

Innovations

Educational Robotics and the Learning Process: In Search of Key Effects

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Abstract. *Introduction.* Educational robotics is becoming an important part of the education system in a number of countries around the world. Educational robotics is being gradually integrated into various stages of education such as preschool, secondary, vocational and additional education. There is a growing number of studies in the field of studying robotics in the educational process. This topic is relevant due to the development of artificial intelligence and robotics, and the introduction of these products into the education system. **Aim:** The purpose of this paper is to explore the impact of educational robots on the learning process in general and to determine the effects that robots have on the educational environment, students themselves and their learning outcomes. **Methodology and research methods.** Through a bibliographic analysis, we have identified several positive effects of using educational robots, including increased student motivation and learning efficiency, advancement of lateral thinking and worldview, development of a comfortable educational environment, shaping an improved education strategy, gamification of educational process, and improvement of social skills. **Results:** The results indicate that the use of educational robotics has significant potential for improving the quality of education in various fields and promoting more flexible and innovative learning models. **Scientific novelty.** Each of positive effects of using educational robots, the features of their formation, as well as the characteristics of educational robots that allow effects to be achieved are discussed in detail. **Practical significance.** The article describes the effects of introducing robots into education, which is possible to improve its quality at various stages and areas.

Keywords: educational robotics, learning process, effects of robotics, robotics education, educational environment

Introduction

The use of innovative educational technologies in teaching and learning has become an important topic in education worldwide. Modern technologies play a crucial

role in helping students acquire skills, knowledge, and motivation for learning [1]. The goal of modern education is to use technology to improve the standard of education by developing individuals with critical and creative thinking abilities who can analyse current problems in society and develop innovative solutions [2]. Robotics is one such technology that is revolutionising the world today. Educational robots are gradually becoming interesting tools for preschool, school and higher levels of education, as well as in particular for the fields of STEM (science, technology, engineering, and mathematics), social sciences, language, medicine, etc. [3].

The education model that integrates robots into the learning process is a popular scenario in a number of countries, especially in Asia [4] [5] [6]. Robots are used as mentors or teachers' assistants during classes and to help students develop social skills. Virtual robot teachers and artificial intelligence (AI)-based online courses also became quite popular [7]. Moreover, the universities of China, Singapore, Japan, Hong Kong, and South Korea are consistently appear in the top university rankings in studying robotics [8], which is the most promising field for the introduction of educational robots [9]. According to the UNESCO Institute for Statistics for a number of Asian countries the pupil-to-teacher ratio is quite high (for example, in Fiji, India, Philippines, etc.) [10] and there is the problem of a shortage of teachers [11] [12]. Thus, the integration of robotics into education is especially relevant for Asian countries.

In recent years, there has been growing interest in studying the effects of applying robotics in various educational environments [13]. Any robot interacting with humans for educational purposes, and designed to help people learn, can be considered as an educational robot [13]. Unlike artificial intelligence, such robots perform a certain range of jobs which mainly amount to analysing information [14].

The decision to use an educational robot of one kind or another depends on the subject, the teacher, the characteristics of the student, and the learning format. Robots can perform various functions in the educational process, depending on the level of their involvement [3] [15]. Firstly, the robot can be used as a learning tool, with students directly involved in designing, building, and programming it, and subsequently interacting with it (for instance, multi-functional suite robots or virtual simulation robots). In this case the robot is a passive object in the educational process. Secondly, the robot can take part in learning as a fellow student, peer, or friend. Such robots (for instance, intelligence assistants, robots teachers and social robots) are helpful for individualised learning, interactive question-and-answer sessions with students, emotional exchanges with students, etc. [16]. Thirdly, robot tutors specifically designed to teach students and help them learn are being actively introduced in various fields of education [3] [15]. In the second and third cases, robots are active participants in the learning process and continuously interact with students and teachers alike.

Educational robots differ in various characteristics. First, its flexibility and adaptability to various disciplines: robots' configuration and functionality can be freely modified to match students' and teachers' needs depending on the subject area and the complexity of learning [15]. Second, its natural interactions with the students: due to their speech and voice recognition functionality and the ability to gauge physiological indicators, educational robots can read and analyse students' behaviour and re-

respond by changing their own, e.g., the tone of their voice or movements [17]. This functionality reduces the barrier between them and humans, which is extremely important for creating a comfortable educational environment. Third, several studies highlight such typical features of robots as the digitisation of data, perfecting repetitive operations [15] [18], and increased attention to each particular student (humanisation) [19] [20]. The aforementioned features of educational robots positively influence the effectiveness of the learning process.

There is a growing number of studies in the field of studying robotics in the educational process. This topic is relevant due to the development of artificial intelligence and robotics, and the introduction of these products into the education system. Most of the research in this area is aimed at studying the effectiveness of teaching with the help of robots, as well as developing new teaching techniques that can be applied using robots [9]. Typically, research focuses on one specific area (STEM, social sciences, etc.) and does not consider the general effects of robots on the educational environment. This study aims to explore the key effects of robotics on the educational process in detail. We present an overview of those effects that are common to different levels and areas of education. This is extremely relevant, since it allows us to trace how the introduction of robots can affect and improve the educational process as a whole.

Research Methodology

Sampling

To understand the key areas of educational robots' application, a bibliometric analysis of the Scopus database was conducted. It identified the main areas where the use of such robots was most effective (e.g., assessing robotics' impact on the learning process, studying the perception of robotics in education by different parties such as teachers, students, etc.). Computer science and engineering were determined to be the leading areas where robots are used as both objects directly designed by students and as active participants in the educational environment (robot teachers, social robots). Social sciences and mathematics also were among the leading areas in terms of robot application, but there robots predominantly serve as tutors and fellow students. Physics and astronomy, decision sciences, psychology, medicine, materials science, arts and humanities, biochemistry and some other fields of study turned out to be less popular fields. Thus, the bulk of the sample for analysis in the scope of this study was made by STEM and a number of social sciences.

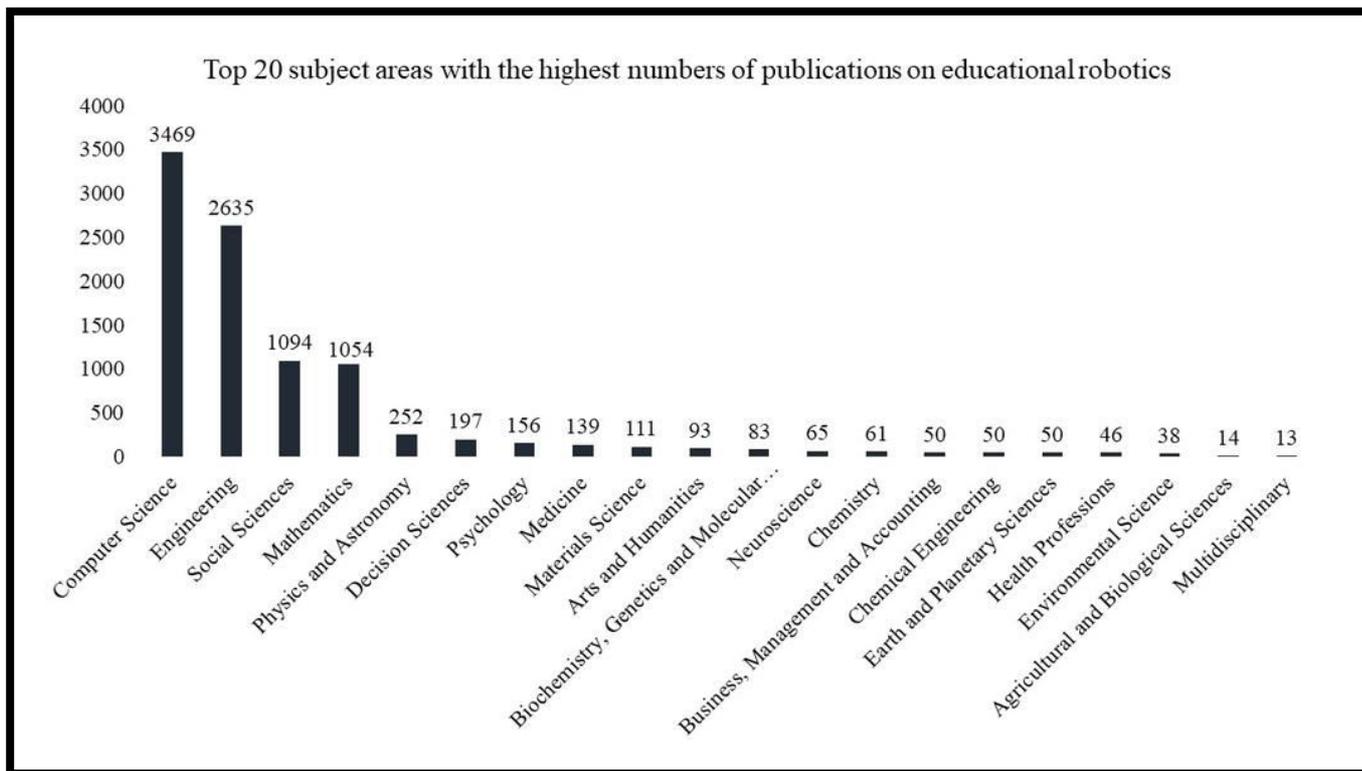


Fig. 1. Educational Robots' Application Areas Based on Bibliometric Analysis

Source: authors, based on 4714 publications found in the Scopus database using the query “education* robot*” for all years (some articles cover more than one area).

As for the leaders in using educational robots, the world leader in relevant research is the United States, followed by China, Japan, Spain, Italy, Brazil, the UK, Germany, Greece, Taiwan, the Russian Federation, and the Republic of Korea.

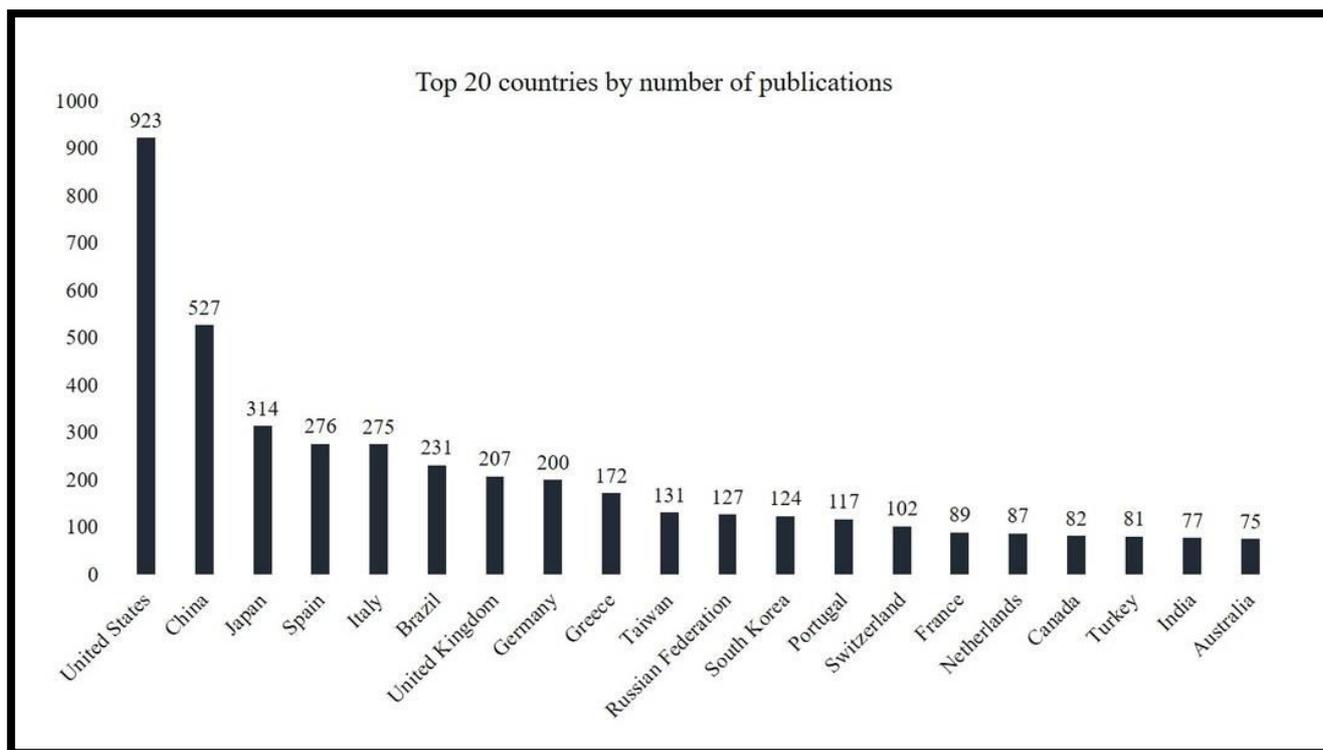


Fig. 2. Countries Conducting Educational Robotics Research Based on Bibliometric Analysis

Source: authors, based on 4714 publications found in the Scopus database using the query “education* robot*” for all years (the figure shows 4217 publications as top 20 countries are selected).

As to the educational environment, studies on this topic most often focus on secondary and additional education. However, since robots are applied in education at various stages, we have analysed the effects of using educational robots on learning in general. Regarding the application of robots at particular stages, in preschool education, robots are mainly used to help children develop basic logical and mathematical thinking skills [21] [22]. In secondary education, robotics is widely taught as a specific subject and also integrated into other academic disciplines (mainly STEM) [23] [24]. In vocational and additional training, robotics is applied in areas where students interact with complex automated systems [25].

Methods and Stages of Analysis

Bibliographic analysis was chosen as the research method. At the first stage of the bibliographic analysis, a database of academic papers was built, covering such areas as computer science, engineering, social sciences, mathematics, etc. As was mentioned earlier, these studies focus on specific features of using robots at all education levels, so the results of our study cover various education areas and stages.

The Mendeley reference manager was used as the data source. Studies were selected based on citation index values (the minimum threshold value was set at ten publications, which allowed the authors to identify the most influential papers on the topic

under consideration). After the database was built, the papers were grouped by area (STEM, humanities, etc.) to take into account specific features of using robots in specific fields; particular attention was paid to robotics' role (robots as active/passive participants in the educational process).

At the second stage, educational robotics studies were analysed, which allowed for determining the specific features of using robots at various education levels. We identified the key effects of applying robotics in the educational environment. These include increased student motivation and learning efficiency; the development of lateral thinking and worldview; building a comfortable educational environment; improved educational strategy; the gamification of the educational process; and the development of social skills.

At the next stage, these effects were analysed in detail and described. This was accomplished by summarising the findings of academic papers in various fields regarding the effectiveness and usefulness of robotics in education. The stages of the study are described in Figure 3.

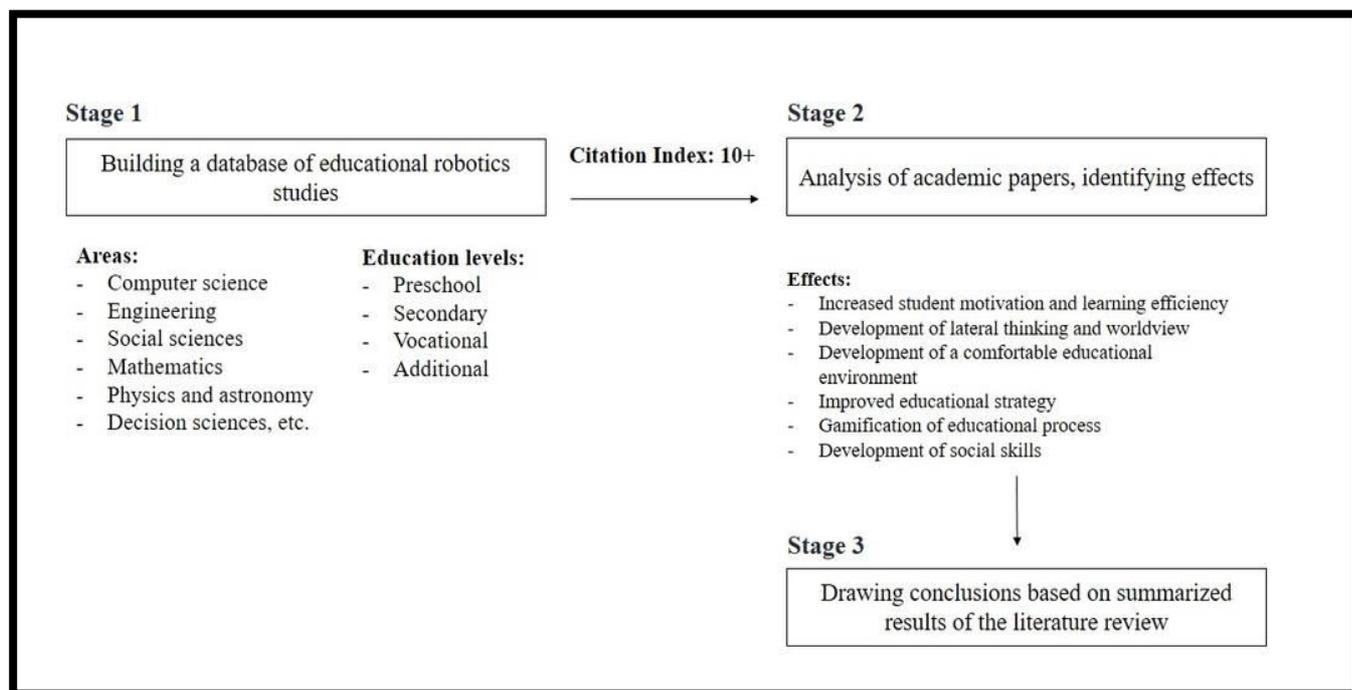


Fig. 3. Stages of the Bibliographic Analysis

Source: prepared by authors.

The identified effects and the frequency of mentions in the analysed literature are presented in Table 1. These topics are common to the education process as a whole at its various stages and in different subject areas. An in-depth analysis of academic papers was carried out for each of the effects. The results were summarised and presented in a structured way.

Table 1

Identified Effects of Robotics and Number of Mentions in Studies

Effect	Number of mentions
Increased student motivation and learning efficiency	34
Development of lateral thinking and a worldview	27
Development of a comfortable educational environment	23
Improved educational strategy	21
Gamification of the educational process	18
Development of social skills	17

Results**Increased Student Motivation and Learning Efficiency**

The fundamental theory explaining the role of robots in the educational process is constructivism¹, which views knowledge as experience gained through interactions with the environment [26] [27] [28]. This theoretical framework assumes a learner-centred educational process and emphasises the use of material objects and linking previous knowledge with new information obtained in the real world [29]. This is a prerequisite for the introduction of educational robotics in order to make the learning process more efficient and practice-oriented.

Empirical studies that evaluate the effects that robots have on the learning process do confirm that by introducing such a practical element education, robots improve educational outcomes. A distinctive feature of educational robots is their ability to affect students' motivation and the subsequent results of educational activities. The effects of using robots in the educational process can be divided into cognitive (promoting the overall thought process) and affective ones (promoting emotional reactions which increase students' interest in learning) [30]. Introducing robotics improves the quality of the educational process in terms of learning outcomes, the assimilation of material [31], and developing problem-solving skills, measured both objectively and subjectively (e.g., through self-assessment) [31][32]. These effects have been noted for all students regardless of their age [33], gender [34] [35], and the subject area in which the educational robot was applied (STEM, humanities, medicine, etc.) [36] [9]. Thus, robots can be seen as useful learning tools that promote the development of various skills and support the educational process [34][37].

Researchers are also interested in assessing educational robots' impact on affective results, where the most important characteristic is the presence effect arising due to interactions and strengthening students' involvement in the learning process. For

¹ According to the constructivism theory, learning is an active process in which the learner constructs new ideas and concepts based on their previous knowledge. New knowledge is created during the learner's interaction with the external environment, as they process information in the course of obtaining practical experience. The constructivist approach is considered particularly effective in science, mathematics, and vocational education.

example, a number of studies confirm that students show a stronger motivation to learn when they interact with educational robots [31] [32] [9] [30]. Both developing educational robotics during classes (when robots are created by students and used in the educational process as passive objects), and using robots as active participants in education (i.e., social robots and robot teachers) increase students' engagement and strengthen their interest in science and technology [9]. The use of educational robotics in the learning process also promotes the active development of the entire range of students' cognitive abilities (perception, imagination, thinking, memory, and speech) [38]. In particular, the use of robots contributes to the emergence of an environment that provides students with new visual and auditory experiences, thus contributing to the development of their perception. Robots create interactive models that help students better understand complex concepts and processes, promote the imagination through the use of virtual and augmented reality, and help capture information through the use of interactive learning materials [30].

Development of Lateral Thinking and Worldview

Studying robotics in the course of education primarily involves the use of various tools, making computations using special devices, evaluating with the help of specialised software, and adjusting and observing robots' activities. The introduction of robots leads to the emergence of a functional educational environment that allows students to learn through practice: make measurements and calculations, configure the robot, design one's own software products, etc. [39] [9]. Thus, the main elements of such an educational process are measurement, observation, calculation, and evaluation, which contribute to the development of cognitive skills as well as scientific and creative thinking [40][41] [42] [9].

Educational robots also help students to develop cognitive skills such as problem solving and strategic thinking [36] [34]. Using educational robotics as a passive object in the educational process promotes the development of critical thinking through designing, assembling, coding, operating, and modifying robots for particular purposes [43][9]. Relevant research has substantiated the idea that educational robotics strengthens students' involvement in the educational process, contributes to practical learning and a deeper immersion in science and technology [9]. Thus, educational robots can help students gain experience that will promote their lateral thinking [44] [9].

Educational robotics contributes to individuals' intellectual development, in particular logical and algorithmic thinking when solving applied problems [45]. This affects the development of a scientific worldview [46] [45]. Educational robots create an environment suitable for the practical application of scientific concepts and principles. For example, students can design their own robot to perform certain tasks based on the knowledge they have already acquired, which helps them see how scientific knowledge can be applied in real life and also deepens their understanding of the importance of science [9]. Therefore, educational robots can contribute to scientific research by becoming a tool for conducting it, which extends students' understanding of the essence of research and its various stages [45]. Accordingly, educational robotics

is used to collect and analyse research results and develop models and simulations, which allows students to test their ideas and assumptions in a safe and controlled environment.

Development of a Comfortable Educational Environment

A number of studies explore such educational robots' functionality as personalisation: robots can be configured to work with each individual student taking into account their particular needs, abilities, and learning pace [47] [48]. In addition to selecting personalised content, robotic teaching systems frequently provide additional customisation to support specific learning styles and interaction preferences. For example, educational robots can be customised for different learning styles, such as visual and auditory, allowing them to adapt to each student's specific needs. This leads to the emergence of an educational environment where each student can work at their own pace and receive personalised support in the most convenient format [30]. Simple forms of personalisation, such as the robot using the student's name or referring to personal data in the educational environment, also improve the perception of information and serve as important factors in forging a comfortable educational environment with a high level of student involvement [49][30]. Also, by "erasing" the psychological barrier, robots become effective participants in the educational process, since interacting with them makes students feel more comfortable due to a reduced fear of making mistakes and negative assessments [50] [51].

To summarise, the personalisation of learning and the elimination of psychological barriers and fears of negative evaluation are the key characteristics of a learning environment that features educational robots. This creates an inclusive educational environment contributing to successful learning and student development by adopting an individual approach to teaching, and adapting each student to the educational process.

Improved Educational Strategy

The use of robots in education from the basic to advanced levels, and with different content, requires a multi-layer architecture that allows for interacting with the robotic system at all stages of the educational process [25]. Since robots have flexible architecture and can be adjusted to meet specific requests, they can be successfully adopted to various levels of learning complexity. The high effectiveness of using robotics in the educational process is confirmed by studies of preschool [52] [30], secondary [52] [9] [30], vocational [39] [2] [9] [25], and additional education [38][54].

When robots are used, the main learning levels are typically determined, the gradual completion of which forms the educational strategy [39]. Due to robotics' adaptability, it can be applied at various stages of education by increasing its complexity. Complexity levels include basic, intermediate, and advanced, which generally correspond to different levels of education. Robots can adapt to specific subject areas and the above complexity levels. At the basic level, students' first contact with robotics takes place. At the intermediate level it is assumed that students already have basic robotics skills, so at this stage this tool is applied more actively, and more complex applications are developed. At the advanced level students perform more complex, in-

strument-oriented tasks [39][9]. Robots' adaptability determines the overall learning strategy, which allows for the successful application of robotics at its different stages.

Gamification of Educational Process

Robots offering a game-like approach are integrated into the modern educational process at various stages. The game environment such robots create is becoming an important factor contributing to the effective assimilation of information and development of various skills by students, such as creativity, imagination, problem-solving, and social skills [55]. In particular, the learning process may involve engaging students in gameplay interactions with robots [56] and direct participation in various games for educational purposes [39][52] [56]. An important element here is interactivity: educational robots offer tasks and games that require the active participation of students, thus promoting their involvement in the learning process and minimising the passive perception of information (e.g., creating a virtual world and learning in it). Thus, game elements contribute to the emergence of an effective learning environment and strengthen students' motivation and interest in learning[57] [58].

Researchers also note the competitive element which allows one to engage students in the teamwork process of designing robots and contributes to the development of communication, leadership, and cooperation skills. Various robotics competitions are becoming increasingly popular (e.g., FIRST Robotics Competition², RoboCup Asia-Pacific³, Asia-Pacific Robot Contest (ABU Robocon)⁴) which promote teamwork skills in a game environment [59] [43], strengthen the intrinsic motivation for learning as well as interest in science and technology [60]. The competitive element inherent to this type of competition promotes the exchange of ideas and collaborative problem solving, encourages students to participate in learning, and increases their motivation to achieve better results [61].

Development of Social Skills

A popular scenario for using robots in the educational process is a project-oriented approach: asking students to accomplish various tasks as a team, which facilitates the development of a wide range of communication skills [43]. Accordingly, there has been an increase in the number of studies on educational robotics and its impact upon students' social skills [62]. Both the introduction of social robot teachers (robots as an active element of the educational process) and educational robots designed by students themselves (robots as a passive element) are considered.

In particular, the integration of physical robotics restructures the educational process in a way that increases social interactions between students as well as between

² An international robotics competition which encourages participants to get involved in science and technology and develop research, engineering, and technological skills: <https://www.firstinspires.org/robotics/frc>

³ An international competition promoting robotics and AI research: <https://robocupap.org/>

⁴An international robot design competition for students of colleges in Asia and Oceania: <https://www.aburobocon2023.com/>

the student and the robot directly (e.g., compared with AI-based educational technologies, since the presence of a robot in the classroom contributes to the emergence of the presence effect which is important for learning). Thus, thanks to the presence of a robot in the classroom, students demonstrate engagement in the learning process and a high level of communication with each other [30]. Educational robotics also plays an important role in the development of personal qualities that increase the effectiveness of people's interaction with others (interpersonal communication skills) [38]. For example, group work on designing robotic systems typically involves project-based learning, which promotes students' engagement in accomplishing the task at hand and encourages them to communicate with each other more effectively than generally is possible with other forms of classroom work [30]. Project assignments require students to communicate and cooperate, which helps to develop these skills.

Discussion and Conclusions

Educational robotics is an effective tool for improving the educational process, which is confirmed by the relevant academic literature. The introduction of robots creates an educational environment that encourages the involvement of students in the learning process. The main characteristics of this environment include an easy atmosphere, the absence of psychological barriers and fear of a negative evaluation, the improvement of personalisation, interactivity, and practical orientation. The positive impact of introducing robotics in education is students' improved cognitive outcomes: successful learning and mastering of the material [31], the improving of soft skills such as teamwork [30] and creativity [45], and the development of lateral thinking and a scientific worldview. Moreover, a number of studies confirm students' increased motivation to learn when interacting with robotics [63] [31][64] [32][65] [9] [30]. Deeper integration into the educational process improves students' assimilation of the material [36][33][34] [35] [31] [32][37][9], their positive perception of science [66], and strengthens the willingness to accomplish interactive tasks [67]. Educational robots can flexibly adapt to students' different needs, including differing levels of complexity and various paces of learning as well as multitudinous information perception types, which makes them an effective educational tool with high potential for use throughout the education system. The findings of this study are structured as a diagram (Figure 4).

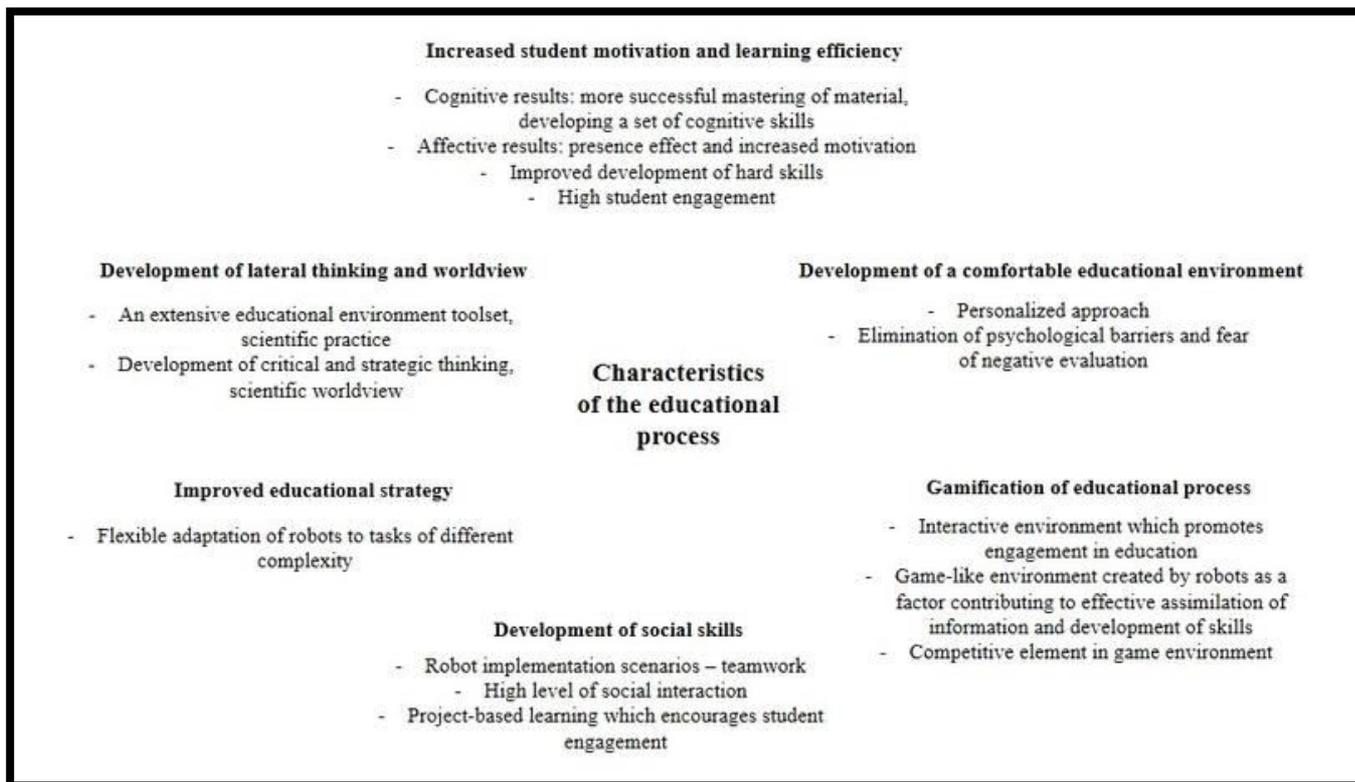


Fig. 4. Characteristics of the Educational Process Identified through Bibliographic Analysis

Source: prepared by authors.

The results obtained are applicable to a number of learning areas identified at the sampling stage. However, it should be noted that studies of educational robotics' effects are most often focused on the STEM field, where the use of robots turns out to be the most popular and effective [68] [9].

As a result, the effects of using robots in the educational process were identified, the importance and power of which set the directions for further research:

- (1) Increased student motivation and learning efficiency;
- (2) Development of lateral thinking and a scientific worldview;
- (3) Development of a comfortable educational environment;
- (4) Improved educational strategy;
- (5) Gamification of the educational process;
- (6) Development of social skills.

Educational robotics are already being successfully applied at various education stages: preschool, secondary, vocational, and additional [9]. In particular, in Asian countries the integration of robots has long been seen as a priority for the development of the educational system [69] [70]. In the course of further research, the effects of applying robotics at various education levels and their relationship with students' skills and the complexity of learning may be considered in more detail. Longitudinal studies are suggested to assess the long-term impact of robots on the educational environment and student outcomes. Also, further research is needed to assess the relative effectiveness of robotics compared with other learning methods based on innovative solutions (such as, e.g., artificial intelligence and learning applications). More detailed research

is also required to determine the role of educational robotics in various contexts, activities, and disciplines. Finally, it is important to reveal the differences in the effectiveness of different types of educational robots for different age groups and subject areas.

Using robots in education provides numerous benefits which can greatly increase the effectiveness of learning. This is achieved due to such characteristics of educational robots as their adaptability to different levels of learning complexity, to the needs of students, applicability for solving practice-oriented problems, and interactivity. It is important to note that we do not propose to replace teachers with robots, but emphasise the additional benefits that robotics can bring to the educational process as well as robotics' ability to mitigate problems due to a shortage of teachers. This is especially relevant for Asian countries, where robots can help address the shortage of teachers and provide access to education for more students. Moreover, the integration of robots is especially effective for STEM education, which is a developed and promising area in Asian countries. We conclude that integrating robotics into the educational process can improve the quality of education at its various stages and promote more flexible and innovative teaching methods.

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Acknowledgement. The article was prepared within the framework of the Basic Research Program of the HSE University.

Disclosure statement. No potential conflict of interest was reported by the authors.