Crimson Publishers
Wings to the Research

Research Article

Methodological, Substantive and Procedural Aspects of Students' Research Skills Formation using Artificial Intelligence

Eugeny I Smirnov[1]*, Anna Yu Skornyakova[2] and Alexey A Olekhov[2]

[1]Department of Theory and Methods of Teaching Mathematics, Yaroslavl State Pedagogical University named after KD Ushinsky, Russia

[2]Department of Mathematics and Methods of Teaching Mathematics, Perm State Humanitarian Pedagogical University, Russia

ISSN: 2637-8078

***Corresponding author:** Eugeny I Smirnov, Department of Theory and Methods of Teaching Mathematics, Yaroslavl State Pedagogical University named after KD Ushinsky, Yaroslavl, Russia

Submission: July 21, 2025
Published: August 25, 2025

Volume 7 - Issue 4

How to cite this article: Eugeny I Smirnov*, Anna Yu Skornyakova and Alexey A Olekhov. Methodological, Substantive and Procedural Aspects of Students' Research Skills Formation using Artificial Intelligence. Significances Bioeng Biosci. 7(4). SBB. 000669. 2025.
DOI: 10.31031/SBB.2025.07.000669

Abstract

The symbiosis of conceptual, mathematical and computer modeling in natural science study of practice-oriented problems is becoming a leading trend in the effective development of students' thinking intellectual operations. Research problem: What are methodological, substantive and procedural aspects of students' research skills formation in natural science course of practice-oriented problems solving by an artificial intelligence using? Research objective: To identify the substantive and procedural mechanisms for students' research skills formation in natural science process of practice-oriented complex problems solving of artificial intelligence using by means of conceptual, mathematical and computer modeling. Materials and methods: Environmental and synergetic approaches, historiogenesis and technology of mastering complex systems and knowledge, methods of visual modeling and personal experiences founding during of natural science processes adaptation of practice-oriented tasks mastering, symbiosis of conceptual, mathematical and computer modeling in an architectures and functionality construction of neural networks and deep learning methods using. Results: Criteria and characteristics of "problem areas" in natural science aimed at subject and digital resources integration with potential of student's research skills development are identified; requirements for organization of student's search and research activities in digital educational environment are defined; didactic stages, principles and methods of multi-stage mathematical and information practice-oriented tasks implementation at natural science using generative and convolutional neural networks are identified.

Keywords: Practice-oriented tasks of natural science; Artificial neural networks; Research skills; Mathematical and computer modeling

Introduction

Student's research skills as a personal phenomenon are considered by educational scientists, as a rule at an operational component of cognitive activity methods [1,2]. However, some of psychologists as Zaporozhets VP, Leontiev AN, Salmina NG, Shadrikov VD and others ([3-5]) have shown that operationality in thinking does not always lead to the effective development of intellectual operations, personal abilities and creative thinking of students. At the same time, the formation of research skills as part of the implementation of an individual's scientific potential can become the basis for the formation of creativity phenomenon in the context of student's self-organization in search and research activities. Elements of the implementation of post-non-classical paradigm in the field of education showed that updating in teaching mathematics the technological concept of personality's self-organization and self-development in the course of research activities is capable of oriented not only to manifest the mechanisms and factors of philosophical phenomenon of fundamentality (persistent manifestation of virtual essence and synergy is realized by complex adaptive constructs of modern natural science knowledge), but also will grow the mathematical fundamentality quality of school education [6-8].

This concept of technology for mastering complex systems and knowledge is manifested in the interaction: Substantive aspect (practice-oriented tasks, complex systems and knowledge in science and real life exists-fractals, nonlinear dynamics, task cryptography, etc., university mechanisms of self-organization and order degree), procedural aspect decision (founding of personality experience, cultures dialogue and communication, becomes contexts mass, conceptual, mathematical and computer modeling exponential) and decision personality-adaptive aspect lyse (development of student's creativity and critical thinking, research skills, visual modeling promotion, motivational sphere development) professional standard [9,10]. The opportunities for student's self-organization in search and research activities are significantly increased through the digital environments using (in particular, artificial intelligence systems and artificial neural networks) due to the multiplicity of goal-setting, optimization of routine operations, generation of cognitive and ancillary products, interdisciplinary interaction, dialogue of cultures and interpretation of research results. The technology for identifying and exploring of complex knowledge "problem areas" in mathematics education allows for the integration of knowledge from various fields of science during the investigation of practice-oriented tasks in natural sciences by artificial intelligence using, creating a precedent for the activation and establishment of student's search and research activities and highlighting the synergistic effects in the process of complex knowledge mastering.

The "problem area" of mathematical education is a complex of substantial, procedural and personal-adaptive components of learning mathematics, based on uncovering contradictions and problems, deficits in the implementation of cognitive activities in a specifically defined educational area and aimed at searching for and investigating the essence of its complex educational elements. The technological nature of research into "problem areas" is based on the determination of criteria for their identification.

The following characteristics of criteria manifestation are present:

A. There is a clear inadequacy of perception in the dynamics of mathematical knowledge and procedures mastering, as well as an inability to transfer connections and procedures of educational elements in their specific manifestation to more general structure.

B. The process of an essence identifying of educational elements in complex 'problem areas' is based on the multiplicity of goal setting and the possibility of mathematical modeling of generalized construct and reasonable finiteness of the adaptation stages for generalized essence to the existing knowledge complex of "problem area".

C. Various exploratory trials are needed by information technologies using (experimental slices, varying conditions and parameters of the "problem area" functioning, comparative analysis of specific manifestations, computer modeling, analogies, analysis through synthesis, etc.).

D. The results of "problem area" study and the processes of interaction with it cannot be fully predicted; this interaction is characterized by the multiplicity of results including side effects.

The formation of student's research skills by artificial intelligence using also implies the basic requirements for organizing search and research activities (in extracurricular activities or in the system of additional mathematics education):

a) To present a repository of practice-oriented tasks generalized constructs in natural sciences and technologies by artificial intelligence using, to demonstrate methods of conceptual, mathematical and computer modeling, basic tools and libraries for information support in artificial neural networks generating, historiogenesis and applied effects, problematic areas of research and opportunities for adaptation to school mathematics and computer science (presentations, essays, lectures, computer design) [11,12].

b) Conduct a diagnosis of modal perception (sign-symbolic, image-geometric, verbal (historical-genetic context), concrete-activity (computational and algorithmic modeling), informational (computer modeling and design, programming, experimentation)) of student's representing systems and determine the priorities and inclinations of learners in search and research activities in digital environment of artificial intelligence (psychological methods, author questionnaires, surveys, observation, etc.) [13,14].

c) Implement the selection procedure and level of practice-oriented tasks content, ensure the pedagogical support in designing stages and forms, means and technologies for adapting specific tools and artificial intelligence libraries for small groups of learners based on visual modeling and the grounding of personal experience (pedagogical support, samples of technological approaches, data collection, thematic and technological plans, scenarios of multi-stage mathematical and information tasks, role distribution in small groups) [15,16].

d) Multiple goal-setting for an essence identifying of research procedures and practice-oriented tasks solving, an actualization of perception modalities in the founding and study of complex systems and knowledge generalized constructs through a visual-modeling, conceptual, mathematical and computer modeling [17,18].

e) Informatization and digitalization of search and research activities, tools and libraries mastering of an artificial neural network supporting, techniques actualizing for experimental mathematics methods mastering in "problem zones" of mathematics education and the symbiosis of mathematical and computer modeling in the interpretation of results [19,20].

f) Critical thinking and creativity in obtaining side products of research (identifying patterns, laboratory-calculation exercises, multi-stage mathematical-information tasks, searching for basins of attraction, attractors and iterative

procedures, bifurcation transitions and determining the dynamics of fluctuations).

The purpose of the study is to identify the substantive and procedural aspects of student's research skills forming through the solving of practice-oriented complex natural science tasks by an artificial intelligence using and means of conceptual, mathematical and computer modeling. The research materials are based on the self-organization and self-determination of students in research activities within the digital educational environment, historigenesis and the processes actualization of complex mathematical knowledge mastering, as well as the synergy manifestation in mathematics teaching mastering as effective mechanisms for personal development and enhancing of mathematical education quality. Environmental and synergetic approaches are implemented, along with methods of visual modeling and founding of personal experiences during the process's adaptation of practice-oriented natural science tasks mastering by artificial intelligence using in school mathematics.

Methods and Materials

The introduction of digital technologies into the process of mathematical education is a leading trend in the modernization of school education worldwide, including in Russia. According to the regulatory documents of UNESCO [21] and strategy for development of information society in Russian Federation for 2017-2030, dynamic development and dissemination of Artificial Intelligence (AI) technologies for specific methodological and educational tasks solving are anticipated. For example, the study by Singh V and Ram S [22] describes the didactic potential of generative AI tools for personalized learning enhancing. A number of researchers [23] propose an intelligent educational system based on artificial intelligence that provides personalized and adaptive learning in real-time. The system combines advanced models of deep learning and natural language processing, allowing for targeted feedback and dynamic adjustments the education triectories. The issues of AI using in the implementation of research projects are analyzed by Menshikov VV et al. [24]. The work [25] employed a deep learning methods based on convolutional neural networks, as well as the concept of "transfer learning". A neural network was trained on the ResNet 50 architecture, allowing for the accurate an identification of disease presence in the cassava plant from an image with an F1-score of 0.93.

We will adhere to the methodology of innovation implementation in AI using in natural sciences, in the context of conceptual, mathematical and computer modeling, based on the Hegelian triad (thesis-antithesis-synthesis):

A. Thesis (statement)-the implementation of complexity and coherence principles (coordinated action of different aspects of complexity mastering and realization of an effective feedback mode) in the integrity of procedures representing for researching practice-oriented tasks in natural sciences, in the actualization of an internal and external connections structure of complex system or object in digital educational environment.

B. Antithesis (justification)-the implementation of funding and fractality principles, historigenesis in identifying the essence of objects and research procedures in "problem areas" or the integrity of local attractors reflecting at complex system (knowledge and procedures) in the processes of mastering or evaluating the quality of student's research activities based on visual modeling and critical rationalism;

C. Synthesis (result)-the effectiveness of principles of student's creative self-organization implementing and verification of an inversive integrity reflection at complex system or object in the processes of mastering or assessing quality of student's research activities by using an innovative context.

Based on the specifics of extracurricular activities organizing (or additional education courses), project-based activities of students in practice-oriented tasks researching in natural sciences by AI using become a relevant means for research skills forming. Based on the studies by Kuznetsova et al. [18], we can identify the following distinctive features of project activities that have a positive effect on research skills formation: Focus of the activity on a final goal achieving; coordinated execution of interrelated actions by project participants; limited duration of time; outcome of the activity being a socially significant product. Thus, project activities include components such as: Analysis of an existing problem; goal setting; determining the means to achieve it; searching, analyzing and processing information; developing and implementing the project; individual and collective evaluation of the results obtained. Thus, we can conclude about the possibility of effective development of research skills through project activities by AI using (training in planning, development of skills in collecting and processing information, materials, ability to navigate the modern information space, development of analytical skills, training in independent knowledge construction, development of project development and presentation skills, fostering a free, creative personality of the learner).

Results

The choice of research object is a key stage in research process and can significantly influence on development of research skills among learners in a digital environment. One of most important modern tasks of personal development is mastering the content of mathematics as a complex knowledge, which involves the process of phenomenon actualizing for transitioning from development processes to self-development processes among learners. The ontological engineering of fostering educational motivation, cognitive and creative independence of learners in the "zones of nearest development" of Vygotsky LS is possible in the context of actualizing the precedent of overcoming difficulties in complex processes and knowledge mastering based on modern educational concepts and technologies. Such innovations are also related to an information environment using (including artificial intelligence) in practice-oriented tasks researching in natural sciences as complex knowledge, requiring the actualization of development processes of student's intellectual mental operations: Modeling, understanding, generating, abstraction and others, as well as avoiding routine

operations of cognitive activity, using specialized frameworks and libraries of Python. The function limit, Riemann hypothesis, surface area (Dubrovsky VA [26], Dvoryatkina EI et al. [27], fuzzy sets (Zade L [28]), chaos and catastrophes theory (Kolmogorov AN, Thom R et al.), fractal geometry (Mandelbrot VV [29], Barnslow M, Sekovanov VS et al. [8,30]), cellular automata, etc. can be studied on the basis of symbiosis of mathematical and computer modeling. However, the nonlinearity and unpredictability of modern world, differential of small fluctuations and prediction of bifurcation transitions to new levels of development create the new precedents.

The effect of not just development is necessary, but self-development of a personality based on the assimilation of complex knowledge:

a) The actualization of an individualization processes and overcoming (the founding of personal experience, etc. [31]);

b) Increasing the learning motivation of each student (emotional-practical effect);

c) Achieving of personalized understanding effect (visual modeling) during the mastery of complex knowledge generalized constructs (modern achievements in science) [32].

Let's list the main principles that should be taken into account when choosing the object of research:

A. The principle of complexity in digital context. The object of research should be relevant for the modern digital space. To achieve this, you can explore a complex natural science construct related to conceptual and mathematical modeling, social media, data collection and analysis, which helps to understand the current trends. For example, you can use an artificial intelligence or virtual reality as digital technologies;

B. The principle of data and resource accessibility. It is necessary to choose the objects for which there is a sufficient amount of open data and resources. The object should allow of various digital tools and technologies using, such as statistical programs, analytical platforms and data visualization tools;

C. The principle of emotional and applied effect and involvement. The research object should arouse the interest of students with the trends of practical orientation and symbiosis of conceptual, mathematical and computer modeling. The possibility of choosing of an individual research trajectory and taking into account the preferences of an individual can increase the motivation and creativity in research process, which is important for the formation of research skills;

D. The principle of interdisciplinarity and holomorphic. The choice of research objects that involve the integration of content and methods of several disciplines (for example, chemistry, biology, psychology, physics, mathematics, computer science).

Let's consider the methodology for implementing of multi-stage mathematical and information-based practical tasks for three thematic groups of students in order to carry out relevant research: Artificial intelligence, virtual reality and geoinformation technologies. When implementing artificial intelligence models, we used the TensorFlow and Keras libraries of Python programming language, which facilitate the description, training and operation of generative and convolutional neural networks. First, let's define the didactic stages sequence of conducting search implementing and research activities in small groups of students:

A. Stage 1. Preparatory. The content of this stage is aimed at: Analyzing the content and choosing the subtask of "problem zone", understanding the basic contradictions and functionality based on updating the repository of samples of practice-oriented tasks research in natural science by artificial intelligence using, identifying the features of generative artificial intelligence using and subtask historiogenesis in "problem zone" with a forecast of difficulties and stages in achieving the result; multiple by setting goals for the implementation of selected subtask (mathematical, informational, illustrative-graphic, historical-genetic); determining the characteristics of student's individual preferences in cognitive activity and functionality as part of a small group; expanding and mastering the database and knowledge; creating a creative environment (stimulating success situations, working in small groups, tolerance to uncertainty, willingness to discussions and multiple solutions to the problem, TV).

An important component is also the development of designing methodology and research behavior implementing among the students and means of pedagogical support based on innovative strategies in the context of visual modeling, educational motivation, insights and reflection. The presence of samples (at the standard and situational levels) for educational and scientific problems solving with details, analysis and features, as well as the presentation of research stages, methods and procedures;

B. Stage 2. Content and technology. The content of the stage is aimed at: Forecasting and introspection of an effectiveness of strategies and methods of solving, updating the stages and choosing the optimal path and multiple goal-setting solutions by generative artificial intelligence using; setting and searching for a plan to solve a research problem, collecting and a variety of forms and methods of presenting information, dynamics of studied processes, phenomena and factors; taking into account the probabilistic and improbable ability to set and solve problems in conditions of uncertainty; development of mathematical, historical, genetic and informational components of the project; development of methods and forms of scientific knowledge, creation of intellectual tension situations; construction of conceptual, subject, information and mathematical models, an analysis of ICT support tools possibilities. First step to update the necessary of subject-specific and informational knowledge, skills and activities and to ensure that students are motivated and committed to the goal of learning and cognitive activity is an involved the creating of mind maps and engaging in discussions about content of mathematics, historiography and an implementation of artificial intelligence tools to solve the problem.

C. Stage 3. Evaluation and correction. The content of this stage is aimed at: Determining of an intermediate subject, meta-subject and personal results; an identifying the dynamics of parameters and indicators of research process for both the teacher and the student (reflective skills, creativity, critical thinking, synergistic effects and self-actualization of the individual); correcting the mechanisms of innovation, stages and tools for generative artificial intelligence using: Founding of the individual's experience and visual modeling, contextual learning and dialogue of cultures; theoretical and empirical generalization of knowledge and methods recording and verification of procedures and algorithms and presentation of results.

D. Stage 4. Generalizing and transforming. The content of this stage is aimed at possibility of innovative constructs and procedures transferring obtained during the study to school practice of routine classes; an integration of personal preferences related to student's cognitive activity with achievements in small groups; an information exchanges and verification of project activities results; an identification of characteristics, parameters, and indicators of formation success of student's cognitive experience in generative artificial intelligence using; an interpretation of obtained results in order to obtain a new creative product, evaluation and forecast of further research, motivation for self-actualization.

Example 1. Some of directions of student's research activity:

a) Titanium sorting. Automation of sponge titanium sorting by artificial neural networks using with an integration algorithm for production.

b) Save Tomato. A Telegram bot for diagnosing tomato diseases by artificial neural networks using.

c) Spectacles. A software tool for automated typhlo translation by artificial neural networks using.

During the development of these and other products, students' research skills were formed both by solving a global research problem directly related to the project's goal and by solving on pre-prepared universal applied mathematical problems from the field of an artificial neural network development (Figure 1). Preparatory stage. In the process of an enterprise with specialists, the task was set to optimize the process of sorting titanium sponge by artificial neural networks using. Sorting titanium sponge or more precisely, removing of defective samples from the conveyor belt, is an important stage of production. At this stage, about 100 employees are involved. On each belt, sorting is performed manually by 5 specialists.

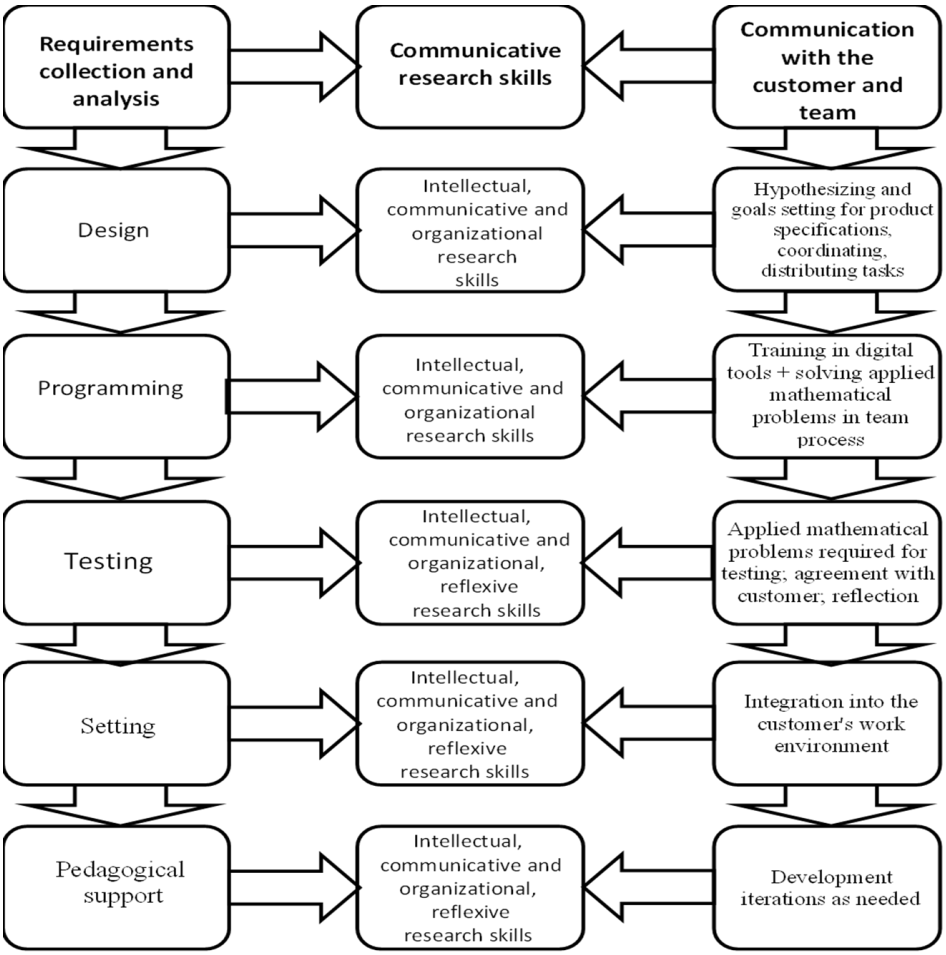

Figure 1: Formation of research skills in the process of developing a digital product.

In order to use the human resources more efficiently, reduce the negative impact on an employee's health and increase the sorting speed, it was decided to study the possibility of titanium sponge sorting by artificial neural networks using. According to the requirements of synergetic approach, our project should be carried out by students independently in the conditions of an open information and educational environment, exchange of information and dialogue of cultures, information support, network and computer modeling and interaction. Therefore, the teacher only tells students about some methods of formulating goals, setting hypotheses and guides them, stimulating them to take responsibility in different aspects of the project for competent distribution of tasks.

Mathematical modeling in the process of problems solving from the field of "Data analysis and preprocessing" (entry-level problems, examples)

Problem 1: Normalization of data.

Condition: To train a neural network, the pixel brightness values of titanium images (from 0 to 255) must be normalized to the range [0;1]. Write down the normalization formula. Calculate the normalized values for pixels with brightnesses of 0, 127 and 255. Why is normalization important for neural networks?

The sections of school mathematics used are: Arithmetic-working with numbers, division and conversion to percentages; algebra-linear data transformation (normalization formula).

Problem 2: Filling in the missing data filling in missing data.

Condition: Three values are missing in the data on size of titanium particles. The known sizes (in "mm") are 5.2, 4.8, ?, 5.5, ?, 5 and ?. Fill in the missing values using the arithmetic mean of known values. What other methods can be used to fill in missing values?

The sections of school mathematics used are: Statistics-arithmetic mean, median; arithmetic-calculations with decimal fractions.

Problem 3: Splitting data into training and test sets.

Condition: The project contains 5,000 images of titanium. To train the neural network, 80% of the data is allocated to training set and remaining 20% is allocated to test set. How many images are there in each set? Why is it important to separate the data?

The sections of school mathematics used are arithmetic: Percentages and proportions.

Problem 4: Statistical analysis.

Condition: The thickness of 10 titanium samples was measured (in "mm"): 2.3, 2.5, 2.4, 2.6, 2.5, 2.7, 2.4, 2.3, 2.6, 2.5. Find the mode, median and mean. Calculate the variance and standard deviation.

The sections of school mathematics used are: Statistics-mode, median, average, variance, standard deviation; arithmetic-working with decimal fractions, square roots.

For advanced students, you can offer more complex tasks presented in the form of cases. Below are examples of tasks encountered when neural network with optimizing parameters.

Example 1. Students of grades 9-11 in the system of additional mathematical education completed the project "Creation and training of artificial neural network models for classification of various tomato diseases". The source material was pre-classified images with various types of tomato leaf diseases, as well as images of completely healthy leaves, published in the public domain on the Kaggle platform (kaggle.com). An open dataset consisting of 17,000 images was used (Figure 2).

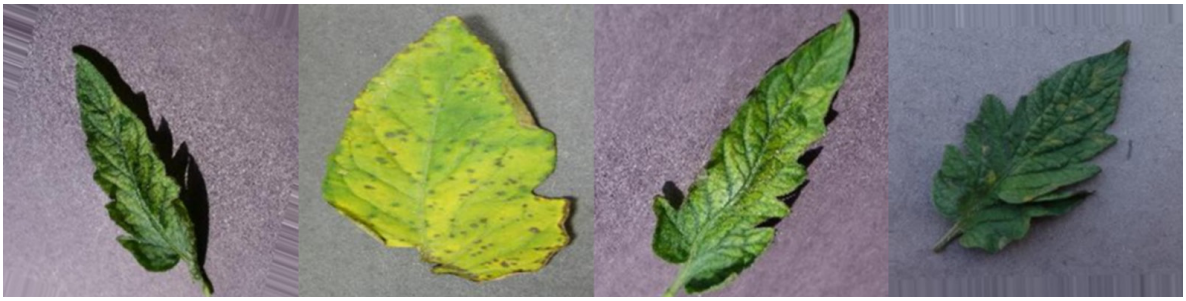

Figure 2: Examples from images dataset.

The described set was divided into the following samples: Training: 10 classes of 800 photos; validation: 10 classes of 200 photos; test: 10 classes of 700 photos. Independently designed networks consisted on pairs of convolutional layers combinations with a convolutional kernel size of (3.3) with layers of dimensionality reduction by maximum element on two times, followed by straightening and processing in fully connected layers.

The optimization algorithm "Adam" was used to train the neural network. The choice of this algorithm is justified by the following advantages: Support for learning rate for each parameter, typical for deep neural networks, especially for computer vision tasks; adaptation of learning rates for each parameter based on the average value of last gradient values for the weight. The value "lr=0.0001" was empirically selected as setting for the hyperparameter of training step. The output layer consisted of 10 neurons with the activation function "Softmax". The best result was achieved by fully connected layers retraining without changing the parameters of convolutional layers. After retraining, classification accuracy

of 95% was achieved on a test sample of 7,000 photographs. The resulting network model was integrated into a bot in telegram messenger. The software product determines the leaf disease in resulting image, lists the main signs of this disease, and also gives the recommendations for treatment. In addition to diagnostic functions, bot saves all received information, including the location of the bush, in the greenhouse disease database.

Discussion

The use of artificial intelligence in practical problems solving is widely represented in scientific publications. For example, in [33], a neural network was developed that can detect the grain diseases at an early stage. This recognition method was implemented by researchers as a bot called @wheat_healthy_bot on the telegram platform, which allows for the assessment of plant damage in the field. Additionally, scientists studied the application of deep learning methods for an automatic classification and detection of cassava diseases based on leaf images. They used deep learning techniques such as convolutional neural networks and the concept of "transfer learning." New directions in science are opening up with the research of AlphaFold and AlphaFold2 artificial intelligence by DeepMind, which were created to predict the three-dimensional structure of a protein [34]. Neural network technologies for developing project and student's research skills in studying morphology and linguistics are considered in the works [35,36]. A feature of this research is the identification of methodology and techniques of student's research skills forming in solving of practice-oriented tasks in natural science by artificial intelligence using.

Conclusion

Digital educational environments in the development of mathematics and natural sciences in school education in Russia are becoming a leading factor in the development and competitiveness of an individual in today's high-tech and unpredictable world. Students are now able to master of an artificial intelligence in education and deep machine learning methods as tools for solving and researching practical science problems through the analysis of large data sets, an automation of routine processes, self-organization and the manifestation of synergistic effects. The study builds the strategies for digital transformation of education, a unity of scientific achievements and education and the priority of personal values in the process of teaching mathematics and natural sciences at school, based on the actualization of models and standards for artificial intelligence using in solving practical problems in natural sciences. It has been shown that the formation of students' research skills is based on the actualization of focus centers of cognitive transformations of an individual: Visual-digital and practice-oriented models of complex systems and knowledge, an emotional response to applied effects and prospects of higher education, cultures dialogue in the study of subject-specific education "problem areas" and possibility of generating artificial neural networks in applied issues of natural science. The results of the study confirm that the using of neural network technologies in project solution of practice-oriented problems of natural science can significantly improve the quality of education and contribute to the formation of student's research skills.

Acknowledgement

The publication was carried out as part of a state assignment with Ministry of Education of Russian Federation on the topic "Development of the content and procedural components of the system student's research skills forming during their project activities by artificial intelligence using (No. OTGE-2025-0017, 1024122400004-0-5.3.1).

References

1. Wessels I, Rueß J, Gess C, Deicke W, Ziegler M (2021) Is research-based learning effective? Evidence from a pre-post analysis in the social sciences. Stud High Educ 46(12): 2595-2609.
2. Kumar R, Chadha N (2024) Mastering research skill. Misha books, India, p. 216.
3. Zvonova EV, Salmina NG (2018) Development of symbolic function in the concept of dialogue cultures. Moscow University Psychology Bulletin 2018(2): 24-39.
4. Salmina NG (1994) Vygotsky's concept and the development of symbolic function. Psychology 5: 69-78.
5. Shadrikov VD (2022) Systemogenesis of human mental qualities. Institute of Psychology RAS, Publishing House, Russia.
6. Dvoryatkina SN, Shcherbatykh SV, Smirnov EI, Khizhnyak AV, Zhuk LV (2021) Open innovation model of student's research activities. Journal of Teacher Education for Sustainability 23(2): 77-90.
7. Smirnov EI, Bogun VV, Uvarov AD (2016) Synergy of mathematical education: An introduction to analysis. Publishing House Kanzler, Portugal, p. 216.
8. Sekovanov VS (2016) Elements of the theory of discrete dynamical systems. Publishing House Lanier, England, p. 180.
9. Ostashkov VN, Smirnov EI, Belonogova EA (2016) The synergy of education in the study of attractors and basins of nonlinear maps attraction. Yaroslavl Pedagogical Bulletin 6: 146-156.
10. Smirnov EI (2012) Funding experience in professional training and innovative activities of teachers. Publishing House Kanzler, Portugal, p. 654.
11. Hyunsuk H (2022) The utility of receiver operating characteristic curve in educational assessment: Performance prediction. Mathematics 10(9): 1493.
12. Sekovanova LA, Sekovanov VS, Smirnov EI, Shchepin RA (2025) Developing students' creativity in studying multi-stage mathematical-informational tasks of fractal geometry. Continuum Mathematics Informatics Education 38(2): 53-70.
13. Wei P, Yi X, Weili G, Haiying S (2024) Risk evaluation of elevators based on fuzzy theory and machine learning algorithms. Mathematics 12(1): 113.
14. Morgacheva NV, Shcherbatykh SV, Sotnikova EB (2023) Assessment and analysis of the level of natural science literacy of students. Perspectives of Science and Education 62(2): 66-84.
15. Maaliw RR (2020) Adaptive virtual learning environment based on learning styles for personalizing e-learning system: Design and implementation. International Journal of Recent Technology and Engineering 8(6): 3398-3406.
16. Dvoryatkina SN, Smirnov EI (2017) Evaluation of the synergetic effects of integrating knowledge and activity based on computer modeling. Proceedings International Scientific and Practical Conference "Modern Information Technologies and IT Education", Moscow, Russia, pp. 35-42.

17. Smirnov EI, Burukhin SF (2017) The complexity of tasks and the synergy of mathematical education. Proceedings international scientific and practical conference "Tasks in teaching mathematics, physics and computer science: Theory, experience and innovations: Proceedings of the international scientific and practical conference dedicated to the 125th anniversary of Larichev PA", Vologda, Russia, pp. 11-17.

18. Kuznetsova IV, Napalkov SV, Smirnov EI, Tikhomirov SA (2020) Introduction to project activities. Synergetic Approach, Saratov University Publishing House, Russia, p. 166.

19. Smirnov AV, Fionov AS, Gorbachev IA, Shamsutdinova ES, Kuznetsova IE, et al. (2021) Using additive technologies to create broadband antennas with fractal geometry. Radioelectronics Nanosystems Information Technologies 13(4): 427-434.

20. Lei Q, Yingqiu Z, Shaonan L, Xingjian Z, Yining Z (2025) The shapley value in data science: Advances in computation, extensions and applications. Mathematics 13(10): 1581.

21. (2015) UNESCO science report: Towards 2030. UNESCO Publishing, France, p. 47.

22. Sysoyev PV, Evstigneev MN, Sorokin DO (2025) Structural model of pre-service teacher training based on artificial intelligence technologies. Perspectives of Science and Education 75(3): 139-155.

23. William V, Diego BF, Alexandra MN, Aracely MN (2025) Adaptive intelligent tutoring systems for STEM education: Analysis of the learning impact and effectiveness of personalized feedback. Smart Learning Environments 12(41): 569.

24. Menshikov VV, Savin NM (2024) Artificial intelligence in research projects: A master class for innovators. Computer Science at School 23(6): 18-31.

25. Tereshchenko SN, Perov AA, Osipov AL (2021) Detection of cassava diseases using computer vision methods. Siberian Journal of Natural Sciences and Architecture 13(1): 144-155.

26. Dubrovsky VN (1978) In search of area definition surfaces. Quantum (5): 31-34.

27. Dvoryatkina S, Smirnov E, Martyushev N, Shcherbatykh S (2023) Software package to support students' research activities in the hybrid intellectual environment of mathematics teaching. Mathematics 11(4): 952.

28. Zade LA (1988) Fuzzy logic. IEEE Transactions on Computers 21(4): 83-93.

29. Mandelbrot VV (2002) Fractal geometry of nature. Institute for Computer Research, Moscow, Russia, p. 656.

30. Uvarov AD, Smirnov EI, Smirnov NE (2017) Computer design of the growth of the lateral surface areas of the black cylinder in the irregular case. Eurasian scientific bulletin 30(8): 35-55.

31. Xian Y, Wang X (2021) Fractal sorting matrix and its application on chaotic image encryption. Information Sciences 547: 1154-1169.

32. Mingxing T, Quoc VL (2021) EfficientNetV2: Smaller models and faster training. International Conference on Machine Learning, Computer Vision and Pattern Recognition, Cornell University, USA.

33. Genaev MA, Skolotneva ES, Gultyaeva EI, Orlova EA, Bekhtold NP, et al. (2021) Automatic identification of wheat fungi diseases using a convolutional neural network. The 6th International Scientific Conference "Plant Genetics, Genomics, Bioinformatics and Biotechnology", Novosibirsk, Russia, p. 80.

34. Senior AW, Evans R, Jumper J, Kirkpatrick J, Sifre L, et al. (2020) Improved protein structure prediction using potentials from deep learning. Nature 577(7792): 706-710.

35. Starovoyt AV, Cherpakova NA (2023) Using neural networks in general education organizations to improve the quality of education. Information and Education: The Limits of Communication 23(15): 169-170.

36. Burnashev RF, Anvarova LA (2024) Application of neural networks in automatic translation and natural language processing. Universe: Technical Sciences 121(4): 40-43.