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EDUCATIONAL ROBOTICS INTEGRATION INTO THE SCHOOL LEARNING PROCESS

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The article deals with the relevance of introducing educational robotics into the modern educational process of general secondary education institutions. The authors substantiate that the development of the digital economy requires specialists with skills in programming, designing and working with robotic systems. In the article, the authors analyse the main areas of integration of robotics elements into the school curriculum, in particular through computer science courses and STEM education. It shows that robotics is an interdisciplinary field that combines knowledge of physics, mathematics, computer science, cybernetics and other sciences. The authors pay special attention to the role of educational robotics in shaping the digital competence of students, developing their critical and engineering thinking, as well as teamwork skills.

The article identifies the key platforms used to teach the basics of robotics, in particular Lego, Arduino and Raspberry Pi, and their relevance to the age groups of students. It describes examples of the use of robotics platforms for solving practical problems in out-of-school and school education.

The study highlights methods of integrating educational robotics, such as project activities, task-based approach, and participation in competitions. It emphasises the importance of preparing teachers to introduce robotics into the educational process.

The article also discusses the challenges associated with the introduction of educational robotics, in particular the need to update the material and technical base and develop appropriate curricula. The results of the study confirm that educational robotics helps to increase the motivation of students to learn, allows them to integrate modern technologies into the educational process, and prepares young people for professional activities in the field of technology. Perspectives for further research focus on studying the impact of educational robotics on the formation of students' key competencies and the effectiveness of various methodological approaches to its teaching.

Keywords: educational robotics, STEM education, digital competence, programming, robotic platforms, innovative learning.

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ІНТЕГРАЦІЯ ОСВІТНЬОЇ РОБОТОТЕХНІКИ У ШКІЛЬНИЙ НАВЧАЛЬНИЙ ПРОЦЕС

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У статті розглядається актуальність впровадження освітньої робототехніки в сучасний навчальний процес закладів загальної середньої освіти. Обґрунтовано, що розвиток цифрової економіки потребує фахівців, які володіють навичками програмування, конструювання та роботи з робототехнічними системами. Автори статті аналізують основні напрями інтеграції елементів робототехніки у шкільну програму, зокрема через курси інформатики та STEM-освіту. Показано, що робототехніка є міждисциплінарною галуззю, яка об'єднує знання з фізики, математики, інформатики, кібернетики та інших наук. Особливу увагу приділено ролі освітньої робототехніки у формуванні цифрової компетентності здобувачів освіти, розвитку їхнього критичного та інженерного мислення, а також навичок командної роботи.

Визначено ключові платформи, що використовуються для навчання основам робототехніки, зокрема Lego, Arduino та Raspberry Pi, і їх відповідність віковим групам здобувачів освіти. Описано приклади використання робототехнічних платформ для вирішення практичних завдань у позашкільній та шкільній освіті.

У дослідженні висвітлюються методи інтеграції освітньої робототехніки, такі як проектна діяльність, задачний підхід та участь у змаганнях. Наголошено на важливості підготовки педагогів до впровадження робототехніки в навчальний процес.

У статті також розглянуто виклики, пов'язані з упровадженням освітньої робототехніки, зокрема необхідність оновлення матеріально-технічної бази та розробки відповідних навчальних програм. Результати роботи підтверджують, що освітня робототехніка сприяє підвищенню мотивації здобувачів освіти до навчання, дозволяє інтегрувати сучасні технології у навчальний процес і готує молодь до професійної діяльності у сфері технологій. Перспективи подальших досліджень спрямовані на вивчення впливу освітньої робототехніки на формування ключових компетентностей учнів та ефективності різних методичних підходів до її викладання.

Ключові слова: освітня робототехніка, STEM-освіта, цифрова компетентність, програмування, робототехнічні платформи, інноваційне навчання.

Introduction of the issue. The development of society depends on the ability of its citizens to effectively use the means of modern information and communication technologies, requires specialists who can develop rapidly, integrate their knowledge into other fields, adapt to constant change, use the acquired knowledge in real situations, take an active position as developers, not as passive recipients of knowledge or consumers of technology. Therefore, the training of the modern generation of young people who know how to design, program, and use robotic systems is linked to the requirements of today. The labour market is increasingly demanding specialists whose existence used to seem fantastic, such as drone operators, robot operators, robot service engineers, robotics programmers, designers of smart homes, roads, etc. As such, the introduction of robotics elements into the educational process is becoming a necessity.

Robotics is an applied science studying the design, development, construction, operation, and use of robots [37]. Nowadays, robotics is an applied science that deals with the development of automated systems and robots designed to replace humans in difficult and dangerous conditions [24].

The emergence of a public demand for training engineering personnel for the digital economy has defined a new direction in the content of schoolchildren's education – learning the basics of robotics. Robotics is currently considered in educational practice as a new direction in the content of education and as a new learning technology. A significant amount of robotics education is closely related to algorithmization and programming.

The introduction of the basics of robotics into the educational process has formed a new area in education – *educational robotics*. Educational robotics combines knowledge from various subjects and fields of knowledge

(physics, mathematics, biology, chemistry, technology, computer science, drawing, cybernetics, mechatronics), provides students with practical experience to understand the technological components of automated systems, allows students of all ages to engage in the process of innovative and scientific and technical creativity, and helps students develop skills in practical engineering problem solving. *The main idea behind educational robotics* is the idea of advanced learning, i.e., teaching technologies that will be needed in the future.

Current state of the issue. Ukrainian scientists and educators are also actively researching the development of robotics in education. In particular, the works of N. Morze [15], O. Strutynska [19], V. Hlazova [9], S. Baranova [5], I. Kabak [11], Y. Buta [7] and others consider aspects of robotics integration into the educational process. Today, Ukraine is actively searching for ways to introduce robotics into the educational process of educational institutions. Among the researchers and practitioners dealing with this topic, we can single out such specialists as N. Morze, R. Belzetskyi, D. Borovyk, A. Vasyliuk, M. Hladun, S. Dziuba, O. Zadorozhna, I. Kit, O. Kit, P. Klymenko, Yu. Kovalov, D. Kozhem'aka, T. Lysenko, V. Lutsenko, A. Luchkovskyi, O. Martyniuk, H. Michurina, K. Nifantiev, V. Nikolaichuk, I. Onishchuk, S. Pakhachuk, V. Sokolov, M. Umryk, S. Khachatrian, B. Shevel and others.

However, the analysis of existing experience and our own observations show that the development of robotics in the educational process in Ukraine is still not receiving enough attention.

Regrettably, despite the interest of students in robotics, most teachers are unable to introduce the basics of robotics into the educational process as they lack the necessary training. This problem is not unique to Ukraine. For example, the United States has introduced a national programme to train teachers who are ready to work in a unified system of science and technology. Something similar is being implemented in China, England, and Australia [11].

Aim of the research lies in analysing the role of educational robotics in modern

education, identifying key approaches to its implementation in the learning process, and justifying the need to integrate robotics elements into the school curriculum, in particular computer science, to develop students' technical thinking, creativity and digital competence.

The following **methods** were used in the study: analysis and synthesis (for reviewing literature, experience of introducing robotics into the educational process, and for structuring information about technological platforms); comparison (for assessing different robotics platforms (Lego, Arduino, Raspberry Pi) and their adaptability to different age groups); systematisation (for classifying educational robotics tools and methods by functional and age criteria); descriptive method (for formulating conclusions about the impact of educational robotics on solving problems).

Results and discussion. Nowadays, according to the state education standard, an individual educational field 'Robotics' does not exist. However, the Ministry of Education and Science has already taken some steps to combine related subjects into one integrated course.

In general, the study of robotics elements occurs sporadically at the subject level during the study of a school computer science course as a separate topic or module. Currently, the basics of robotics are taught mainly in the system of additional education of schoolchildren in clubs, electives, educational centres of scientific and technical creativity, modern innovation centres, and private educational institutions.

As a rule, the basics of robotics are taught to the youngest students, encouraging them to learn more complex topics in the future. The study of robotics elements in the school computer science course activates additional cognitive activities in students, increases their motivation to study complex theoretical material, and changes their attitude to complex disciplines of the natural and mathematical cycle.

Therefore, we note that *the purpose of educational robotics* is developing the abilities of children who are interested in robotics, implementing their creative ideas

in practice through design, modelling, programming using modern computer technologies and intelligent designers.

The main tasks of implementing the study of the basis of robotics in the educational process are as follows: acquaintance of students with the basic technologies used in the creation of robots; demonstration of the possibilities of robotics as one of the main areas of scientific and technological progress; disclosure of interdisciplinary links with physics, mathematics, computer science; formation of students' skills in working with technical devices and skills in practical solution of actual engineering and technical problems; formation of students' skills and abilities in designing, modelling and constructing; developing students' project skills, mastering the methods of conducting experiments; developing students' scientific outlook; increasing students' motivation to invent and create their own robotic systems; strengthening students' specialised training, their orientation towards engineering and technical professions; forming and developing students' sustainable motivation to learn; learning the rules of competitions in design, programming and robotics.

It is important to note that learning the basics of robotics is based on the "three pillars": design, modelling, and construction, which are based on programming.

A significant amount of robotics education is closely related to algorithmization and programming. Without mastering the concepts of algorithm, basic control algorithmic structures and their use in programming, it is impossible to master the control of a robotic structure, as well as to solve such problems as robot movement in space and obstacle avoidance using sensors, movement along a given trajectory, etc.

The main principle that should be followed in the process of teaching the basics of robotics: *from simple to complex*. It is also necessary to rationally *plan the time for studying*, because, in general, training takes place during extracurricular activities.

Robotics involves solving practice-oriented problems. And the teacher

should not give students ready-made solutions right away. It is important to teach students how to formulate questions, put forward hypotheses, look for ways to solve problems, and analyse the results of their work. The teacher should understand that different students may get different results. Students, in turn, must understand that to solve a problem, they must acquire new knowledge, conduct research, analyse the results, and draw conclusions.

In this regard, it is advisable to teach robotics using a task-based approach. By "task-based approach" we mean a special method of teaching using tasks; but "as a kind of a broader method – the method of appropriately selected tasks, which is based on learning through tasks, when in the educational process students acquire new theoretical knowledge in the course of solving an educational applied task, and the educational task itself is considered as a certain means of mastering new theoretical material".

Nevertheless, the most appropriate and easiest way to learn the basics of robotics is as part of a school computer science course. And, as we said, learning should start with the simplest things.

That's why the use of LEGO in the educational process can be considered a propaedeutic course in robotics. After all, LEGO has developed a number of construction sets, including robotic constructors that can be programmed.

The LEGO WeDo construction set can be used to teach the basics of robotics in primary school. In addition to the standard LEGO parts (slats, axles, wheels, gears), it consists of a set of sensors and actuators that can be connected to USB. It also includes software in the form of an intuitive programming environment based on Scratch. In addition, the kit comes with a set of 12 tasks that are separate projects with a step-by-step description of how to complete them. This allows students to assemble and program models on their own, and then use them to complete practical tasks.

In secondary school, the most popular construction set is LEGO Mindstorms NXT.

It also consists of standard parts, and it also has sensors, motors and the NXT programmable unit. It is the presence of a separate programmable unit in combination with a high-level programming environment that makes this set a serious tool that allows you to create robots that can perform quite complex tasks. At the same time, this constructor is simple and flexible in use, it makes it possible to select parts for almost any task, and the combination of several sets allows you to solve a rather complex task.

TETRIX, a robotics construction set designed specifically for robotics classes or lessons, can be used to teach robotics elements in high school. The workflow is designed so that students can assemble at least one robot during the lesson. The main building element in the kit is beams made of lightweight aluminium alloy, which is used in rocketry. They give the three available robot models the necessary rigidity and stability. It also contains a set of metal parts, sensors, servos, and an NXT programmable unit. Robots are programmed in the RobotC language. By the way, this particular constructor is the main one used in the international FIRST Tech Challenge competition.

Programming a working robot as an autonomous device or an entire robotic complex allows students to learn various methods of modelling objects and processes, as well as the principles of autonomous control of robotic objects. Robot control, while seemingly simple, is complex and involves solving complex engineering problems. Robotics includes the study of the basic principles of calculations of the simplest mechanical systems, algorithms for their automatic operation, programming methods and principles of operation of controllers. Designing and controlling robots develops not only engineering thinking, but also self-confidence, creativity, and the ability to make non-standard decisions.

Currently, a significant number of microcontrollers and platforms are available for controlling physical processes. The vast majority of them are united by the fact that individual programming modules are combined into

an easy-to-use design.

A *robotics platform* is a set of technical components (controller, motors, connection systems) and a software component for programming (control) [13].

As the manufacture of technical components for construction is a complex and time-consuming process, ready-made platforms with a large number of modular (off-the-shelf) components and software are used to facilitate their programming. Generally, all robotic platforms are supplied in special boxes (cases) for easy storage.

Robotics platforms can be classified according to the criteria of a set of components for creating robots:

1. Designers for creating and programming robots.

The kits include a basic set of components for mounting, motors (including servos), a microcontroller ready for programming from a computer or smartphone, instructions for assembling ready-made robot models, and a programming tool. All of these kits contain enough parts to build and program at least one robot with a repeating function. You can program a robot to perform certain actions using visual programming languages (Scratch, Blockly).

This group includes Lego, Lego Mindstorm, JIMU, MakeBlock, Robobloq, Ubtech Jimu Robot, Robotis dream.

It should be noted that Lego is the most commonly used construction set in Ukraine when studying robotics elements.

2. Programmable circuit kits.

The kits have an interface with additional add-ons, which simplifies the process of designing and connecting peripherals. Typically, the set includes a variety of sensors, different types of motors and other components, which does not limit students to creating only robots. The programming languages used here are already more complex, high-level programming languages such as C++, Python, etc.

The Arduino and Raspberry Pi platforms are widely used in the study of the basics of robotics.

The Raspberry Pi is a miniature and very lightweight single-board computer with a Linux (Raspbian) operating system developed by the British company

Raspberry Pi Foundation in 2012. It was originally intended as a low-cost option for learning programming, but quickly gained popularity in other areas, including robotics. Today, there are already eight versions of this computer, each with its own specifications and price. It consists mainly of a fully assembled four-layer printed circuit board, to which you also need to order a case, power supply and memory cards separately, and it is possible to connect a monitor, keyboard, mouse, camera, microphone with speakers, as well as special sensors and actuators. Due to its compact size, it is very convenient to use.

The official language used to program the Raspberry Pi is Python. You can learn Python from the 7th grade, when students already understand computer science. And using a Raspberry Pi-based robot in combination with computer science lessons will improve the learning of programming.

Arduino is a hardware computing platform whose main components are an I/O board and a development environment. Like Raspberry Pi, Arduino is a single-board computer.

Arduino is an open source platform for working with a variety of physical objects. It is a board with a microcontroller and a development environment for creating software. The platform was released in 2005 as a tool for students of the Interaction Design Institute Ivrea (IDII) in Italy [32].

There are many types of Arduino platforms. Each of them is characterised by its size, number and purpose of outputs, frequency, and microcontroller memory. But they have a common feature in that they are interchangeable. In addition, the presence of expansion boards (shields) also increases its functionality. Shields (except for small modules and the LilyPad board) are connected to the Arduino using the pin connectors on them. Thus, shields can provide an Internet connection, wireless communication for some Arduino devices, recording data on microSD cards, controlling DC motors, sending SMS messages, making calls, exchanging data via GPRS, overlaying text on analogue video, etc.

For a more in-depth study of the basics of robotics, the Arduino platform is best used in high school, as Arduino's

capabilities are broader than Raspberry Pi's due to the more powerful C++ programming language, which is now used in a large number of not only software projects but also devices. Thus, with Arduino, students will be able to create more projects, while also using their creative and technical knowledge.

Thus, thanks to its simple and intuitive programming environment, wide range of expansion boards, and affordable price, Arduino has a number of advantages over other similar platforms. It is ideal as a starting platform for developing robotics skills for beginners. Gradually, it allows you to program actions to control any mechanism, including complex constructors and robots.

However, the Arduino platform has a drawback. There are expansion boards that require soldering connectors or wires, which, in turn, can be dangerous for students. For this reason, it is better to look for analogues of these boards with built-in connectors so that you do not need to use a soldering iron.

3. Designers for physical experiments without programming.

A separate group includes construction sets that are not designed to create robots, but are well suited for learning the basics of automation and performing physical experiments without programming. These are, for example, Engino STEM, Fischertechnik, Lego Science and Technology, BitKit Hydraulics, etc. They are mainly used to teach younger children.

It should be noted that each of these robotic platforms is aimed at certain age groups and allows solving certain types of tasks.

However, experience shows that Lego and Arduino-based kits are mostly used to teach the basics of robotics. In our opinion, this is primarily due to the active advertising of these brands, a sufficient number of educational materials that are freely available and the use of these platforms exclusively in robotics competitions and contests.

Since most robotics kits can be programmed, all robotics constructors are also divided into groups depending on *the*

programming language:

- use of visual programming (Scratch by Massachusetts Institute of Technology and Blockly by Google);
- use of high-level programming languages (most often C++);
- no programming support.

Another criterion that can be used to classify robotics platforms is the *function of controlling* (programming) the robot via a smartphone and/or tablet:

- Windows, Mac OS, Linux (for programming robots from a computer);
- iOS, Android (for programming robots from mobile devices);
- no support.

As students of different age groups are engaged in the basics of robotics, all the designers can be *divided by age*:

- under 6 years old;
- 6-8 years old;
- 8-12 years old;
- 12 years and older.

However, despite all the obstacles that arise on the way to the development of robotics, the interest of students of all ages in the classroom is only growing. But learning will be more effective and productive if students use their knowledge in real-life situations. One of the best ways to showcase the results of their work is through group games, contests, competitions, championships, and olympiads. After all, participation in such events enables students to consolidate their knowledge, forms an adequate self-assessment of their capabilities, and motivates them to continue working.

Robotics has been included in the programmes of many championships and competitions, and the participation of Ukrainian teams in them contributes to the development of the study of the basics of robotics in our country. For example, the World Robot Olympiad, the All-Ukrainian STEM Festival ROBOTICA, the FIRST Tech Challenge tournament, the INFOMATRIX international computer project competition, WoldSkills Ukraine, and the Asimov Olympics robotics competition, the All-Ukrainian Online Robotics Competition, the Robotics and Intelligent Machines section of the Intel Techno Ukraine All-Ukrainian Science and Technology

Competition, the Sikorsky Challenge Science Festival, the Robotics section of the Junior Academy of Sciences, science picnics, hackathons, etc.

Therefore, it is worth noting that working with students in robotics clubs, electives, and additional classes makes it possible to train specialists with a new way of thinking, capable of solving problems using modern tools: computer-aided design systems, computer modelling environments, automatic control, and, as a result, capable of making a breakthrough in modern science and technology.

Considering the large number of robotics competitions involving more and more participants, it can be noted that sports (competitive) robotics is rapidly developing alongside educational robotics.

Learning based on sports robotics encourages students to explore ideas, control objects, test many different engineering solutions, ask questions, make observations, collect data, and form hypotheses about what they are working with. In addition, students see the result immediately: either everything is done correctly and the robot works, or there is a mistake somewhere and the robot does not work. That is, there is instant feedback in such activities. Also, robotics allows students to visualise their decisions that they make to solve a problem. It is also important that sports robotics encourages teamwork.

Although, as practice shows, children are both quickly carried away and quickly lose interest in solving a problem if the slightest difficulty arises on the way. The teacher should intervene here and help find different ways to win, motivate students in solving problems, and aim them at the result.

Conclusions and research perspectives. As a result of the study of the problem of educational robotics, the following conclusions can be drawn: the introduction of robotics in education creates new opportunities for the development of modern skills in students, such as technical thinking, skills in working with innovative technologies, creativity and teamwork (this meets modern educational needs and

contributes to the formation of digital competence, which is an important component for the successful self-realisation of young people in the digital economy; educational robotics is becoming a powerful tool for strengthening schools.

Therefore, the introduction of robotics in education, in particular in the school computer science course, promotes the integration of new technologies into the learning process, develops skills that meet the requirements of modern society, and creates the preconditions for preparing young people for successful professional activities in the field of technology.

Perspectives for further research in educational robotics include methodological aspects of its integration into the educational process, development of students' digital and technical competence, teacher training, improvement of educational platforms and technologies, and use of robotics as a career guidance tool. Significant directions include researching the effectiveness of different teaching approaches, the impact of robotics on students' critical thinking and creativity, developing professional development courses for teachers, introducing artificial intelligence and cloud technologies into education, and analyzing the role of robotics in choosing a future profession.

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