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STEM TECHNOLOGY IN THE STUDY OF EDUCATIONAL ROBOTICS

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Abstract

STEM education is aimed at the formation of adaptation skills to those changes that occur in technology and science and will become key for further education and employment. One of the directions for the introduction of educational STEM technologies is educational robotics. In recent years, advances in robotics and automated systems have changed personal and business areas of life. Modern production and industry need specialists with knowledge of robotics. Therefore, the introduction in the educational program of the section related to robotics is gaining increasing importance and relevance now. The objectives of the study are to justify the relevance and importance of introducing educational robotics in schools, determine the state of teaching robotics and outline ways of introducing educational robotics and ways of preparing future robotics teachers. In the study, the current state and tasks of educational robotics in the secondary education system, as well as an approach to the study of robotics using STEM education, are discussed at the theoretical level. Based on an expert survey, the main characteristics of STEM education and the tasks of introducing educational robotics in STEM education are determined and a characteristic of the state of teaching robotics in schools is given.

Keywords

Educational robotics - STEM education – Projects – Training programs

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Introduction

Robotics is one of the industries in the world that is currently developing most intensively. This is evidenced by the data of the world robotics report of the International Federation of Robotics (IFR) for 2018. According to it, in 2017, a new record was set for the production of industrial robots, namely, their production volume increased by 30% compared to the previous year. In addition, over the past five years, total sales of industrial robots have doubled. Companies also plan to invest significant resources in the robotic industry, namely, in the development of autonomous transport, stationary robots, nonhumanoid ground robots, humanoid robots, air robots (drones) and underwater robots. Thus, a wide range of modern technologies based on robotic systems attracts a lot of business attention¹. Today, industrial robots and integrated automation of production are in demand in many sectors of public activity: industry (painting, welding, cutting from metal, etc.), military (combat robots, intelligence service), medicine (microscopic work for use in microsurgery, robots-couriers in hospitals), aviation (unmanned drones), space industry (self-propelled vehicles based on robotic systems), service sector (robots to help people with special needs), everyday life (robot vacuum cleaners), etc. Robotics is changing the way people live and work. It also means that there is already an urgent need for specialists for the development, construction and programming of robots. Training of future specialists in the field of robotics requires an update of the content of school and university education in accordance with the requirements of today². In addition, robotics is a popular and effective method for studying important areas of science and construction and is based on the active use of modern technologies in production, ICT and a high intellectual level of specialists who will work in an innovative economy. Therefore, today the issues of the introduction of robotics in the educational process of educational institutions are of particular importance. Robotics is one of the branches of science and technology that is currently being intensively developed. Thus, the preparation of modern youth for the construction, programming and use of robotic systems is connected with the requirements of today. Namely, it is the emergence of new professions in this industry and, as a consequence, the need for appropriate specialists: robot operator, robot designer, robotics service engineer, robotics programmer, medical robot operator, unmanned vehicles operator, designer of smart homes, builder of smart roads. That is why the educational potential of robotics is big and now, there is an urgent need for specialists for the development, construction and programming of robots. Thus, the involvement of students in the study of robotics is extremely important for the further development of technology in Russia and the relevance of the introduction of educational robotics in Russian schools is undeniable.

Literature review

According to researchers, one of the training tools for specialists who are able to think creatively and create innovations is STEM education. It is supported in such countries as Australia, the UK, Denmark, Israel, China, Korea, Singapore, the US and Japan at the level of state programs³.

¹ IFR releases its annual world Robotics Report. Available at: <https://www.universal-robots.com/about-universal-robots/news-centre/ifr-releases-world-robotics-report-for-2018/>

² M. S. Logachev y G. S. Zhukova, "Problems of Professional Education in Russia: Quality Monitoring of Educational Programs", *Revista Inclusiones*, Vol: 7 (2020): 263-274.

³ D. W. White, "What Is STEM Education and Why Is It Important?", *Florida Association of Teacher Educators Journal*, num 1 Vol: 14 (2014): 1-9 y A. V. Frolov, "RoI STEM-obrazovaniia v "novoi ekonomike" SSHA", *Voprosy novoi ekonomiki* num 4 Vol: 16 (2010): 80-90.

STEM education is a direction in education, using which in the training programs, the natural science component is strengthened with the help of innovative technologies⁴.

According to researchers, STEM is a concept and an educational system that is used by developed countries in different educational sectors in order to develop skills necessary for children and youth to be successful and to contribute to the innovative development of the country as a whole. This concept involves a combination of various sciences and technologies, as well as engineering and mathematical thinking. An important concept related to STEM education is interdisciplinarity in education, which is considered pedagogical innovation⁵.

The key pedagogical problem in the development of STEM-oriented training programs, according to scientists, is the technology of integration of components, which, on the one hand, are close disciplines. On the other hand, they are independent established ontologies: science as a way of cognition that helps to understand the environment world; technology as a way to improve the world sensitive to social change; engineering as a way to create and improve devices to solve real problems; mathematics as a way of describing the world⁶.

Therefore, according to I. E. Lublinskaia, there is a combination of the scientific method, technology, construction and mathematics at the basis of the development of an educational STEM program. The integration may result in the introduction of a separate STEM/Science subject or certain changes in the curriculum of each of the STEM subjects based on the introduction of innovations and strengthening of the practical component when solving real problems⁷.

STEM education is based on the use of tools and equipment related to technical modeling, energy, electrical engineering, computer science, ICT, as well as research in the field of energy-saving technologies, automation, robotics, intelligent systems, radio engineering, radio electronics, aviation, space and aerospace technologies, etc.⁸ As world experience shows, the introduction of STEM education is changing Russian economy as a whole, making it more innovative and competitive. According to research, STEM develops an ability to research, as well as creative activities, experimentation, ability to work in a team on joint projects, including the use of ICT. It also contributes to the formation of analytical, critical and innovative thinking⁹. In addition, it is predicted that 75% of the professions that are currently emerging and developing will require STEM skills¹⁰.

⁴ T. J. Kennedy & M. R. L. Odell, "Engaging Students In STEM Education", *Science Education International*, Vol: 25 num 3 (2014): 246-258.

⁵ T. I. Anisimova; O. V. Shatunova & F. M. Sabirova, "STEAM-obrazovanie kak innovatsionnaia tekhnologiya dlia Industrii 4.0", *Nauchnyi dialog* num 11 (2018): 322-332.

⁶ R. Brown; J. Brown; K. Reardon & C. Merrill, "Understanding STEM: Current perceptions", *Technology and Engineering Teacher*, Vol: 70 num 6 (2011): 5-9.

⁷ I. E. Lublinskaia, *STEM v shkole i novye standarty srednego estestvennonauchnogo obrazovaniia v SSHA. Problemy prepodavaniia estestvoznaniia v Rossii i za rubezhom* (Moscow, LENAND, 2014).

⁸ I. V. Rudenko; N. V. Iashina & U. A. Kuzmina, "STEM-obrazovanie – resurs modernizatsii inzhenernogo obrazovaniia", *Tekhnicheskoe tvorchestvo molodezhi* num 1 Vol: 113 (2019): 7-12.

⁹ S. Fan & K. Yu, "How an integrative STEM curriculum can benefit students in engineering design practices", *International Journal of Technology and Design Education*, Vol: 27 (2017): 107-129

¹⁰ Y. Li, "Journal for STEM education research – Promoting the development of interdisciplinary research in STEM education", *Journal for STEM Education Research*, Vol: 1 num 1-2 (2018): 1-6

However, despite the fact that STEM approaches are implemented in Russia in many educational institutions, nowadays, it is mainly an out-of-school STEM education: various contests of the natural scientific and mathematical direction, scientific competitions and events for students, etc.¹¹ Therefore, the reform of natural scientific, mathematical and engineering education based on the adaptation of world experience and proven practices of implementing STEM education is relevant today¹².

It is also important to involve modern rapidly developing industries in the main components of STEM education (teaching natural sciences, mathematics and technology). One of these areas is robotics. Therefore, the problem of training specialists in the field of robotics, and especially the training of future teachers robotics, is extremely important¹³.

Robotics is an applied science that studies the design, development, construction, operation and use of robots¹⁴.

Today, scientists and teachers are actively looking for ways to introduce and use robotics in the educational process of educational institutions¹⁵. However, an analysis of Russian experience shows that insufficient attention is paid to the development of robotics in the educational process¹⁶. In particular, teaching educational robotics in educational institutions occurs occasionally:

in schools in the process of teaching computer science, ICT, technology and physics (as modules or/and individual topics);

at elective courses and study groups in secondary schools in extracurricular hours (including the process of preparing students for participation in festivals and competitions in robotics at various levels, the development of scientific and technical creativity of students, etc.);

in institutions of out-of-school education (both state and commercial).

This indicates the absence of a systematic approach to teaching educational robotics in schools due to the fact that in the state standard for education today, there is no separate educational field "Robotics"¹⁷.

¹¹ V. N. Chemenkov & D. A. Krylov, "STEM – novyi podkhod k inzhenerному obrazovaniyu", *Pedagogicheskie nauki* num 5 Vol: 20 (2015): 59-64.

¹² P. L. Sitnikov, "Ot politekhnizma k STEM-obrazovaniyu", *Sovremennoe obrazovanie v Rossii i za rubezhom*, num 1 (2014): 54-57.

¹³ A. Eguchi, "Educational Robotics for Promoting 21st Century Skills", *Journal of Automation Mobile Robotics and Intelligent Systems*, Vol: 8 num 1 (2013): 5-11.

¹⁴ D. Alimisis, "Educational Robotics: Open Questions And New Challenges Themes", *Science & Technology Education*, Vol: 6 num 1 (2013): 63-71.

¹⁵ J. Johnson, "Children, Robotics and Education", *Artificial Life and Robotics*, Vol: 7 (2003): 16-21 y D. A. Gagarina y A. S. Gagarin, *Robototekhnika v Rossii: obrazovatenyi landshaft. Chast 1* (Moscow: National Research University Higher School of Economics, 2019).

¹⁶ I. V. Tusikova, "Izucheniye robototekhniki: put k inzhenernym spetsialnostiam", *Shkola i proizvodstvo* num 5 (2013): 45-47.

¹⁷ M. V. Kuzmina; S. I. Melekhina; A. A. Pivovarov; U. A. Skurikhina y N. I. Chuprakov, *Obrazovatelnaia robototekhnika: uchebno-metodicheskoe posobie* (Kirov, OOO Tipografiia "Staraia Viatka", 2016).

The hypothesis of the study: Today, there is a social demand for teaching educational robotics in schools as a promising direction of STEM education.

Proposed Methodology

General description

In the study, a set of theoretical and empirical methods was used:

- theoretical: content analysis – analysis of the theoretical foundations of STEM education and educational robotics, functional analysis – determining the features of STEM education and educational robotics, system analysis – systematization of study results;

- empirical: expert survey and online questionnaire of representatives of the expert community – teachers and scientists (teachers, university and college teachers, researchers, graduate students of the education industry, future teachers, etc.) from schools and universities (51 people) to determine the main characteristics of STEM education, the objectives of the introduction of educational robotics in schools, as well as the state of teaching robotics in schools and the level of awareness of teachers and scientists in the field of STEM education.

- Questions for the questionnaire can be conditionally divided into the following blocks:

- determination of the level of awareness of teachers and scientists regarding the teaching robotics in schools and their opinions on the need for the introduction of robotics in educational institutions;

- determination of the state of teaching robotics in schools;

- determination of the opinion of teachers and scientists on the need for training teachers robotics in institutions of higher education.

Algorithm

At the first stage of the study, an analysis of the scientific literature on the use of educational STEM technologies in the study of educational robotics is carried out.

At the second stage of the study, the main characteristics of STEM education and the tasks of introducing educational robotics in schools are determined and the state of teaching robotics in schools is described.

Flow chart

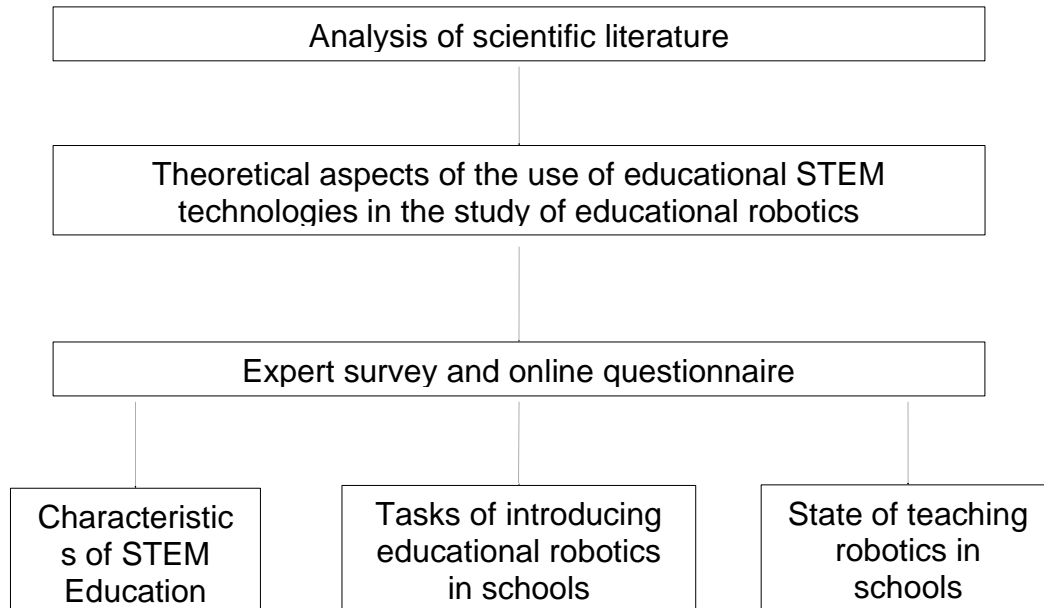


Figure 1
Scheme of the study

Results

According to the experts, the main characteristics of STEM education are the following (Table 1).

Nº	Characteristic	Summary	%*
1	Educational process is divided into “topics”, and not into individual subjects	The educational technology of STEM is based on a synthesis of interdisciplinary and construction approaches, in which the natural sciences are integrated into technological, construction and mathematics. To do this, it is necessary to revise the curriculum, abolishing the independent and abstract teaching of natural sciences and studying them together with technological disciplines, engineering and mathematics, since in practice all these areas are inextricably linked.	91%
2	Putting the knowledge into practice	In practical classes, students can demonstrate how scientific and technical knowledge can be applied in practice. To do this, they independently participate in the development, construction and improvement of modern technical products. First, students study a specific product and its characteristics, then create its prototype.	88%
3	Development of analytical thinking to solve problems	Using STEM helps to develop critical thinking necessary to solve problems that students will subsequently face in life. This characteristic is close to TRIZ (Teoriia Resheniia Izobretatelskikh Zadach, Theory of Inventive Problem Solving) methods – a field of knowledge about mechanisms of development of technical systems and methods for solving problems in	84%

		the field of invention.	
4	Increased self-confidence	The process of creating building structures, machines and mechanisms, testing robots teaches children to achieve their goals and develop their skills in real projects. Each new success increases their self-confidence.	78%
5	Development of communication and teamwork skills	At all stages of project development and implementation, there is active communication and teamwork of all project participants. At the same time, the creation of conditions for discussions and the expression of individual opinions should be encouraged. To do this, students need to learn how to speak and present their constructive proposals. There is a constant communication of both teachers and their colleagues in the team. Due to the activation of creative energy, students better absorb and remember the material of the lesson.	78%
6	Increased interest in the study of technical disciplines	The use of STEM education at the initial stage of teaching creates the prerequisites for increasing student's interest not only in technical, but also in natural sciences. Participation in the development makes students interested in fundamental science, as they see with their own eyes that the creation of real objects and structures is impossible without in-depth knowledge of the corresponding disciplines and in some cases, specific subject areas, for example, biology, chemical technologies, etc.	74.5%
7	Creative and innovative approaches to project implementation	The complete STEM education process includes the following steps: 1) question (statement of the project objective), 2) discussion of the project, 3) discussion of the appearance – design of the construction, 4) building construction, 5) testing of the construction capabilities, 6) further improvement of the construction. The listed stages form the basis of a systematic construction approach. The combined use of various technical solutions and technologies forms the basis for the development of creativity and innovative approach. Only parallel study and subsequent application of scientific knowledge and technology can become the basis for the development of innovative projects.	74.5%
8	Bridge between study and subsequent career	Prospects for the introduction of education in the subsequent career growth, since in the near future, in nine of the ten most popular specialties, STEM knowledge will be required.	72.5%
9	Preparation of students for technological innovations in their future activities	Recent decades provide examples of the emergence of revolutionary technologies. Therefore, one of the tasks of STEM programs is to prepare school graduates for technological innovations that await them in the future.	69%
10	STEM system as one of the supplements to the training program	One of the consequences of using STEM programs for students is an increase in their interest in regular classes in the school curriculum. In particular, in STEM sections students in practice test and consolidate the knowledge that they receive in the lessons of mathematics, physics, computer science.	69%

Note: compiled based on the expert survey; * – percentage of expert references

Table 1

Characteristics of STEM education

The main tasks of the introduction of educational robotics in the STEM education process, the experts include the following (Table 2).

Nº	Task	%*
1	the formation and development of student's interest in natural and exact sciences, as well as their scientific and technical creativity, which corresponds with ideas of STEM education	91%
2	the formation of student's skills when working with technical devices and the skills of practical solutions to corresponding engineering problems	91%
3	the formation of student's skills to work with various sources of information, evaluate them and, on this basis, formulate their own opinion, judgment, and assessment, as well as initiate and create their own development	88%
4	the intellectual development, in particular, the development of logical, algorithmic and creative thinking, memory, attention and scientific intuition in students	88%
5	the formation of a scientific worldview in students as an integral component of the general human culture and the necessary condition for a full life in modern society	84%
6	the formation of cross-industry competencies (knowledge at the junction of various subjects, industries, abilities and skills to apply them in real practical situations)	78%
7	the formation and development of sustainable motivation for learning in students	78%
8	the formation of personality traits that can independently set goals, construction of ways for their implementation, monitor and evaluate their achievements	74.5%
9	the implementation of metasubject links between computer science, mathematics, physics and technology	74.5%
10	the formation of information culture in students	72.5%

Note: compiled based on the expert survey; * – percentage of expert references

Table 2

Tasks of the introduction of educational robotics in the education process

The analysis of the survey of teachers and scientists aimed to determine the state of teaching robotics in schools and the level of awareness of respondents in this field has shown that:

- the majority of respondents (96%) consider robotics a modern educational trend;
- the most popular robotic platforms are Lego, Arduino and Raspberry Pi;
- the majority of respondents (91%) believe that robotics should be implemented in school education;
- the majority of respondents (69%) believe that educational robotics should be implemented in secondary schools, however, a significant percentage of respondents (32%) believe that robotics should be introduced only in schools with a natural and mathematical and/or engineering profile;
- today, the issue of how to introduce robotics to schools remains relevant, since 40% of respondents believe that educational robotics should be introduced into education as a component of STEM education through semantic lines of several STEM subjects at once (computer science, physics, mathematics, technology), 25% – as an elective course and 20% – as a separate academic subject;
- a significant part of respondents (46%) believe that robotics can be distinguished into a separate subject area, for example, “Educational robotics”;

– according to the study, in most schools teaching robotics is absent (69%). At the same time, a significant part of respondents (32%) noted that certain types of robotics training in their schools exist: as an elective course or a study group (51%); as an extracurricular project in preparation for robotics competitions (26%); sometimes as a separate topic in the lessons of computer science, physics and/or technology (16%); as a separate academic subject (7%);

– the majority of respondents (78%) believe that it is necessary to train teachers robotics in institutions of higher education;

– the majority of respondents (78%) are ready for advanced training (retraining, obtaining a second higher education, self-education, etc.) in order to introduce educational robotics in schools or to teach it in extracurricular education institutions.

Discussion

During the discussion of the study results, the experts note the following global trends in the development of the robotics industry:

- growth of industrial robots;
- introduction of robotic mechanisms and integrated automation of production in many sectors of public activity (industry, military, space, automotive, aviation, medicine, the service sector, everyday life, etc.);
- development of the Smart Factories as one of the components of the Industry 4.0 concept, the main idea of which is the development and integration of automated production, data exchange and production technologies into a single self-regulatory system with minimal or no human intervention in the production process;
- accelerating the speed of production automation in the coming years (according to research by the World Economic Forum (WEF), by 2025, the ratio in the distribution of human-robot labor will change towards robotization¹⁸);
- increased interest of the world's largest companies in robotics startups;
- growing demand for specialists in the robotics industry as a whole, since there is already an urgent need for specialists for the development, construction and programming of robots¹⁹;
- increasing popularity of robotics as an educational trend in the world, including due to the intensive development of this industry and the high demand for corresponding specialists.

¹⁸ I. V. Tusikova, "Izuchenie robototekhniki: put k inzhenernym spetsialnostiam", Shkola i proizvodstvo num 5 (2013): 45-47.

¹⁹ M. V. Kuzmina; S. I. Melekhina; A. A. Pivovarov; U. A. Skurikhina & N. I. Chuprakovl, *Obrazovatelnaia robototekhnika: uchebno-metodicheskoe posobie* (Kirov, OOO Tipografiia "Staraia Viatka", 2016).

Thus, the experts conclude about the rapid development of robotics, which, in turn, raises the need for the training of corresponding qualified specialists.

According to the experts, robotics is also one of the areas of development of modern STEM education. Learning with the help of robotics, as experts note, provides an opportunity for students to solve real-life problems that require knowledge of STEM subjects, in particular:

- mathematics (spatial concepts, geometry – to understand the ways of movement of robots);
- physics (electronics, the principles of operation of sensors, which is the basis of robots);
- technologies and design (design of devices, parts of robots, their construction),
- computer science and ICT (programming of robotic systems).

When it comes to robotics in the context of its use in the educational process, the experts note the emergence of a new direction in education – educational robotics.

According to the experts, educational robotics is an interdisciplinary area of student education, in the process of which knowledge on STEM subjects (physics, technology, mathematics), cybernetics, mechatronics and computer science is integrated. At the same time, students see the use of knowledge in mathematics and science when working on projects using robotic platforms. Thus, intersubject communications of robotics and STEM subjects are realized. As the experts say, teaching educational robotics meets the ideas of advanced education (teaching technologies that will be needed in the future) and allows involving students of different ages in the process of innovative, scientific and technical creativity²⁰. According to the experts, educational robotics is an effective tool for learning through project activities, in which STEM, programming and technical creativity are integrated into one project. Teaching robotics gives students an opportunity, through modeling and construction, to explore how the technology works in real life. According to one of the respondents, “teaching robotics provides students with practical experience to understand the technological components of the functioning of automated systems, adaptation to constant changes during the management of complex systems and use of previously acquired knowledge in real situations”. Thus, the experts note the increasing popularity of robotics as an educational trend, as well as the relevance and timeliness of the introduction of educational robotics in the educational process at school²¹.

²⁰ E. E. Bukhteeva; O. A. Zimovnina; S. E. Shishov; R. S. Rabadanova y I. V. Polozhenzova, *Prakticheskie i teoreticheskie obosnovaniia avtonomizatsii uchebnoi deiatelnosti studentov v professionalnom obrazovanii. AI- Amazonia Investiga*. Recibido: 8 de mayo de 2019. Aceptado: 25 de junio de 2019. 575 – 581; S. E. Shishov; G. N. Ulina; N. S. Vinogradova; Zh. N. Dibrova y R. S. Rabadanova, “Massovye otkrytye onlain-kursy: sovremennye tendentsii i perspektivy razvitiia. IJCET-IAEME”, *International Journal of Civil Engineering and Technology* Vol: 9 Issue 13 (2018): 1156 -1163 y P. F. Kubrushko; S. E. Shishov; V. A. Kalnei; N. E. Shafazhinskaia y R. S. Rabadanova, “Vospriiatie uchebnoi informatsii v protsesse obucheniia studentov stroitelnykh i gumanitarnukh universitetov: sravnitelnyi analiz. IJCET-IAEME”, *International Journal of Civil Engineering and Technology* Vol: 9 Issue 11 (2018): 2331 - 2337.

²¹ E. E. Bukhteeva; O. A. Zimovnina; S. E. Shishov; R. S. Rabadanova y I. V. Polozhenzova, “Prakticheskie i teoreticheskie obosnovaniia avtonomizatsii uchebnoi deiatelnosti studentov v professionalnom obrazovanii”, *Amazonia Investiga* num 8 Vol: 20 (2019): 575 – 581; S. E. Shishov;

At the same time, the experts note that in Russia, the development of educational robotics as part of the educational process occurs occasionally at the subject level, in computer science and ICT classes, in out-of-school education, but currently, there is no systematic approach. Therefore, the introduction of robotics in the educational process of secondary and higher education institutions as one of the areas of STEM education, as well as the development of appropriate curricula for students, future teachers and for the teacher training system, are important.

Conclusion

Robotics is currently an educational trend, which is a popular and effective method for studying important areas of science and construction, based on the active use of modern technologies in production, ICT and a high intellectual level of specialists who will work in an innovative economy

There is an urgent need to teach students educational robotics in order to train specialists for future professions related to the robotics industry and to develop student's scientific thinking and technical creativity.

There is a need to introduce educational robotics as a compulsory component of the school curriculum. In particular, ways to introduce educational robotics include:

- the introduction of robotics as a separate educational field, the development of appropriate school curricula and programs and their implementation in the educational process (the most effective way);
- the introduction of educational robotics in the school course in computer science (for example, as a separate module and/or content line);
- the introduction of educational robotics in the school technology course;
- the introduction of educational robotics as components of STEM education through content lines of STEM subjects (physics, computer science, mathematics and technology).

The training of future specialists in the field of robotics requires updating the content of school and university education in accordance with the requirements of today. Therefore, today, the introduction of robotics in the educational process of universities as a mandatory component of the training of future teachers is of particular importance.

In general, the results of the study have confirmed the hypothesis that today, there is a social demand for teaching educational robotics in schools as a promising direction of STEM education.

At the same time, there are questions that remain debatable: whether educational robotics should be implemented in secondary schools or only in schools of a natural and mathematical and/or engineering and technical field; at which class or what age one needs

G. N. Ulina; N. S. Vinogradova; Zh. N. Dibrova y R. S. Rabadanova, "Massovye otkrytye onlain-kursy... y P. F. Kubrushko; S. E. Shishov; V. A. Kalnei; N. E. Shafazhinskaia y R. S. Rabadanova, "Vospriatie uchebnoi...

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to study educational robotics; the goals and content of teaching educational robotics at school (depends on the solution of previous issues); the content of the training of future teachers robotics (depends on the solution of previous issues).

However, the relevance and timeliness of the introduction of educational robotics in schools and the need for training teachers of robotics are not in doubt. Our further studies will be directed to the solution of the above-mentioned issues.

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