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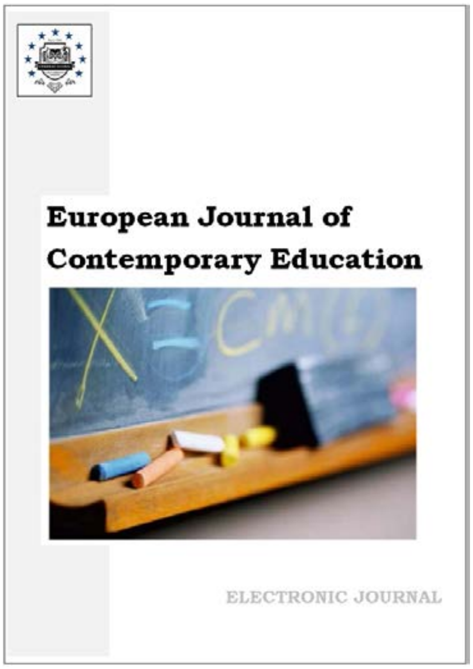

Methodological and Procedural Aspects of Student's Research Skills Formation by Artificial Intelligence Using

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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 aspects 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.

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1. 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 (Wessels, 2021; Kumar, 2024). However, some of psychologists as V.P. Zaporozhets, A.N. Leontiev, N.G. Salmina, V.D. Shadrikov and others (Zvonova, 2018; Salmina, 1994; Shadrikov, 2022) 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.

Recent advances in educational theory demonstrate that implementing the post-non-classical paradigm in teaching mathematics can significantly enhance the quality of school-level mathematical education. This is achieved through a technology-driven approach to learners' self-organisation and self-development during research activities. The paradigm shift enables: revealing mechanisms and factors underlying the philosophical phenomenon of fundamentality (persistent manifestation of virtual essence); realising synergy via complex adaptive constructs in modern natural science knowledge; elevating the mathematical fundamentality of school education (Dvoryatkina, 2021; Smirnov i dr., 2016; Sekovanov, 2016). This approach to mastering complex systems and knowledge operates through the interplay of three interconnected aspects: substantive aspect – engagement with practice-oriented tasks that reflect real-world complexity; an exploration of complex systems and knowledge domains such as: fractals; nonlinear dynamics; cryptographic problems; integration of self-organisation mechanisms (drawing on Stepin's theoretical framework); procedural aspect – founding of personal experience by building knowledge through iterative, experiential learning; fostering dialogue between cultures by connecting mathematical, scientific, and humanities perspectives; promoting effective communication in research contexts; an implementing conceptual, mathematical, and computer modelling techniques (Ostashkov i dr., 2016; Smirnov, 2012); person-adaptive aspect by developing creativity and critical thinking skills; an enhancing research competencies from hypothesis formulation to data analysis; an applying visual modelling to make abstract concepts tangible; strengthening the motivational sphere as fostering intrinsic interest in mathematical inquiry.This tripartite framework: bridges abstract mathematical theory with real-world applications; supports differentiated instruction by addressing individual learners' cognitive and motivational profiles; cultivates adaptive expertise as an ability to transfer knowledge across novel contexts; an aligns with contemporary demands for STEM literacy and innovation-driven economies. This approach not only deepens conceptual understanding but also prepares students for the complexities of 21st-century scientific and technological challenges.

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 an ancillary product, interdisciplinary interaction, dialogue of cultures, and interpretation of research results. The technology for an identifying and an exploring of «problem areas» in mathematics education enables to interdisciplinary knowledge integration by using of merging insights from multiple scientific fields when addressing practice-oriented natural science tasks; AI-driven investigation by leveraging artificial intelligence tools to analyse and solve complex problems; an activation of student research with stimulating independent inquiry and exploratory activities; synergistic learning effects with enhancing knowledge acquisition through combined cognitive and technological approaches. A «problem area» emerges through an uncovering contradiction by an identifying inconsistencies or gaps in current understanding; revealing cognitive deficits by detecting weaknesses in students' thinking processes; an investigating complex element by an examining intricate aspect of educational content that resist conventional approaches. Successful implementation leads to: enhanced mathematical literacy as deeper grasp of abstract concepts; improved problem-solving skills for ability to tackle complex, interdisciplinary challenges; an increased student autonomy by confidence in independent research and inquiry; strengthened cognitive flexibility with capacity to adapt the strategies across different contexts. The technological nature of research into "problem areas" is based on the determination of criteria for their identification.

The methodology for identifying and examining «problem areas» in mathematics education offers a powerful framework for integrating of an interdisciplinary knowledge when tackling practice-oriented natural science tasks particularly through the use of artificial intelligence (AI). This approach: creates conditions for activating students' search and research activities; reveals synergistic effects in mastering complex knowledge; fosters deeper engagement with multifaceted educational content. A «problem area» represents an integrated complex comprising three core components: substantial as the body of knowledge, concepts, and theories relevant to a specific mathematical domain; procedural as the methods, algorithms, and operations used to process and apply this knowledge; personal-adaptive as the learner's individual cognitive strategies, motivational factors, and adaptive mechanisms in knowledge acquisition. This complex emerges through: an uncovering internal contradictions and unresolved issues within a defined educational domain; an identifying cognitive deficit as gaps or inefficiencies in students' thinking processes; an investigating the essence of complex educational elements that challenge conventional learning approaches.

The research process is grounded in a systematic methodology for identifying and analysing these areas, which hinges on defining clear criteria for detection. Key technological aspects include: data-driven analysis as leveraging AI to process educational datasets (student performance, error patterns, cognitive load metrics); pattern recognition by using machine learning to detect recurring challenges or knowledge gaps; dynamic modelling as simulating how students interact with complex concepts to pinpoint friction points; criterion development as an establishing measurable indicators (e.g., frequency of errors, time to mastery, conceptual coherence) to define what constitutes a «problem area». By applying this technology, educators can achieve: enhanced interdisciplinarity as the bridging mathematics with natural sciences, computer science, and cognitive psychology; personalised learning pathways as an adapting instruction to address individual students' cognitive bottlenecks; proactive intervention as an anticipating and mitigating knowledge gaps before they hinder progress; research skill development as an empowering students to become active investigators of mathematical phenomena.

Characteristics of criteria manifestation research in «problem area»

The analysis of «problem areas» in mathematics education reveals several defining characteristics that shape both the challenges and methodologies involved. Below are the key manifestations:

1. Inadequacy of perception and transfer limitations. A core issue is the systemic insufficiency in how learners: perceive the dynamic nature of mathematical knowledge acquisition; master procedural components of learning; transfer of specific connections and operations (from concrete educational elements) to higher-order conceptual structures. This limitation manifests as: fragmented understanding of interrelated concepts; difficulty generalising of problem-solving strategies; an inability to see the overarching patterns across mathematical domains.

2. Essence identification through multi-goal modelling. The process of uncovering the essence of educational elements within «problem areas» relies on: multiplicity of goal setting by exploring multiple objectives and pathways simultaneously; mathematical modelling of generalised constructs on creating abstract representations that capture core principles; finite adaptation stages by structuring progressive steps to align new knowledge with existing cognitive frameworks.

3. Exploratory trials via information technologies. Effective investigation requires technology-mediated experimentation, including: experimental slices as segmented analysis of problem components; parameter variation as testing different conditions within the «problem area»; comparative analysis as contrasting specific manifestations across contexts; computer modelling as simulating complex interactions; analogical reasoning by drawing parallels with known systems; analysis through synthesis by building understanding by reconstructing systems from parts.

4. Unpredictability and multiplicity of outcomes. Interactions with «problem areas» are inherently non-linear and characterised by: unpredictable results so an outcome cannot be fully anticipated due to system complexity; multiple potential pathways as diverse solutions may emerge from the same initial conditions; side effects as an unexpected cognitive or conceptual shifts may occur during exploration.

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 an additional mathematics education):

– This section outlines two interconnected strategies for enhancing mathematics and computer science instruction through the artificial intelligence (AI) and cognitive profiling: to create a structured resource bank that bridges theoretical knowledge with real-world applications in natural sciences and technologies as repository of practice-oriented tasks and modelling tools curated collection of interdisciplinary problems (physics, biology, engineering) solvable via mathematical and computational methods; AI-enhanced problem formulations (e.g., data-driven scenarios, simulation-based tasks). Modelling methodologies: conceptual modelling as frameworks for abstracting real-world phenomena; mathematical modelling as equations, functions, and algorithms for problem representation; computer modelling as a software implementation (Python, MATLAB, Wolfram Mathematica). Delivery formats: multimedia presentations; research essays; lecture series; computer-aided design projects (Hyunsuk, 2022; Sekovanova, 2025);

– To assess students' cognitive preferences and tailor AI-supported research activities accordingly to diagnosis of modal perception in digital Learning environments. Perception modalities analysed: sign-symbolic preference for algebraic notation, formal logic, and symbolic reasoning; strengths in equation manipulation and abstract pattern recognition; an image-geometric and visual-spatial reasoning (graphs, diagrams, 3D models), aptitude for geometric proofs and data visualisation; verbal (historical-genetic context) narrative understanding of concept development; interest in the history of mathematics and science; concrete-activity (computational and algorithmic) hands-on problem-solving via coding and simulations, procedural thinking (step-by-step execution); an informational (computer modelling and design) proficiency in programming and digital tool use, data analysis and system design skills (Wei Pan, 2024; Morgacheva, 2023);

– To adaptive the design of practice-oriented tasks (differentiated selection of practice-oriented tasks based on learners' proficiency levels; pedagogical scaffolding by structured support in designing learning stages, forms, and tools; AI-integrated adaptation by customising artificial intelligence libraries for small learner groups; an experiential grounding by anchoring knowledge in personal experience through visual modelling (Maaliw, 2020; Dvoryatkina, 2017);

– To define of multi-goal research framework on flexible methodology for investigating complex educational phenomena: multi-dimensional goal setting with simultaneous pursuit of complementary research objectives; an essence identification on uncovering core principles in research procedures and task solutions; modality activation by engaging diverse perception channels; conceptual integration by synthesising visual, conceptual, mathematical, and computational modelling approaches (Smirnov, 2017; Kuznetsova, 2020);

– To enhance of mathematical inquiry by digital transformation of research activities of modern technologies leveraging: informatization by integrating digital tools into research workflows; neural network support by mastering AI libraries for data analysis and pattern recognition; experimental mathematics by an applying computational methods in «problem zones»; modelling symbiosis by combining mathematical and computer-based approaches for result interpretation (Smirnov i dr., 2021; Lei Qin, 2025);

– To develop of cultivating critical thinking and creativity by using higher-order cognitive skills through: pattern identification with recognising structural regularities in mathematical phenomena; laboratory-calculation exercises on hands-on exploration of mathematical concepts; multi-stage tasks as progressive problem-solving challenges integrating mathematics and informatics; dynamic systems analysis as studying mechanism: basins of attraction; attractors and iterative procedures; bifurcation transitions; fluctuation dynamics. This framework aligns with contemporary demands for: STEM education; 21st-century skill development; lifelong learning competencies.

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.

2. Materials and methods

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 (UNESCO Science Report, 2015) 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 V. Singh and S. Ram (Sysoyev, 2025) describes the didactic potential of generative AI tools for personalized learning enhancing. A number of researchers (William Villegas-Ch, 2025) 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 V.V. Menshikov and N.M. Savin in (Menshikov i dr., 2024). The work (Tereschenko, 2021) 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.

An innovation implementation in AI-Enhanced natural sciences: A Hegelian framework

We propose a methodology for integrating artificial intelligence into natural science education through conceptual, mathematical, and computational modelling. This approach is grounded in the Hegelian dialectical triad (thesis-antithesis-synthesis), which structures the innovation process into three interdependent phases.

1. *Thesis: Establishing Foundational Complexity*

The initial phase emphasises: complexity and coherence principles as an ensuring harmonised interaction between diverse aspects of knowledge acquisition; feedback mechanisms as an implementing dynamic, responsive evaluation loops in research processes; systemic integrity as maintaining holistic procedures for investigating of practice-oriented natural science tasks; structural connectivity as mapping both the internal and external relationships within complex systems or objects in digital learning environments.

This stage creates a stable framework where learners engage with multifaceted scientific concepts while developing systematic analytical skills.

2. *Antithesis: challenging and deconstructing assumptions*

The second phase introduces critical examination through: funding and fractality principles as dissecting knowledge into scalable, self-similar components; historigenesis analysis as tracing the evolutionary development of research objects and methodologies; problem-area focus as an identifying local attractors (key focal points) within complex knowledge systems; visual modelling and critical rationalism as an evaluating research quality via representational tools and logical scrutiny.

Here, learners confront contradictions and ambiguities in scientific knowledge, fostering deeper critical thinking and methodological flexibility.

3. *Synthesis: creative integration and validation*

The final phase achieves: creative self-organisation as an empowering students to design and implement innovative research approaches; an inversive integrity reflection as an examining complex systems from multiple perspectives to reveal hidden patterns; an innovative context application as deploying AI tools to assess and enhance research quality; holistic mastery as synthesising knowledge across conceptual, mathematical, and computational domains.

This culmination transforms by fragmented understanding into a cohesive, an adaptable knowledge framework, where students demonstrate both analytical rigour and creative problem-solving. 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 I.V. Kuznetsova, S.V. Napalkov, E.I. Smirnov, S.A. Tikhomirov, 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.

Historiogenesis, complex systems, and AI-driven knowledge mastery in education

The integration of artificial intelligence (AI) into applied research necessitates two foundational components: historiogenesis (evolutionary analysis of knowledge development); technologies for complex systems mastering (Sysoyev et al., 2025; Dvoryatkina et al., 2023)); nature of complex knowledge (complex knowledge emerges from intricate systems, generating multilayered hierarchies and challenges). These can be addressed through: development of generalised mathematical and computational constructs; analysis of semiotic and informational linkages in nonlinear systems (real and virtual); integration of descriptive and computational diversity within knowledge frameworks (Uvarov i dr., 2017). A synergistic paradigm plays a pivotal role by enabling: creation of personalised learning environments; integration of educational elements across multiple levels; fostering self-organisation among learners.

This approach, advanced by scholars like S.P. Kurdyumov, G.G. Malinetsky, I.R. Prigozhin, E.I. Smirnov, and G. Haken, relies on interdisciplinary collaboration to generate novel, higher-order structures with emergent properties (Dvoryatkina et al., 2021). Intelligent management systems by including hybrid neural networks transform mathematics education by introducing adaptive, data-driven of pedagogical frameworks. Their impact is realised through three foundational principles: openness to external influences the integration of real-world data and interdisciplinary knowledge; responsiveness to evolving of educational needs and technological advancements; flexibility in adapting instructional strategies to contextual variables. Synthesis of mathematical and computational modelling bridging abstract mathematical theory with algorithmic implementation; an enabling simulation of complex systems for deeper of conceptual understanding; supporting of an evidence-based decision-making in instruction. *Key characteristics and their educational implications* include: dynamic cognitive processes these reflect the non-linear nature of learning: stochastic transitions with random fluctuations in attention and comprehension that require adaptive scaffolding; threshold effects on critical points where incremental input triggers of qualitative understanding shifts; bifurcation transitions with moments when learners diverge into distinct cognitive pathways (e.g., visual vs. algebraic reasoning); fluctuation-driven creativity by an emergent problem-solving strategies arising from cognitive variability. Also an adaptive goal-setting a multi-layered approach to learning objectives: multi-objective computer modelling by simultaneous pursuit of conceptual mastery, procedural fluency, and metacognitive development; personalised data processing as tailored analysis of diverse input types: visual (graphs, diagrams); textual (problem statements, explanations); signal-based (interactive simulations); tabular (structured datasets); feedback loops by continuous adjustment of tasks based on performance metrics. Intelligent management in mathematics education represents a paradigm shift from static instruction to dynamic, adaptive systems. This approach does not replace human pedagogy but augments it with precision tools for understanding and supporting the intricate processes of mathematical cognition (Dvoryatkina et al., 2023).

The theory of founding: phenomenological foundation (German: Fundierung) denotes an ontological justification by using the principle that complex entities derive from simpler foundational elements. In pedagogy, V.D. Shadrikov and E.I. Smirnov (2002) introduced personal experience founding as a process enabling: gradual deepening of scientific knowledge; expansion of cognitive actions; formation of a holistic knowledge cluster (founding spiral). In this study, founding manifests through: symbiosis of conceptual, mathematical, and computational modelling; AI-supported architectures (e.g., neural networks) (Smirnov, 2012); visual modelling: an innovative construct serves as a triadic interactive system (personality-model-understanding) aimed at: elucidating object/action essences; structuring of cognitive procedures; an enhancing comprehension through staged representation.

Core elements include: student centring: integration of perceptual, cognitive, reflective, emotional-volitional, motivational, and creative substructures; model adequacy: an alignment between a priori models and cognitive outcomes; sign system interplay: verbal, symbolic, graphic, digital, and concrete-activity modalities; knowledge stability: coherence of mathematical, scientific, and informational domains; perceptual sensitivity: responsiveness to diverse of input modalities; cognitive activation: engagement of higher-order thinking processes (Smirnov, 2012).

An environmental and synergetic approaches in project development are the most important component of students' cognitive activity content in supporting context of an artificial intelligence systems. It is essential to master and identify the essence and synergy of complex integration processes, applied scenarios, and procedures in the context of building stages and hierarchies, multiple goal-setting and analysis of side solutions, finding bifurcational transitions and basins of attraction in studied processes, and coordinating information flows in the creation of new product. The term "synergy" (synergeia (Greek) – joint action, cooperation) was proposed in the late 1960s by German chemist and theoretical physicist from Stuttgart (Germany) G. Haken. The subject of synergetics is complex self-organizing open systems that are far from equilibrium conditions (when there is a nonlinear exchange of matter, energy, and information). Synergy of processes of complex multi-stage practice-oriented tasks solving (Sekovanova i dr., 2025):

– Adaptation of modern achievements in science based on a dialogue of mathematical, informational, and natural science cultures;

– Actualization of synergistic effects in the deployment of educational content;

– Multiple goal-setting, stochastic planning, and emergent results of problem-solving;

– Visual modeling of bifurcation transitions of studied solutions to generalized hierarchical levels of order and organization.

– Identifying attractors and basins of attraction for basic constructs of mathematical knowledge, scenarios, and procedures.

Thus, we can conclude about the possibility of effective development of research skills through project activities with methodological and procedural aspects of student's research skills formation by AI using (training in planning of conceptual, mathematical and computer modeling symbiosis in an architectures and functionality construction of neural networks, development of visual modeling and personal experience founding 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 environmental and synergetic approaches in project development and presentation skills in historiogenesis and technology of mastering complex systems and knowledge adapting for fostering a free, creative personality of the learner).

3. 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.

Ontological engineering of learner development: motivation and cognitive autonomy in Vygotsky's framework

The cultivation of educational motivation, cognitive independence, and creative autonomy within learners are particularly lie in L.S. Vygotsky's «zones of proximal development» which requires deliberate strategies to help students overcome challenges inherent in mastering complex knowledge. This approach aligns with contemporary pedagogical paradigms and leverages advanced educational technologies. A pivotal component of this framework is the strategic use of information environments, including an artificial intelligence (AI), in practice-oriented research within natural sciences. Such disciplines often involve an intricate knowledge system that necessitate: development of an advanced intellectual operations (e.g., modelling, comprehension, idea generation, abstraction); minimisation of routine cognitive tasks through specialised computational tools (e.g., Python libraries and frameworks). Complex mathematical and scientific concepts can be effectively explored through a synergistic blend of mathematical and computational modelling. Notable examples include: function limits and Riemann hypothesis as foundational elements in advanced mathematical analysis; surface area calculations (as studied by G. Schwartz, V.A. Dubrovsky, E.I. Smirnov, S.N. Dvoryatkina, et al. (Dubrovsky, 1978; Uvarov, 2017); fuzzy set theory (pioneered by L. Zadeh and A. Kofman (Zadeh, 1988)) as a framework for handling uncertainty and imprecision; chaos and catastrophe theories (developed by A. N. Kolmogorov, R. Thom, and colleagues) as tools for analysing nonlinear dynamic systems; fractal geometry (explored by B. Mandelbrot, M. Barnsley, V.S. Sekovanov, et al. (Mandelbrot, 2002; Dvoryatkina, 2023) as a method for describing self-similar structures across scales; cellular automata for discrete models used to simulate complex systems.

The inherent unpredictability of contemporary reality marked by sensitivity to minor fluctuations and potential for bifurcation transitions to new developmental stages which generates a novel pedagogical challenges. These conditions demand an innovative approach to knowledge construction and transfer, emphasising adaptability and foresight. Rather than focusing solely on linear development, the educational process should prioritise self-development through deep engagement with complex knowledge. Critical objectives include: an individualisation processes as cultivating personal experience and an agency in learning (as discussed in (Xian, 2021)); an enhanced motivation as fostering an emotional and practical investment in learning for each student; personalised understanding as leveraging visual modelling techniques to facilitate comprehension of advanced scientific constructs and contemporary research achievements (as outlined in (Mingxing, 2021)).

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

– *The principle of complexity in digital context*. The object of research should be relevant for 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;

– *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;

– *The principle of an 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;

– *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: an artificial intelligence, virtual reality, and geoinformation technologies. When implementing the 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.

Didactic stages of student's search and research activities in small groups

Stage 1. Preliminary Preparation. This foundational phase establishes the cognitive and procedural groundwork for investigating of complex mathematical challenges. It combines systemic analysis, historical insight, and pedagogical scaffolding to prepare learners for in-depth inquiry: contradiction and functionality analysis by revisiting repositories of practice-oriented natural science tasks enhanced with AI; uncovering core contradictions (e.g., theory-practice gaps, cognitive barriers); mapping functional aspects (input-output relationships, constraints, variables); generative AI and historiogenesis review by an analysing how generative AI tools can support the subtask exploration; tracing the historical development (historiogenesis) of the subtask: an evolution of methods and concepts; key breakthroughs and persistent challenges; anticipating potential hurdles and milestone steps in research trajectory; multidimensional objective formulation: setting interconnected goals as mathematical and conceptual understanding, proof construction; informational as data processing, algorithmic thinking; illustrative-graphic as visual modelling, diagrammatic reasoning; historical-genetic as contextualising knowledge within its developmental trajectory.

By the end of this phase, learners will: possess a clear understanding of subtask's thematic boundaries and challenges; demonstrate familiarity with historical and contemporary approaches to the problem; articulate multifaceted research objectives; exhibit enhanced cognitive flexibility through an exposure to diverse the solution pathways; an engage collaboratively in small-group inquiry; an apply visual and computational tools to model aspects of the problem. This phase lays the groundwork for subsequent stages of hypothesis testing, experimental validation, and knowledge synthesis within the «problem zone».

Stage 2. Content and Technological Implementation. This phase shifts from exploration to structured problem-solving, leveraging advanced tools and methodologies to transform an initial insights into actionable research pathways. Anticipation and efficacy evaluation for forecasting of potential solution trajectories; an assessing strategy effectiveness through: risk-benefit analysis; resource allocation projections; time-efficiency estimates; using generative AI to: simulate alternative approaches; optimise multi-layered goal structures; generate scenario variations. Creating a comprehensive action plan for addressing the research query; an integrating diverse information of presentation formats: textual narratives; visualisations (graphs, flowcharts); computational outputs; multimedia components. Process evolution tracking by monitoring dynamic changes in: studied processes and phenomena; an influencing factor (internal/external); emergent patterns and anomalies; documenting developmental stages through: iterative logs; version control systems; comparative analysis frameworks. Building multi-layered representations: conceptual models as an abstract framework for understanding; domain-specific models by tailored to subtask's context; informational models by data structures and processing protocols; mathematical models by formal equations and algorithms. ICT Tool Exploration by leveraging technology for research support: data analysis platforms (e.g., Python libraries, R); visualisation software (e.g., Tableau, Matplotlib); collaboration tools (e.g., shared workspaces, version control).

By the end of this phase, researchers will have: a detailed action plan with milestones and deliverables; refined multi-layered goals aligned with research objectives; an evolving process documentation tracking key development; strategies for managing uncertainty and risk; an enhanced disciplinary dimension (mathematical, historical, etc.); functional conceptual and computational models; proficiency in ICT research tools relevant to the subtask; a founding for empirical testing in subsequent phases.

This stage bridges theoretical exploration and practical implementation, setting the stage for hypothesis validation and knowledge synthesis in later research phases. Initial actions include: refreshing subject-specific and informational competencies; boosting student motivation and goal alignment through: mind mapping exercises; discussions on mathematical concepts, historiographical contexts, and AI tool integration for problem resolution.

Stage 3. Assessment and Refinement. This phase aims to: measure interim subject-specific, meta-subject, and personal outcomes; monitor progress indicators for both educators and learners (e.g., reflective abilities, creativity, critical thinking, synergistic effects, and self-actualisation); adjust innovation mechanisms, research stages, and generative AI tools, emphasising: individual experiential learning; contextual education; intercultural dialogue; synthesise knowledge theoretically and empirically; document, validate, and refine procedures/algorithms; prepare findings for presentation.

Stage 4. Synthesis and Application. This final stage focuses on: transferring innovative constructs and procedures from the research context to routine classroom practice; aligning students' cognitive preferences with group achievements; exchanging information and validating project outcomes; identifying key parameters that gauge the success of students' cognitive growth in generative AI usage; interpreting results to generate a novel creative outputs; forecasting of future research directions; reinforcing motivation for self-actualisation and continued inquiry.

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

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

– *Save Tomato*. A Telegram bot for diagnosing tomato diseases by artificial neural networks using.

– *Spectacles*. A software tool for automated typhlo translation by using of artificial neural networks.

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 and 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 using of artificial neural networks. 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.

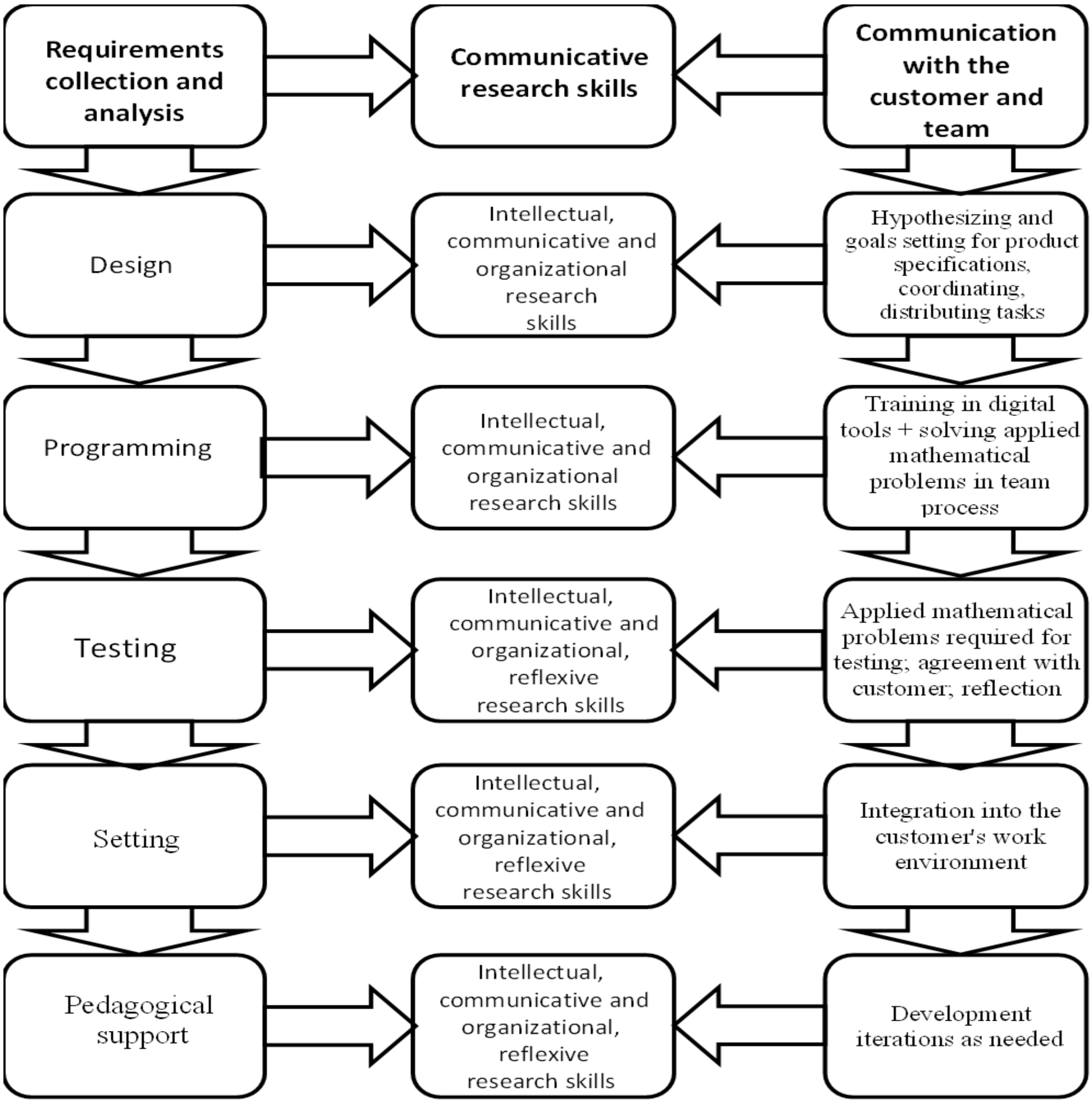

Fig. 1. Formation of research skills in the process of digital product developing

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 cultures dialogue, 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 project different aspects for competent distribution of tasks.

Content and technology stage. General hypotheses: using artificial neural networks, it is possible to recognize the defective samples of titanium sponge; it is possible to automatically remove of titanium sponge specific samples from conveyor belt. From the general hypotheses, students come to a specific one: it is possible to develop an automated tool for defective samples recognizing of titanium sponge with their subsequent removal from the conveyor belt on an enterprise scale. Then, multiple goal setting is implemented by using one of selected methods. For example: Goal according to the 5W1H method: 1. What: to develop an automated tool for recognizing and removing on defective samples of titanium sponge. 2. Why: to improve the product quality and the efficiency of production process. 3. Who: A team of engineers and automation specialists. 4. Where: At the manufacturing facility where the titanium sponge is produced. 5. When: Within the next year. 6. How: Using machine vision and automation technologies to integrate into the existing conveyor system.

Backward of planning method: The final goal is to implement an automated tool for recognizing and removing of defective titanium sponge samples in the facility. Step 5: Testing and debugging the system on the production line, training the staff – 1 month until project completion. Step 4: Integrate the developed tool into the production process, adjust the parameters – 2 months until project completion. Step 3: Developing software for defect recognition and removal system management – 4 months until project completion. Stage 2: Research and selection of automation and machine vision equipment, pilot testing – 6 months before project completion. Stage 1: Analysis of current processes and requirements, technical specifications setting – 8 months before project completion.

For planning, students choose one of the methods suggested by teacher. Then, based on the chosen methodology, students structure the substantive part of the project (indicating step-by-step results and by-products, bifurcation points and basins of attraction, attractors of dynamic processes, variability and fluctuations of initial states). At the identified stages, research skills are formed in the process of performing project activities. However, starting from the second stage, students can already solve applied mathematical problems, which also form research skills. For example, when discussing risks, we may encounter the problem of low efficiency of trained neural network. What if we empirically find out that the probability of correct sample recognition is 0.8, and we need a probability of at least 0.9? Students can use brainstorm and suggest various solutions to this problem, including mathematical ones. For example, take a picture of the sample several times. The probability of an error in one scan is 0.2. However, if you take a picture of the sample from several angles, for example, 4 times, the probability that neural network will make an incorrect conclusion 4 times is 0.0016. This problem will help in designing the hardware of elements analysis. So, students can propose that the sample fly through a photo frame that includes 4 photos of the sample from different sides. At subsequent stages of design, research skills are also formed within the framework of applied mathematical problems solving. For advanced students, more complex problems can be proposed, presented in the form of cases. Below are examples of problems encountered when neural network parameters optimizing.

Example 2. 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. 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.

4. Discussion

The use of artificial intelligence in practical problems solving is widely represented in scientific publications. For example, in (Genaev, 2021), 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 (Senior, 2020). Neural network technologies for developing project and student's research skills in studying morphology and linguistics are considered in the works (Starovoyt i dr., 2023; Burnashev i dr., 2024). 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.

5. 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.

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References

Burnashev i dr., 2024 – *Burnashev, R.F., Anvarova, L.A.* (2024). Primenenie nejronnyh setej v avtomaticheskom perevode i obrabotke estestvennogo yazyka [Application of neural networks in automatic translation and natural language processing]. *Universum: tekhnicheskie nauki*. 121(4): 40-43. [in Russian]

Dubrovsky, 1978 – *Dubrovsky, V.N.* (1978). V poiskah opredeleniya ploshchadi poverhnosti [In search of area definition surfaces]. *Kvant*. (5): 31-34. [in Russian]

Dvoryatkina et al., 2017 – *Dvoryatkina, S.N., Smirnov, E.I.* (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"*. M. Pp. 35-42.

Dvoryatkina et al., 2021 – *Dvoryatkina, S.N., Shcherbatykh, S.V., Smirnov, E.I., Khizhnyak, A.V., Zhuk, L.V.* (2021). Open Innovation Model of Student's Research Activities. *Journal of Teacher Education for Sustainability*. 23(2): 82-95.

Dvoryatkina et al., 2023 – *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.

Genaev et al., 2021 – *Genaev, M.A., Skolotneva, E.S., Gultyaeva, E.I., Orlova, E.A., Bekhtold, N.P., Afonnikov, D.A.* (2021). Automatic identification of wheat fungi diseases using a convolutional neural network. *The 6th International Scientific Conference "Plant Genetics, Genomics, Bioinformatics, and Biotechnology"*. June 14–18. Novosibirsk. P. 80.

Hyunsuk, 2022 – *Hyunsuk, H.* (2022). The utility of receiver operating characteristic curve in educational assessment. *Mathematics*. 10 (9): 1493.

Kumar et al., 2024 – *Kumar R., Chadha N.* (2024). Mastering Research Skill. *Misha books*. 216 p.

Kuznetsova i dr., 2020 – *Kuznetsova, I.V., Napalkov, S.V., Smirnov, E.I., Tikhomirov, S.A.* (2020). Vvedenie v proektnuyu deyatel'nost'. Sinergeticheskij podhod [Introduction to project activities. Synergetic approach]. Izdatel'stvo Saratovskogo ugniversiteta. 166 p. [in Russian]

Lei Qin et al., 2025 – *Lei Qin, Yingqiu Zhu, Shaonan Liu, Xingjian Zhang, Yining Zhao* (2025). The Shapley Value in Data Science. *Advances in Computation, Extensions, and Applications by Mathematics*. 13(10): 1581. DOI: https://doi.org/10.3390/math13101581

Maaliw, 2020 – *Maaliw, R.R.* (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.

Mandelbrot, 2002 – *Mandelbrot, V.V.* (2002). Fraktal'naya geometriya prirody [Fractal geometry of nature]. M.: Institut komp'yuternyh issledovanii. 656 p. [in Russian]

Menshikov i dr., 2024 – *Menshikov, V.V., Savin, N.M.* (2024). Iskusstvennyj intellekt v issledovatel'skih proektah: Master-klass dlya innovatorov [Artificial intelligence in research projects: a master class for innovators]. *Informatika v shkole*. 23(6): 18-31. [in Russian]

Mingxing et al., 2021 – *Mingxing, T., Quoc, V.* (2021). EfficientNetV2: Smaller Models and Faster Training. *International Conference on Machine Learning "Computer Vision and Pattern Recognition"*. Cornell Univerdity.

Morgacheva et al., 2023 – *Morgacheva, N.V., Shcherbatykh, S.V., Sotnikova, E.B.* (2023). Assessment and analysis of the level of natural science literacy of students. *Perspectives of Science and Education*. 62(2): 66-84.

Ostashkov i dr., 2016 – *Ostashkov, V.N., Smirnov, E.I. Belonogova, E.A.* (2016). Sinergiya obrazovaniya v izuchenii attaktorov i bassejnov prityazheniya nelinejnyh otobrazhenij [The synergy of education in the study of attractors and basins of nonlinear maps attraction]. *Yaroslavskij pedagogicheskij vestnik*. 6: 146-156. [in Russian]

Salmina, 1994 – *Salmina, N.G.* (1994). Kontseptsiya Vygotskogo i razvitie simvolicheskoj funktsii [Vygotsky's concept and the development of symbolic function]. *Voprosy psihologii*. 5: 69-78. [in Russian]

Sekovanov, 2016 – *Sekovanov, V.S.* (2016). Elementy teorii diskretnyh dinamicheskih sistem [Elements of the theory of discrete dynamical systems]. *Izdatel'stvo "Lan"*. 180 p. [in Russian]

Sekovanova i dr., 2025 – *Sekovanova, L.A., Sekovanov, V.S., Smirnov, E.I., Shchepin, R.A.* (2025). Razvitie kreativnosti studentov v izuchenii mnogoetapnyh matematiko-informacionnyh zadanij fraktal'noj geometrii [Development of students' creativity in the study of multi-stage mathematical and informational tasks on fractal geometry]. *Kontinuum. Matematika. Informatika. Obrazovanie*. 38(2): 53-70. [in Russian]

Senior et al., 2020 – *Senior, A.W., Evans, R., Jumper, J., Kirkpatrick, J., Sifre, L., Green, T.* (2020). Improved protein structure prediction using potentials from deep learning. *Nature*. 577: 706-710.

Shadrikov, 2022 – *Shadrikov, V.D.* (2022). Sistemogenez mental'nyh kachestv cheloveka [Systemogenesis of human mental qualities]. Izd-vo «Institut psihologii RAN». [in Russian]

Smirnov i dr., 2016 – *Smirnov, E.I., Bogun, V.V., Uvarov, A.D.* (2016). Sinergiya matematicheskogo analiza. Vvedenie v analiz [Synergy of mathematical education: An introduction to analysis]. *Izdatel'stvo "Kancler"*. 216 p. [in Russian]

Smirnov et al., 2017 – *Smirnov, E.I. Burukhin, S.F.* (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 P.A. Larichev"*. Vologda, Pp. 11-17.

Smirnov i dr., 2021 – *Smirnov, A.V., Fionov, A.S., Gorbachev, I.A., Shamsutdinova, E.S., Kuznetsova, I.E., Kolesov, V.V.* (2021). Ispol'zovanie additivnyh tekhnologij dlya sozdaniya shirokopolostnyh antenn s fraktal'noj geometriej [Using additive technologies to create broadband antennas with fractal geometry]. *Radioelektronika. Nano sistemy. Informacionnye tekhnologii*. 13(4): 427-434. [in Russian]

Smirnov, 2012 – *Smirnov, E.I.* (2012). Fundirovanie opyta v professional'noj podgotovke i innovacionnoj deyatel'nosti pedagoga [Foundation of experience in professional training and innovative activity of a teacher]. *Izdatel'stvo "Kancler\"*. 654 p. [in Russian].

Starovoyt i dr., 2023 – *Starovoyt, A.V., Cherpakova, N.A.* (2023). Ispol'zovanie nejronnyh setej v obshcheobrazovatel'nyh organizaciyah dlya povysheniya kachestva obucheniya [Using neural networks in general education organizations to improve the quality of education]. *Informaciya i obrazovanie: granicy kommunikacij*. 23(15): 169-170. [in Russian]

Sysoyev et al., 2025 – *Sysoyev, P.V., Evstigneev, M.N., Sorokin, D.O.* (2025). Structural model of pre-service teacher training based on artificial intelligence technologies. *Perspectives of Science and Education*. 3: 139-155.

Tereshchenko i dr., 2021 – *Tereshchenko, S.N., Perov, A.A., Osipov, A.L.* (2021). Opredelenie zabolevanij manioka metodami komp'yuternogo zreniya [Detection of cassava diseases using computer vision methods]. *Sibirskij zhurnal nauk o prirode i arhitekture*. 13(1): 144-155. [in Russian]

UNESCO Science Report, 2015 – UNESCO Science Report. Towards 2030. *UNESCO Publishing*. 47 p. [in Russian]

Uvarov i dr., 2017 – *Uvarov, A.D., Smirnov, E.I, Smirnov, N.E.* (2017). Komp'yuternyj dizajn rosta ploshchadej bokovoj poverhnosti cilindra Shvarca v neregulyarnom sluchae [Computer design of nonlinear growth of "areas" of irregular cylinder of Schwartz]. *Evrazijskij nauchnyj byulleten'*. 30(8): 35-55. [in Russian]

Wei Pan et al., 2024 – *Wei Pan, Yi Xiang, Weili Gong, Haiying Shen* (2024). Risk Evaluation of Elevators Based on Fuzzy Theory and Machine Learning Algorithms. *Mathematics*. 12 (1): 113.

Wei Pan et al., 2024 – *Wei Pan, Yi Xiang, Weili Gong, Haiying Shen* (2024). Risk Evaluation of Elevators Based on Fuzzy Theory and Machine Learning Algorithms. *Mathematics*. 12(1): 113.

Wessels et al., 2021 – *Wessels, I., Rueß, J., Gess, C., Deicke, W., Ziegler, M.* (2021). Is research-based learning effective? Evidence from a pre–post analysis in the socialsciences. *Stud. High. Educ.* 46: 2595-2609.

William et al., 2025 – *William, Villegas-Ch., Diego, Buenano-Fernandez, Alexandra, Maldonado Navarro, Aracely, Mera-Navarrete* (2025). Adaptive intelligent tutoring systems for STEM education: analysis of the learning impact and effectiveness of personalized feedback. *Smart Learning Environments*. 12(41): 569.

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

Zade, 1988 – *Zade, L.A.* (1988). Fuzzy logic. *IEEE Transactions on Computers*. 21(4): 83-93.

Zvonova et al., 2018 – *Zvonova, E.V., Salmina, N.G.* (2018). Razvitie simvolicheskoj funkcii v koncepcii dialoga kul'tur [Development of symbolic function in the concept of cultures dialogue]. *Vestnik Moskovskogo universiteta. Psihologiya*. 14(2): 24-39. [in Russian]