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Teaching artificial intelligence in secondary school: from development to practice

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Abstract. *Problem statement.* Currently, various global and national institutions promote mainstreaming artificial intelligence (AI) technology into training programs for school students. The effectiveness of introducing artificial intelligence into school curricula depends on four factors: 1) defining methodological foundations for creating educational content; 2) selecting and structuring appropriate learning content; 3) adapting the content to the needs of different age groups; 4) integrating the content into school programs. The current study provides theoretical foundations for generating learning content for AI lessons aimed at secondary school students and determines possible ways of integrating that content into school programs. *Methodology.* The empirical part of the study involved 225 secondary school students aged 11–14 (forms 5 to 9) as well as 125 teachers from comprehensive schools located in Moscow and the Moscow region. Analysis, synthesis, testing and sampling average methods were used. *Results.* The authors conducted a pilot testing of the developed educational materials, measured students' AI-related skill and knowledge and processed the obtained data using the method of selective averages. The theoretical research conducted showed the leadership of artificial intelligence training in primary schools, mechanisms for developing learning outcomes in the field of artificial intelligence for primary school students, the opportunity to reveal the possibility of forming the content of artificial intelligence training based on various approaches. The goals and results of teaching the basics of artificial intelligence within the framework of basic school were determined. The content of training was formulated. *Conclusion.* The research is characterized by scientific and practical novelty, as it helps determine methodological grounds for teaching AI to secondary school students and proposes a detailed unit plan for an AI training course in secondary school.

Keywords: methods of teaching informatics, educational programs, educational content

Author's contribution. The authors contributed equally to this article.

Conflicts of interest. The authors declare that there is no conflict of interest.

Обучение технологии искусственного интеллекта в общеобразовательной школе: от разработки до практики

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Аннотация. *Постановка проблемы.* Сегодня необходимость освоения школьниками дидактических элементов в области искусственного интеллекта (ИИ) подчеркивается на государственном уровне. Проблемы внедрения обучения искусственному интеллекту связаны: 1) с определением концептуальных основ формирования содержания обучения; 2) отбором и структурированием содержания обучения; 3) адаптацией содержания обучения возрасту учащихся; 4) интеграцией в школьное образование содержания обучения. Цель исследования заключается в формировании теоретически обоснованного содержания обучения искусственному интеллекту учащихся основной школы, а также в определении возможных вариантов интеграции разработанного содержания обучения в школьное образование. *Методология.* В эмпирическом исследовании приняли участие 225 учащихся 5–9 классов и 125 преподавателей московских и подмосковных образовательных организаций. Использовались такие методы, как анализ, синтез, тестирование и метод выборочных средних *Результаты.* Подтверждена целесообразность внедрения обучения искусственному интеллекту в основную школу. Выработана концепция обучения в области искусственного интеллекта учащихся основной школы. Раскрыты возможности формирования содержания обучения искусственному интеллекту на основе различных подходов. Определены цели и результаты обучения основам искусственного интеллекта в рамках основной школы. Сформировано содержание обучения, которое возможно и необходимо осваивать в области искусственного интеллекта учащимся основной школы с учетом межпредметных и внутрипредметных связей. Разработаны учебно-методические материалы для обучения учащихся основной школы начиная с 5 класса. *Заключение.* В соответствии с вариативностью отечественного школьного образования сформированное содержание обучения позволяет предложить различные учебные курсы и учебные модули для освоения учащимися основной школы искусственного интеллекта в различных видах деятельности.

Ключевые слова: методика обучения информатике, учебные курсы, учебные модули

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Problem statement. Issues related to artificial intelligence (AI), including integrating AI in education [1], are now gaining increased global attention. Recently, UNESCO[1] and The European Trade Union Committee for Education[2] have held several events on the advantages and challenges of applying AI in educational contexts. The organizations produced regulatory documents on the development and use of AI technologies in education, including EU's regulatory framework for artificial intelligence systems.[3]

The Russian government sees artificial intelligence as a driving force for the national economy and technological innovation, and AI-related training courses in educational institutions are singled out as a prerequisite for technological progress and economic growth.[4]

Russian schools began teaching AI skills to schoolchildren more than 30 years ago, accumulating plenty of experience over the years. Contrary to global approaches to teaching AI, Russian educational establishments do not solely focus on developing practical skills of using AI-powered tools, yet also embrace artificial intelligence as an exciting theoretical object. Simultaneously, Russian educators tend to see AI lessons as an extracurricular activity or an integral part of an advanced computer science course offered only to high school students.

Today, there is a strong demand for research that, in accordance with current trends in computer science as a school discipline [2], will help develop a general framework and resources for AI training courses for secondary school students.

The authors pursue **several goals**: to inform the pedagogical community about the practical outcomes of their research, to provide theoretical justification for teaching AI to secondary school students, to outline options for integrating the generated learning content into school curricula.

Methodology. The study was carried out from 2019 to 2021 by the faculty of the Institute of Digital Education. It involved 225 secondary school students

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[1] Kuleshov A, Ignatiev A, Abramova A, Marshalko G, Fedorov M. Actual goals of international cooperation in the development and regulation of artificial intelligence. *Digital Russia*. 2020, February 20. (In Russ.) Available from: https://d-russia.ru/aktualnye-zadachi-mezhdunarodnogo-vzaimodejstviya-po-razvitiyu-i-regulirovaniyu-iskusstvennogo-intellekta.html (accessed: 08.06.2023).

[2] *ETUCE position on "A new framework for the Implementation of the European Education Area 2021–2030"*. European Trade Union Committee for Education; 2021. Available from: https://www.csee-etuce.org/en/resources/statements/4472-etuce-position-on-a-new-framework-for-the-implementation-of-the-european-education-area-2021-2030 (accessed: 10.06.2023).

[3] *Regulatory framework proposal on artificial intelligence*. European Commission; 2020. Available from: https://digital-strategy.ec.europa.eu/en/policies/regulatory-framework-ai (accessed: 05.06.2023).

[4] Decree of the President of the Russian Federation on the Development of Artificial Intelligence in the Russian Federation No. 490. 2019. (In Russ.) Available from: https://cset.georgetown.edu/wp-content/uploads/Decree-of-the-President-of-the-Russian-Federation-on-the-Development-of-Artificial-Intelligence-in-the-Russian-Federation-.pdf (accessed: 10.06.2023).

aged from 11 to 15 (forms 5 to 9) and 125 teachers from educational establishments located in Moscow and the Moscow region: four comprehensive schools (No. 1574, 1679, 2121, 1558) and two children's holiday clubs (Palace of Children and Youth named after Arkady Gaidar and Berezka Recreation Camp of the Russian Federal Tax Service).

The study started with a pedagogical analysis of teaching AI, with the authors asking teachers to fill in two questionnaires (*The need and forms of organizing AI lessons in a secondary school*, *The demand for educational and methodological resources for teaching AI in comprehensive schools*). Further, the authors tested their original educational and methodological materials and measured students' AI skill levels at the entry and final stages. The obtained data were processed using the method of selective averages.

Results and discussion. The analysis of emerging practices of introducing artificial intelligence into national curricula in certain countries, namely the USA [3], China[5] [4], England,[6] Germany,[7] Israel [5] and India,[8] has shown a great variety in approaches to including elements of AI into educational and methodological materials. Some countries put emphasis on practical activities for high school students, some pay more attention to teaching theoretical foundations of artificial intelligence technology, and some propose AI classes for schoolchildren of younger ages[9] [6].

In the initial stage of the study, we interviewed schoolteachers on how AI lessons can be integrated into school curricula and appropriate lesson designs.

The surveyed teachers unanimously agreed that AI learning should start as early as in secondary school.

However, teachers' opinions divide regarding how AI should feature in a school curriculum: 15% of teachers see AI as a topic in a computer science course; 15% insist on teaching AI as an optional (elective) subject, while 70% believe AI training should happen both in computer science lessons and in elective classes (Figure 1).

In a similar survey conducted in 2019, the participants (101 teachers) welcomed the idea of teaching AI to secondary school students, yet said they had not been provided with educational and methodological support to enable this type of training

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[5] Liu D. China ramps up tech education in bid to become artificial intelligence leader. *NBC News.* 2020, January 4. Available from: https://www.nbcnews.com/news/world/china-ramps-tech-education-bid-become-artificial-intelligence-leader-n1107806 (accessed: 08.06.2023).

[6] Webber JE, Stephens D. Google's problem with AI. *The Guardian*. 2019, May 6. Available from: https://www.theguardian.com/technology/audio/2019/may/06/googles-problem-with-ai-and-ethics-chips-with-everything-podcast (accessed: 28.05.2023).

[7] *Pakt für Informatik bereitet Schülerinnen und Schüler auf die digitalen Anforderungen der Arbeitswelt vor.* Ministerium für Schule und Bildung des Landes Nordrhein – Westfalen; 2021. Available from: https://www.schulministerium.nrw/presse/pressemitteilungen/pakt-fuer-informatik-bereitet-schuelerinnen-und-schueler-auf-die (accessed: 18.06.2023).

[8] Anirudh V. AI finally enters Indian classrooms with schools integrating AI in curriculum after CBSE's approval. *Analytics India Magazine*. 2019, January 16. Available from: https://www.analyticsindiamag.com/ai-enters-indian-classrooms-schools-integrating-ai-in-curriculum-after-cbses-approval (accessed: 07.06.2023).

[9] Artificial intelligence market in the education sector in US by end-user and education model: forecast and analysis 2021–2025. *Technavio*. 2022, August. Available from: https://www.technavio.com/report/artificial-intelligence-market-in-the-education-sector-in-us-industry-analysis (accessed: 10.06.2023).

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for students aged 11 and above. The surveyed teachers agreed on the necessity to teach the basics of artificial intelligence. Yet only 5% believed AI should become a part of a computer science course, 20% said AI should be an elective subject, and 75% would prefer to combine computer science lessons with a corresponding elective course. The summarized results show (Figure 1) that most respondents see AI training as a part of a computer science course, as the specifics of this school subject make it a perfect platform for forming AI-related knowledge, skills and capabilities.
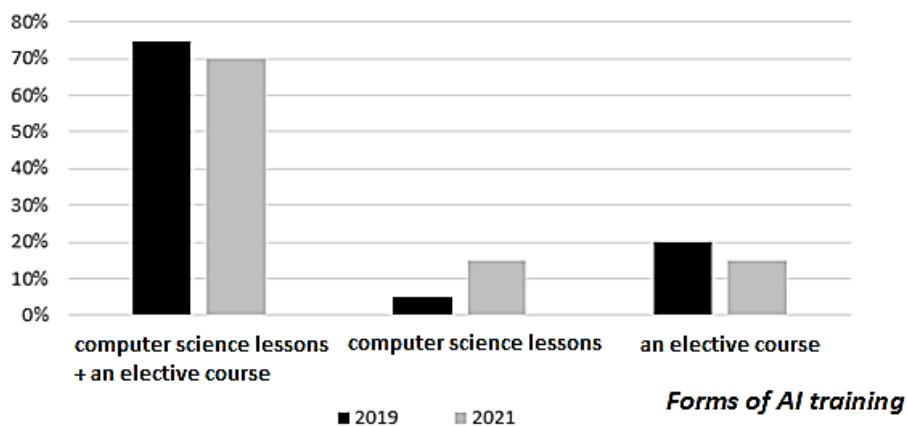

Figure 1. The results of the surveys on forms of teaching AI to secondary school students

As AI training will inevitably appear in the national curriculum, there is an urgent need to add some elements of artificial intelligence technology to current computer science education. This move will help upgrade the methodological system behind computer science as a school subject, namely, to adjust its objectives, content, teaching techniques and tools.

Earlier studies on the issue [7; 8] allowed:

– to argue the expediency of making artificial intelligence technology a part of a computer science course;

– to develop a conceptual basis for AI training in secondary schools;

– to identify key approaches to teaching AI to secondary school students;

– to pinpoint ways of developing content for AI-related subjects based on various approaches (system, fundamental, interdisciplinary);

– to define the goals of teaching the basics of AI in comprehensive schools;

– to highlight thematic sections of a compulsory computer science course that includes basic AI training;

– to identify interdisciplinary connections necessary for students' successful acquisition of AI-related knowledge and skills.

The proposed methodological model makes it possible to decide on the content of AI lessons built into a computer science course as well as outline various curricular and extracurricular activities that can become a part of an AI training course for secondary school students.

The theoretical foundations of AI as an advanced computer technology should be integrated into a general computer science course aimed at developing students' knowledge of information technologies and essential IT skills [9]. When taking a compulsory computer science course, students are expected to master didactic elements [10] that allow them to effectively study AI, consolidate and further develop the acquired skills and capabilities.

Before discussing the content of a basic AI course, it is necessary to determine the meaning of 'artificial intelligence' since its definitions are often flexible, multidimensional, or ambiguous.

Scientists and experts in the field of artificial intelligence offer various interpretations to this term, highlighting those aspects of the technology that are most relevant to their own research. Our analysis of multiple definitions concludes that *artificial intelligence* is a theoretical and applied computer science that solves problems of making hardware and software models of human intellect.

Artificial intelligence as a key component of a school curriculum can be defined as a theoretical and applied computer science devoted to the R & D of artificial intelligence systems. It is also necessary to mention artificial *intelligence systems* (AI systems) – computer systems that mimic human intelligence to perform complex tasks on information processing.

The content of an artificial intelligence course should correspond with students' age, needs and interests. AI-related training resources are expected to facilitate students' personality development as well as foster basic competences for advanced AI education and employing AI-powered tools in various activities.

Teaching AI to secondary school students should be based on humanistic, interdisciplinary, theoretical and empirical approaches.

Computer science as a school subject considers most prominent advances in information technology: computer programming, artificial neural networks, machine learning, automated project management, information systems security, etc. Therefore, AI training resources used within a compulsory computer science course should give students a basic idea of key AI development trends.

The education system in Russia does not recognize artificial intelligence as a school subject. However, lessons on AI can be easily integrated into a mandatory computer science course in case there is an increase in classroom hours. If this happens, according to the didactic spiral principle, the knowledge and skills acquired by secondary school students will be later deepened and expanded in the context of an advanced computer science course for high school students or a special elective course.

In our earlier study, we have already described the key learning outcomes (knowledge, skills and abilities) of an AI training course for secondary school students [11].

Subject results:

– to be aware of artificial intelligence (AI) as an actively developing subject area of computer science;

– to understand how AI systems are managed by computer programs (AI software);

– to have the knowledge about the current state and further development of AI systems;

– to be able to give examples of how AI technology may be used in modern-day life and in the future;

– to be able to interact with AI systems and optimize their performance when solving specific tasks;

– to understand how big data is stored and processed, big data as a prerequisite for machine learning;

– to have the knowledge about machine learning technology and various tasks it can perform;

– to be able to conduct experiments on teaching AI systems and adjust their parameters;

– to have the knowledge about robotic systems and how they are currently applied in various industries;

– to be able to interact with smart robotic systems;

– to be able to code in Python programming language to make changes to existing artificial intelligence software (expert systems, neural networks, image recognition algorithms, chatbots, computer games, etc.).

Interdisciplinary results:

– to be able to independently find solutions to educational and cognitive tasks, including non-standard ones;

– to be able to prioritize solutions to educational and cognitive tasks in terms of their effectiveness;

– to be able to present information effectively (figures, tables, diagrams, etc.) to solve educational and cognitive tasks;

– to strive to acquire and develop knowledge of information technology culture;

– to demonstrate readiness to independently obtain new AI-related competences and skills.

Personal outcomes:

– to develop a cohesive, systemic, informed, personal worldview aligned with the current state of science and technology;

– to be able to make personal choices when addressing moral and social issues related to AI;

– to be able to behave in a responsible and ethical way when working with AI systems;

– to become aware of the importance of continuous development of AI technology and improvement of AI-powered tools.

In this paper, we propose to build AI learning based on skills and knowledge formed at computer science lessons. Computer Science in secondary school covers such topics as: information as a key term of computer science; types of information and types of data; information processing and information technology; computers and types of computing devices; elements of a computer system; algorithms for system and data management; objects and models; computational modeling and simulation experiments.

In our opinion, the content of AI training starting in form 5 of secondary school should include the following sections: 'Benefits of Artificial Intelligence', 'How Intelligence Becomes Artificial', 'Machines That Recognize Objects', 'Machines That Understand Speech', 'Machines That Play', 'Robots That Learn', 'Programming in Python'.

Benefits of artificial intelligence. Machines as artificial systems created by people to perform certain functions. The notions of 'machine', 'system' and 'artificial system'. Human intelligence and intelligent problem-solving. The notions of 'artificial intelligence' and 'artificial intelligence systems'. Developing, applying and managing intelligent systems. Computer programs that operate artificial intelligence systems and simpler electronic devices. The notions of 'computer program (software)' and 'programming language'. Using programming languages for software development. Historical milestones of artificial intelligence technology. The meaning of 'object' and 'data'. Ramon Llull's logical machine. Automation of software management. The Turing test. Intellectual capabilities of Perceptron, MYCIN and Deep Blue expert systems. The notion of 'machine learning'. Examples of development and application of artificial intelligence systems.

Intelligence that becomes artificial. Capabilities of expert systems as a part of AI. The notion of 'expert system'. Expert system development team: the domain expert, the knowledge engineer, the programmer. Types of expert systems. Examples of how expert systems are used in various industries and areas of human experience. Expert system development. Creating components of an expert system: knowledge base and its design, inference engine, user interface. Testing and debugging of an expert system. Features of a prototypical expert system. Computational capabilities of neural networks. The human brain as a network of fibers and neurons. How neurons connect to each other, the strength of interneuronal connectivity. The notion of 'artificial neuron'. How neurons process input and output signals. The notion of 'neural network' and 'neurocomputer'. Perceptron: architecture and functions. Examples of how neurocomputers are used in various industries and areas of human experience. Application of neural networks in machine learning. Values of input signals, strength (weight) of connections between neurons, threshold potential of a neuron, the rules of an output signal production, the rules of changing weights of connections between neurons.

Machines that recognize objects. Human visual perception, receiving visual information from the environment via the eyes as a visual organ. The notions of 'computer vision' and 'machine vision'. Identifying objects and their features. The notion of 'class'. Classifying objects by using their attributes (features). Role of machine learning and neural networks in image recognition. Solving problems in object recognition with machine vision algorithms. Image segmentation. A pixel as an object of detection, color as a low-level feature. Multilayer perceptron (MLP) as a multi-layer neural network. Input layer, output layer and hidden layers of a neural network. Recognition of numbers and characters using a multilayer perceptron. Design and key characteristics of a multilayer perceptron. How the number of neurons tells on the problem-solving capability of an MLP neural network. Multilayer perceptron training. Image recognition using a multi-layer perceptron. The notion of 'pattern'. Recognizing objects using MLP as a pattern recognition system. Limitations in using neural networks for pattern recognition. Gesture and facial expression recognition using a multilayer perceptron. Reference points of observed objects. Prospects and challenges in moving object detection and recognition.

Machines that recognize speech. Formal (artificial) language and natural language. Intelligent systems for natural language processing (NLP). The five stages of NLP: lexical and morphological analysis, syntax analysis, semantic

analysis, discourse integration, pragmatic analysis. Speech recognition machines. Text recognition. Machine translation (MT). Machine translation software. Design of bilingual dictionaries for MT. Principal stages of MT. Converting words into their root forms. Quality of machine translation. Voice recognition software. Audio analysis. Recognizing sounds using machine learning. Phoneme-grapheme correspondence for word recognition. Neural networks for speech recognition and synthesis. Natural language interaction with machines. Functionality of machines with a natural language interface. Human behavior forecasting during computer-human interactions. Chatbot systems. Using expert systems and neural networks for implementation of chatbots. Voice assistants. Using Python to build a voice assistant. Further development of intelligent systems for human-computer interaction in a natural language.

Machines that play. Intellectual games as a type of human activity that requires a certain level of intelligence and cognitive effort. Intelligent computer games. The impact of artificial intelligence on the gaming industry. Design and implementation of a computer chess game. Different approaches to building AI into a computer game. Rules of an adaptive computer game. Effective playing strategies and tactics. A step-by-step guide on intelligent computer game development. Symmetry in a computer game. Relationship between a game's difficulty slope and mistakes made by a computer. Developing artificial intelligence algorithms for computer games. Managing in-game object behaviour. Virtual environment in an intelligent computer game. In-game entities: characters and objects. Non-playable/computer-controlled entities: bots, mobile objects (mobs) and non-player characters (NPCs). Machine learning in intelligent computer games. Real-time strategy games. Real-time virtual reality. Managing group actions by non-playable entities. Gaming sessions. Use of machine learning techniques in real-time strategy gaming. Prospects of increasing the efficiency of machine learning using ML accelerators (AI accelerators).

Robots that learn. Historical background of robotic science. The origin and definitions of the word 'robot'. Key characteristics of modern robots: task-performing programmable machines guided by sensors. Types of robots based on their application and functionality. The notions of 'intelligent robotics', 'intelligent robotic systems' and 'intelligent robots'. Examples of an artificial intelligence robot. Sensors and probes of a robotic system. Types of sensors: light sensors, sound sensors, tactile sensors, navigation and position sensors, proximity sensors, rotation angle sensors, etc. The importance of sensors for robot learning. Machine learning methods in robotics. Operating intelligent robotic systems. Types of intelligent robots and tasks they perform: robotic vacuum cleaners, unmanned cars and trucks, unmanned agricultural machinery, unmanned aircraft. Intelligent systems integration. The future of AI robots. Emerging trends in intelligent robotics: social, industrial and medical aspects. Ethical issues with intelligent robotic systems: changes to the labour market, establishing ground rules for human-robot interactions. Where humans have advantage over intelligent robots.

Programming in Python. Computer programming. Computer program as a sequence of instructions, written to perform a specified task with a computer. Programming language as an artificial language. Programming languages for artificial intelligence. Python as a language for programming intelligent systems. Py-

thon alphabets and syntax. Developing software for human-computer interaction: implementation of neural networks and expert systems, training a neural network, speech synthesis and speech recognition, making a computer game in Python. How to write and edit code. Software testing and debugging.

The distribution of study times for an AI training course in secondary school (Table) abides by standard requirements for STEM subjects to combine classes on theory with practical and laboratory work. The hours in parentheses (67% of the total number of hours) are allocated to practical classes where students acquire new AI-related skills and laboratory classes on writing programs in Python [12].

The authors understand that students' learning outcomes often depend on the quality of training provided in pedagogical universities and advanced training courses for practicing schoolteachers. For this purpose, we developed a set of educational materials on artificial intelligence technology, aimed at both students pursuing a pedagogical degree and computer science teachers in comprehensive schools.

A unit plan for an AI training course in secondary school

No.	Lesson theme	Theory	Practice	Lab	Total
Chapter 1. Benefits of artificial intelligence		**3**	**3**	**3**	**9 (6)**
1.1.	What we know about artificial intelligence	1	1	1	3 (2)
1.2.	Managing intellectual systems	1	1	1	3 (2)
1.3.	History of intellectual systems	1	1	1	3 (2)
Chapter 2. Intellect that becomes artificial		**4**	**4**	**4**	**12 (8)**
2.1.	How expert systems work	1	1	1	3 (2)
2.2.	Developing expert systems	1	1	1	3 (2)
2.3.	How neural networks work	1	1	1	3 (2)
2.4.	Developing neural networks	1	1	1	3 (2)
Chapter 3. Machines that recognize objects		**4**	**4**	**4**	**12 (8)**
3.1.	Machine vision	1	1	1	3 (2)
3.2.	Recognition of numerals and characters	1	1	1	3 (2)
3.3.	Image recognition	1	1	1	3 (2)
3.4.	Recognition of gestures and facial expressions	1	1	1	3 (2)
Chapter 4. Machines that recognize speech		**4**	**4**	**4**	**12 (8)**
4.1.	Natural language processing	1	1	1	3 (2)
4.2.	Text recognition	1	1	1	3 (2)
4.3.	Voice and speech recognition	1	1	1	3 (2)
4.4.	Interacting with computers in natural language	1	1	1	3 (2)
Chapter 5. Machines that play		**4**	**4**	**4**	**12 (8)**
5.1.	Artificial intelligence game playing	1	1	1	3 (2)
5.2.	Intelligent behavior and playing strategies	1	1	1	3 (2)
5.3.	AI algorithms for intelligent computer games	1	1	1	3 (2)
5.4.	Machine learning for real-time strategy games	1	1	1	3 (2)
Chapter 6. Robots that learn		**4**	**4**	**3**	**11 (7)**
6.1.	Historical background of robotics	1	1	1	3 (2)
6.2.	Sensors for intellectual robotic systems	1	1	1	3 (2)
6.3.	Intelligent robots and tasks they perform	1	1	1	3 (2)
6.4.	The future of intelligent robotic systems	1	1		2 (1)
	Time reserve			2	*2 (2)*
Total		**23**	**23**	**24**	**70 (47)**

Pilot testing of the developed teaching and methodological materials occurred in 2021 and involved 24 Moscow school teachers who received 36 hours of advanced training according to the program *Methods of teaching artificial intelligence to secondary school students (forms 5 to 6)*. As a result, all 24 participants, computer science teachers, adopted an unambiguous attitude toward AI training, speaking in favor of a school AI course.

The teachers also rated the developed educational materials on the scale from 0 to 10, describing them as interesting, easy to understand, complex and useful (Figure 2).

The diagram demonstrates that the developed educational materials appear interesting, easy to understand and useful, yet also have a level of complexity that will help engage students in intellectual activity and provide them with opportunities for independent research and insight.

The developed methodological materials were used at computer science lessons for secondary school students (225 children in total). In the process, the authors conducted an experiment to see whether the students possess/have acquired the following AI skills: to be able to give examples of how intelligent systems are used; to be able to give examples of AI system management; to be able to give examples of how machine learning can be used in problem-solving; to be able to interact with AI systems when solving problems; to be able to conduct experiments on AI systems training.

Since AI systems are not studied in secondary school, we found it impossible to compare the learning curves of the control group and the experimental group. Therefore, we decided to measure each of the five skills twice (before and after AI-themed lessons) and in the experimental group only. Moreover, the final level tasks were more difficult than the entry-level tasks.
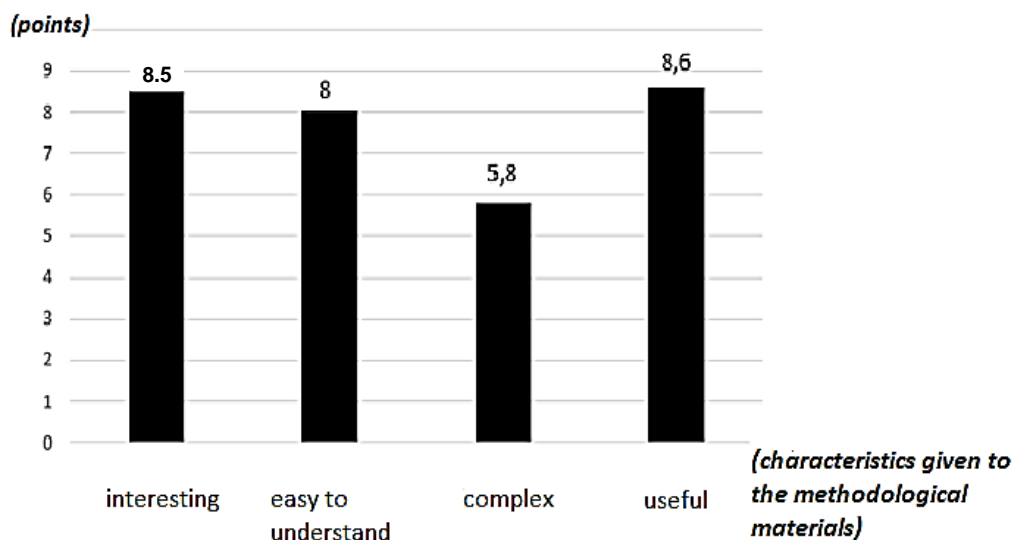

Figure 2. Teacher's opinions on the developed methodological materials for AI training in secondary school

The entry-level measurements indicated that almost all students had some intuitive understanding of artificial intelligence, but found it difficult to identify

its key concepts or use AI-powered tools. The final level measurements showed solid knowledge of the basics of AI and its main functions, as well as an improvement in students' ability to interact with AI systems.

Based on the results of the entry- and final level measurements, average scores were calculated using a 5-point grading system for each of the five AI skills, as well as a generalized score (sample average) (Figure 3). Higher scores indicate an increase in students' AI knowledge and skills, which confirms the effectiveness of AI training for secondary school students.
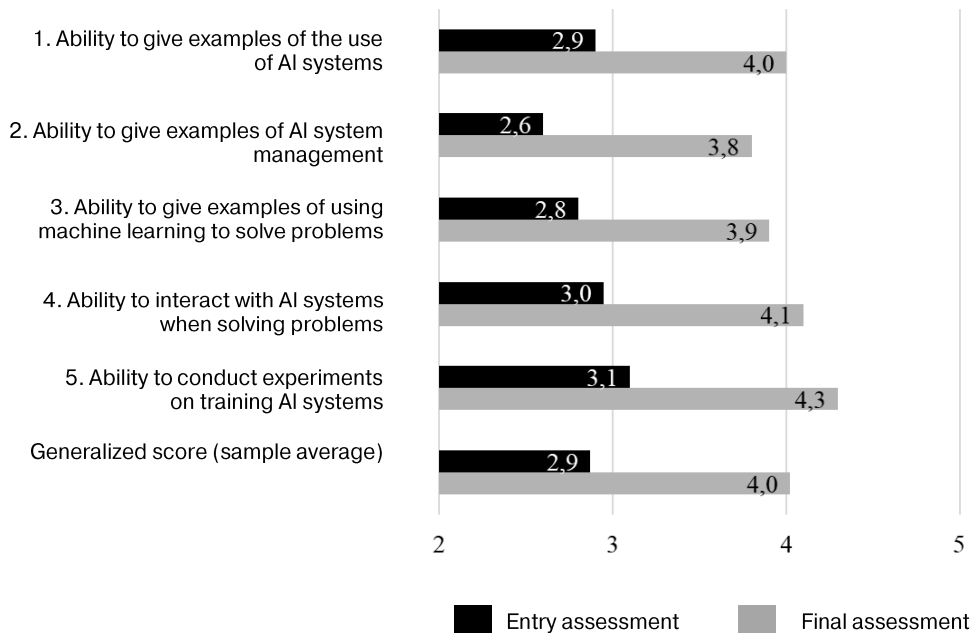

Figure 3. Levels of mastering AI skills by secondary school students

As of today, school teachers are well aware of the urgency to add AI theory and practice into school curriculums, and the proposed content enables conducting AI classes within a compulsory computer science course or/and as an elective course.

Lately, the USA, China, the United Kingdom, Germany, Israel and several other countries have included basic AI training in their high school programs, primarily as an optional (elective) subject. The authors believe that Israel deserves a special mentioning, as recently Israeli high school students have been offered classes on AI programming, where students learn to write algorithms for machine learning tools for intelligent systems [5].

The authors agree with L.L. Bosova [2], I.A. Kalinin & N.N. Samylkina [13], L.N. Yasnitskiy [14] and other Russian educationalists who believe that AI training should become an essential part of a school computer science program. AI-themed lessons will motivate students to seek job opportunities in the information technology and artificial intelligence sector that is the driving force behind the development of the information society and the digital economy.

We have also spotted a trend that school students begin to master the basics of AI technology at an earlier age. Today, Russian top businesses are funding nu-

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merous AI-related educational projects aimed at both high school students and secondary school students (namely, the educational project on artificial intelligence by Sberbank), which supports the results of our research.

However, the obtained data indicate that it is advisable for secondary schools to integrate AI and IT theory lessons into a compulsory computer science course. The content and methodological guidelines developed for this subject are likely to help secondary school students effectively learn key elements of AI technology as well as reinforce and develop their previously formed skills and competences.

The outcomes of the present study can serve as a methodological basis for an AI training course in secondary school; the developed educational materials were tested in practice and proved their relevance for teaching AI to secondary school students, either as a part of a compulsory computer science course or as an elective course.

Conclusion. As this study showed, artificial intelligence has not yet become a part of the national curricula. Some countries differ in their opinions on how AI should be implemented in school education. AI is most commonly recognized as an effective tool of learning management rather than a school subject. However, Russian teachers have already accumulated some positive experience of teaching AI in computer science lessons or as an extracurricular subject. The results of this study conclude that AI training can become an essential part of a compulsory computer science course as early as in secondary school.

The authors determined the conceptual foundations of AI-themed education [8]; highlighted various approaches to forming the content for AI training (system-activity, fundamental and interdisciplinary) [7, 9]; determined the outcomes of a basic AI training course (subject, meta-subject and personal outcomes) in secondary schools [11]. We also selected age-appropriate content for an AI course and organized it into a unit plan, taking into account its inter-subject and meta-subject connections with a standard computer science course.

Another output of the study is the developed educational and methodological materials that proved their effectiveness in practice. Further research will involve developing digital educational resources and solving organizational and methodological problems of AI-themed education, including the issue of continuity of teaching content at different levels of general education.

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