variability of iterative dynamics of the development of ideas about Mandelbrot and Julie sets;
- iterative processes and computer-generated design of Julia's filling sets;
- iterative processes and computer design of Mandelbrot sets;
- topological and fractal dimensions of the Julia sets and the Mandelbrot;
- smooth Julia sets for Chebyshev polynomials: mathematical and computer modeling;
- a technique for visualizing the Julie and Mandelbrot sets in information environments;
- calculation of the Feigenbaum constant for the Mandelbrot set;
- computer design and construction of Cantor and connected Julia sets.

The block structure of procedural development model RA is represented by a functional hybrid of ITS, the stages of realization of pedagogical activity on development of RA, managerial and correctional-developing modules.

Dynamic random selection of parameters on the layers of an artificial neural network with the use of expert systems is the basis for the construction of an ITS. In the process of recognizing the results of mastering a complex didactic field of educational elements (knowledge, skills, mathematical methods, algorithms, and procedures), a direct-acting neural network with backward error propagation and fuzzy modeling of the rules for fuzzification of input variables, including on hidden layers, are used. The value of the activation function is determined by the generalized Gaussian function or sigmoidal function.

The model of functioning of a hybrid intelligent training system with an extensible database is formally presented in the form of a hierarchical tree. The factor of differentiation of database elements is the level of complexity of the generalized construct: each variation of the generalized construct is the endpoint of a hierarchical tree of subtasks arranged in logical chains and equipped with instructions, an information block and a bibliographic list. The hierarchical tree is based on a database of educational and research projects, at each next level of the tree, experts form a database of logical continuation of the study of a specific block of knowledge, thus *forming an individual educational trajectory* of the student's research activity.

Highlight *the main technological stages of development* of research activity of students in teaching mathematics in ITS is based on the deployment ponderous procedures in the process of building a didactic field training elements:

- *motivational-value (self-actualization)*: actualization of the value and personal-adaptive characteristics of the cognitive activity of the student on the development of the generalized construct of complex knowledge; it uses such techniques to create a motivational fields as historical-genetic and problematic rationale for the emergence of a generalized construct, visual modeling and computer-aided design (for example, in the field of fractal geometry model of the Lorentz strange attractor, a computer

implementation of a fuzzy Menger sponge, a script, Verhulst, etc.), establishment of intra-subject and inter-subject relations;

- *preliminary-preparatory (self-determination)*: implementation of empirical tests, search for particular manifestations of the essence of the generalized construct, creation of a situation of intellectual tension, problem situations; actualization of previously learned and anticipation of future mathematical knowledge, historiogenesis of basic concepts, actualization of forms and methods of scientific knowledge;
- *process-activity (self-organization)*: identification by means of computer and mathematical modeling of essential connections and characteristics of the generalized construct in the course of a series of research tasks, the development of research procedures by students – setting goals and objectives of the research, putting forward hypotheses and testing them, generating subjectively new knowledge, solving chains of interdisciplinary practice-oriented problems, updating the multiplicity of solutions, identifying analogies, patterns, associations in the studied processes and phenomena, considering facts in dynamics, searching for real-world applications, establishing interdisciplinary connections, predicting future problems;
- *evaluation and correction (verification of educational results)*: discussion of project results, generating insights, reflexive control, the translation of the dialogue in the internal plan, monitoring and evaluation of the effectiveness of educational strategies, diagnostics of level of development of mental functions and mental operations, revealing the extent to which synergy effects, the dynamics of personal characteristics of the trainees; correction process procedures and substantive content of education.

The organizational and management module includes:

- *teaching methods* as a system of consistent and orderly actions of the teacher, organizing the educational, cognitive, research activities of schoolchildren: experimental procedures, demonstration of the variability of definitions, methods of representation and conditions for the existence of a generalized knowledge construct, showing analogies and associations, historiogenesis, variation of the modalities of information perception (sign-symbolic, figurative-geometric, verbal. concrete-activity and tactile-kinesthetic), mathematical modeling, design methods, computer experiment and computational procedures, WebQuest technology, Wiki-technology;
- *forms of training*-traditional within the framework of a class-based learning system (lectures, conversations, discussions, workshops on problem-solving, test tasks, standard calculations); innovative (work in the ITS, mathematical essays, long calculation tasks, presentations, video clips, business games, scientific conferences and seminars, distance learning of small groups, networking, discussion forums);
- learning a visual model, practice-oriented system jobs, educational-methodical complexes, computer simulation tools (dynamic geometry, GeoGebra, Mathematical designer, Autograph, computer algebra systems Mathcad, MathLab, Maple, Mathematica, educational software products, etc.);
- *correctional*-developing module includes methods, forms and means of verification (control and independent work, monitoring, testing, diagnostic techniques).

The diagnostic block of the model includes tools for quantitative and qualitative assessment of the degree of achievement by students of subject, metasubject and personal results in the process of development of educational and research activities:

1. Levels of development of research activity of schoolchildren, reflecting the present state of its motivational, cognitive and structural-operational components, due to the influence of the intellectual learning system.

2. Criteria for assessing the elements of scientific knowledge and the quality of research activities and their characteristic indicators:

- *scientific thinking* (stability, generality of thinking, correlation of creative and logical acts, completeness, evidence, understanding, concretization, principles and style of scientific thinking-induction, deduction, insight, analogy, inversion, anticipation);
- *scientific activity* (research of experience (collection and processing of information, analysis, synthesis, associations, analogies, etc.), awareness of the limitations of experience, problem formulation and search for contradictions, hypotheses, improvisation, trial and error, actions in conditions of uncertainty, setting up an experiment, obtaining a new result);
- *scientific communication* (ability to work with scientific information, justification of the practical significance of the project, assessment of the accuracy of its practical implementation, intercultural interaction, teamwork, social verification of new knowledge);
- *typology of perception modalities* (sign-symbolic, verbal, figurative-geometric, concrete-activity);
- *experience and personal qualities* (technological readiness, need and interest in research activities, creative independence, self-organization of educational research, self-assessment).

The main results of realization of the developed didactic model of development of RA in the process of learning mathematics are: high (creative) level of development of research activity of schoolchildren, overcoming of formalism in the teaching of mathematics, the effect of achieving the entity, understanding and comprehension of multi-stage mathematical abstractions of modern scientific knowledge, formation of creative activity and motivation research, self-organization of personality, the development of personal qualities.

Discussion

The issues of designing the infrastructure that makes up the intellectual educational environment are given a significant place in the scientific literature [9; 15; 22-25], and this study occupies its own specific methodological niche. The hybrid intelligent system, using an arsenal of methods for modeling human intellectual activity (cluster analysis, artificial neural networks, genetic algorithms), allows us to solve the problem of forming individual educational trajectories in the educational environment. It is established that the construction of an individual educational trajectory is provided by the modular structure of the course and is a sequence of alternating and presenting educational objects to the student [23]. The conducted research has proved one of the directions of possible use of intelligent systems in education, which can be associated with improving the quality of research activities of schoolchildren in the direction of implementing individual educational routes. The creation of open educational environment, the development of complex mathematical structures, a plurality of goal setting and the possibility of obtaining by-products in the course of research-based intelligent control to create the basis for self-organization of personality and effective development of intellectual operations, increase educational and professional motivation,

creativity and critical thinking of the student in learning mathematics in school. The results obtained are fully consistent with international studies [16; 20].

The most important component of content research activities in mathematics stands adapting modern advances in the science of learning math that allows you to develop generalized complex constructs knowledge through research activities on the basis of intelligent management. The study defines a method for deploying the essence of the generalized construct of modern scientific knowledge on the basis of parameterization necessary to ensure the processes of self-organization, individualization of training and evaluation of its results, which has been successfully implemented in the practice of training [7; 19]. The success of passing and studying the chain of blocks of research activity (individual educational trajectory) based on the implementation of personal preferences and achievements in a rich information and educational environment stimulates the manifestation of the processes of self-organization of the individual. Thus, information support of the processes of selection and formation of research activities by means of a hybrid intellectual system actualizes the processes of individualization of teaching mathematics. The richness of the information and educational environment creates the basis for the synergy of mathematical education in the study of complex knowledge in the context of identifying the essence of the generalized construct of modern scientific achievements.

Further tasks of the research are: creation and practical implementation of a software package that implements the functionality of a hybrid intellectual system in terms of developing students' research activities based on the identified key parameters and structure of an artificial neural network using expert systems and fuzzy modeling; detailing the algorithm of interaction between the intellectual system and the expert (teacher) with the manifestation of synergetic effects of the development of personal qualities and thinking of students.

Conclusion

Theoretical-methodological and procedural-technological bases of the model of development of research activity of high school students in the conditions of application of the hybrid intellectual environment on the basis of interactive interaction "subject (student) – intellectual system – expert (teacher)" are developed. In particular, the study developed:

- principles of intelligent control of the process of teaching mathematics in an intelligent learning environment that integrates the functions of expert systems, fuzzy logic, artificial neural networks and genetic algorithms.
- technological constructs of clusters of funding components of generalized structures of complex knowledge on the example of fractal geometry. It is revealed that the didactic field of educational elements is equipped with a system of multi-level hierarchical databases of exercises, motivational-applied, research, practice-oriented tasks that require the integration of mathematical, informational, natural science and humanitarian knowledge and procedures.

Acknowledgments

The research was founded by RFFI Project № 19-29-14009

REFERENCES

1. Belyanin V.A., Purysheva N.S. Educational Research Problems as a Means for Shaping Research Competence of Future Physics Teachers. *Vestnik of Lobachevsky University of Nizhni Novgorod*, 2011, vol. 5, no. 1, pp. 24-30.
2. Bordovskaya N.V. The methodological status of the definition "research potential of a student". *New in psychological and educational research*, 2012, vol.26, no. 2, pp. 119.
3. Bordovskiy G.A. Research activity is a decisive condition for improving the quality of training a specialist. *Training of a specialist in the field of education: Research activities in improving professional training*, 1999, vol. 7, pp. 3-7.
4. Chvanova M. S., Kotova N. A. Modeling of University's Educational Sphere Basing on Innovative Approach. *Bulletin of Tambov University*, 2016, vol. 155-156, no. 3-4, pp. 14-24.
5. Dalinger V. V. Methods of teaching mathematics. Search and research activity. Moscow: Yurayt Publishing House, 2019.
6. Dvoryatkina S. N., Smirnov E. I., Shcherbatykh S. V. Intellectual Management in Mathematical Modeling of Students' Research Activities. *Continuum. Maths. Informatics. Education*, 2020, vol. 19, no. 3, pp.48-61.
7. Dvoryatkina S.N., Melnikov R.A., Smirnov E.I. Technology of synergy manifestation in the research of solution's stability of differential equations system. *European Journal of Contemporary Education*, 2017, vol. 6, no. 4, pp. 684-689.
8. Isaev D. Sobolev A., Pak M. The Program of Extracurricular Activities in Chemistry: "Chemistry for Curious Schoolchildren". In: *EDULEARN20 Proceedings, 12th International Conference on Education and New Learning Technologies*, 2020, pp. 5787-5797.
9. Karpacheva I.A., Merenkova V.S., Dvoryatkina S.N. Managing the Learning Process: from Traditional Models to Intelligent Management. *Psychology of Education in a Multicultural Space*, 2020, vol. 51, no. 3, pp. 95-109.
10. Karpov A.O. Early Engagement of Schoolchildren in Research Activities: The Human Factor. In: Andre T. (eds) *Advances in Human Factors in Training, Education, and Learning Sciences. AHFE 2017. Advances in Intelligent Systems and Computing*, 2018, vol. 596, pp. 84-94. Springer.
11. Kennedy Baker J. M. Leading professional inquiry to develop students' research skills. University of Northern British Columbia, 2012. <https://doi.org/10.24124/2012/bpgub859>
12. Klarin M.V.: Characteristic features of the research approach: learning from problem solving. *School technology*, 2004, no. 1, pp. 11-24.
13. Makotrova G.V. Development of the research potential of schoolchildren in the context of the implementation of the Federal State Educational Standard. *Domestic and foreign pedagogy*, 2016, no. 2, pp. 201–205.
14. Obukhov A.S. Development of research activities of students. Moscow: National Book Center, 2015.
15. Ostapenko R.I. Managing the process of the formation of information and mathematical competence University students through self-diagnosis. *Economic Consultant*, 2014, vol. 5, no. 1, pp. 160-164.
16. Rishor, D. M. Redesigning Mathematics Tasks: A Tool to Increase Critical Thinking Skills. In: *Management Association, I. (Eds.), Research Anthology on Developing Critical Thinking Skills in Students*, 2021, pp. 687-711.
17. Rozenberg I.N. The complexity and complementarity. *Perspectives of Science & Education*, 2016, vol. 23, no. 5, pp. 7-10.
18. Sharshov, I.A. Estimation of the Efficiency of Scientific Research Activities in a Modern University. *Psychological-pedagogical Journal Gaudeamus*, 2014, vol. 23, no. 1, pp. 38-44.
19. Smirnov, E., Sekovanov, V., & Mironkin D. Multi-Stage Mathematic-Information Tasks as a Means to Develop Pupils' Creativity in Profile Mathematical Classes. *Yaroslavl pedagogical Bulletin*, 2014, vol. 2, no. 1, pp. 124-129.
20. Smirnov, E. I., Solovieva, A. A. Self-organization of Students' Research Activity of Psychological Profiles when Studying Mathematics. *Yaroslavsky Pedagogical Bulletin*, 2019, vol. 106, no. 1, pp. 70-88.
21. Smirnov, E.I., Tikhomirov, S.A., Dvoryatkina, S.N. Self-organization technology of student's mathematical activities based on intelligent management. *Perspectives of Science and Education*, 2020, vol. 45, no. 3, pp. 77–86.
22. Soboleva, E. V., Sokolova, A. N., & Votintseva, M. L. A model of cognitive activity in the Quandary text labyrinth digital environment. *Perspectives of Science and Education*, 2018, vol. 35, no. 5, pp. 221-230. DOI: 10.32744/pse.2018.5.25.
23. Soboleva, E. V., Sokolova, A. N. Forsyth-Model of Cognitive Activity in the Digital Environ ment of the Text Maze. *Modern Information Technologies and IT-Education*, 2019, vol. 15, no. 2, pp. 395-405. DOI: 10.25559/SITITO.15.201902.395-405
24. Wang, S. A Practical Research of Hybrid Learning Mode in Teaching and Research Activities. In: Cheung S.K.S., Fong J., Zhang J., Kwan R., Kwok L.F. (eds) *Hybrid Learning. Theory and Practice. ICHL 2014. Lecture Notes in Computer Science*, vol. 8595. Springer, Cham. https://doi.org/10.1007/978-3-319-08961-4_8
25. Zaporozhko, V.V., Parfenov, D.I., Zabrodina, L.S., Shardakov, V.M. Development and Research of a Simulation Model to Evaluate the Effectiveness of the Intelligent Cloud Educational Environment. *Modern Information Technologies and IT-Education*, 2019, vol. 15, no. 4, pp. 846-854. DOI: 10.25559/SITITO.15.201904.846-854
26. Zhuk, L.V. Adaptive Teaching Mathematics in Intellectual Educational Environment: History, Technology, Practice. *Psychology of Education in a Multicultural Space*, 2020, vol. 50, no. 2, pp. 66-75.

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 ID: 57193775897

Жук Лариса Викторовна
(Российская Федерация, Елец)

Доцент; кандидат педагогических наук; доцент
кафедры математики и методики ее преподавания
ФГБОУ ВО «Елецкий государственный университет им.
И.А. Бунина»

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 математики
Ярославский государственный педагогический
университет им. К. Д. Ушинского

E-mail: smiei@mail.ru
ORCID ID: 0000-0002-8780-7186
Scopus 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 ID: 57196473659

Information about the authors
Svetlana N. Dvoryatkina

(Russian Federation, Yelets)
Doctor of Pedagogical Sciences,
Professor, 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 ID: 57193775897

Larisa V. Zhuk
(Russian Federation, Yelets)
PhD in Education,

Associate professor, Mathematics and Methods of its
teaching Department
Bunin Yelets State University
E-mail: krasnikovalarisa@yandex.ru
ORCID ID: 0000-0002-5054-882X

Eugeniy I. Smirnov
(Russian Federation, Yaroslavl)
Doctor of Pedagogical Sciences,
Professor, 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 ID: 55734369900

Sergey V. Shcherbatykh
(Russia, Yelets)
Professor, Doctor of Pedagogical Sciences
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 ID: 57196473659