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ROBOTS IN ELEMENTARY SCHOOL: SOME EDUCATIONAL, LEGAL AND TECHNICAL ASPECTS

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***Abstract:** This article focuses on robots in elementary school. The authors present an analysis of a number of educational, legal and technical aspects. The article also includes an overview of literature on robotics in elementary school. In the second part a description is provided of more adequate equipment: LEGO Robotics and the LEGO MINDSTORMS RCX Intelligent Brick and Robotics Invention System, WeDo 2.0, Dash & Dot Pack: 2 companionable robots for teaching robotics to children. Next, the authors discuss selected legal regulations relating to school curricula, for example, proposals put forward by the Council for the Informatization of Education at the Ministry of National Education. One of the sections contains good examples of use of robotics in Polish schools. The position of the course of robotics (including elements of design, construction and programming of robots) in modern teaching in Polish schools is also presented,*

using as an example the experience of teachers working in Bielsko-Biala (Silesia region). Besides, research results of a study, conducted in Poland and in Ukraine, are discussed. Finally, the authors present their conclusions.

Keywords: robotics in school, survey, 21st century competences, education.

INTRODUCTION

Twenty-first century education systems should create an environment wherein students encounter critical learning components (such as problem-solving, teamwork, and communication skills) and embrace lifelong learning. A review of literature demonstrates that new technologies, in general, and robotics, in particular, are well suited for this aim. (Khanlari 2016)

This article includes an overview of literature on robotics in elementary school. In the second part a description is provided of more adequate equipment. Next, the authors discuss selected legal and curriculum regulations. One of the sections contains good examples of use of robotics in Polish schools and some research results. Finally, the authors present their conclusions.

BACKGROUND

Arts & Bots combines intrinsically creative craft materials, common robotics components, a custom programming environment and teacher professional development to create a flexible robotics intervention for secondary school classrooms. In order to engage students underserved by other robotics programs, Arts & Bots is oriented to support the creation of collaborative expression-focused robots, as opposed to more commonly implemented competitive task-focused robot activities. Specifically, Arts & Bots targets integration into traditional nontechnical classes, such as literature and history, to reach a broader base of students than would be enrolled in elective technology programs. Study (Cross et al. 2015) describes three classroom implementations, including a secondary school poetry project. By including Arts & Bots in these core courses, we expose diverse students to engineering education activities such as hands-on experiences with computer programming, prototyping, and the engineering design process. Authors presents their outcomes grouped within two primary themes: first, in Technological Fluency, we present students' self-reporting of concepts learned, confidence with technology, and breaking of technology stereotypes; second, in Complementary Non-Technical Skills, they present other skills students learned by participating in the Arts & Bots program. (Cross et al. 2015)

Compared with other media, programmable bricks provide children with the opportunity to create their own product and, through this process, to express creative thinking. Studies (Demo et al. 2008) have found that learning robotics or integrating programming bricks into courses can help to develop students' problem-

solving abilities and enhance their learning performance. This study attempted to develop a one-to-one Topobo robotics course for kindergarten children and to explore teacher-student interaction patterns. This study used a creative thinking spiral as the framework for the Topobo robotics course. The research sample included a five-year-old child and a preschool teacher. Topobo, the programmable bricks, was the main learning tool in this course, and the sequential analysis method was used to identify teacher-student interaction patterns. Based on the frequency of the teacher-student interactions, this study found that two behaviours, the student's "play" and the teacher's "guidance," appeared most frequently. Moreover, the results of sequential analysis and content analysis of the videotaped learning process indicated that the teacher's guidance helped the student to assemble or play with the Topobo bricks. The teacher's questions encouraged the student to express and share his ideas or identify and solve problems. This study proposes suggestions for future studies on this issue (Demo et al. 2008).

Learning to collaborate is an important educational goal. The concept of collaborative learning is differently defined by several authors. Problem solving and problem-based learning are also important in our educational framework. We shall situate and clarify here the instructional design concepts used in an educational setting based on a "collaborative and problem based learning environment" applied to educational robotics. Educational robotics activities are developed at several school levels (primary, secondary) and in adults' training contexts. The instructional design of such learning activities is based on a constructivist approach of learning. Their educational objectives are varied. In our approach, the goal is not only that the learners acquire specific skills (e.g. knowledge on electricity, electronics, robotics...), but also and mainly demultiplicative, strategic and dynamic skills. The methodology focuses on collaboration to design and develop common projects and on problem solving skills development. The pupils work in small groups (2-4). In the reported research, some learners' interactions have been observed during the activity in a primary school with an observation grid. The analysis of the verbalisations between the learners and their actions on the computers and the robotics materials coming from those observations offer the opportunity to study the way the learners are collaborating (Denis, Hubert 2001)

Recently, Wonder Workshop, creators of the Dash & Dot robots, released 21 comprehensive lesson plans made to help K-5 educators approach coding with young students while generating an interest in the subject. These lesson plans are made with Dash & Dot robots in mind. These smart robots help teach students the basics of coding, while providing an enriching process that creates both an interest and foundation in its basic concepts. (Papallo 2015)

EQUIPMENT FOR SCHOOLS. SOME EXAMPLES.

History of LEGO Robotics and some examples

Since its introduction in 1998, the LEGO MINDSTORMS build and program robotics tool set has become the best-selling product in the LEGO Group's history. Garnering worldwide acclaim, the Robotics Invention System™ fueled the imaginations and satisfied the inner tinkerer of generations of LEGO and robotics enthusiasts alike, leading to the development of a global community of users and students of all ages over the last 15 years who create and command robots the LEGO way.

The first-computer controlled LEGO products are released in 1986.

In 1988 collaboration between The LEGO Group and Massachusetts Institute of Technology begins on development of an “intelligent brick” that will bring LEGO creations to life via computer programming.

In January 1998 the LEGO MINDSTORMS RCX Intelligent Brick and Robotics Invention System are unveiled to the press at The Museum of Modern Art in London.

In January 2013 the 15th anniversary of LEGO MINDSTORMS is celebrated and the next generation platform – LEGO MINDSTORMS EV3 – is unveiled at the International Consumer Electronics Show; in September 2013 the third incarnation of LEGO robotics, LEGO MINDSTORMS EV3, is launched worldwide. (History – Mindstorms LEGO.com, <http://www.lego.com/en-us/mindstorms/history>)

Key learning values (LEGO MINDSTORMS Education EV3, 10+ yrs)

The LEGO MINDSTORMS Education EV3 lets students design and build programmable robots using high quality motors, sensors, gears, wheels, axles, and other technical components. By using hands-on robotics, students will gain a better understanding of how technology works in real world applications.

The solution enables students to understand and interpret two-dimensional drawings to create three-dimensional models; build, test troubleshoot and revise designs to improve robot performance; gain practical, hands-on experience using mathematical concepts such as estimating and measuring distance, time and speed. (LEGO MINDSTORMS Education EV3 Core Set, <https://education.lego.com/en-us/products/lego-mindstorms-education-ev3-core-set-/5003400>)

Key learning values (WeDo 2.0, 7+ yrs)

WeDo 2.0 strengthens students' understanding of the eight science and engineering practices, including asking questions and solving problems, modelling, prototyping, investigating, analysing and interpreting data, computational thinking, creating evidence based arguments, and obtaining, evaluating, and communicating information.

Develop your students' competencies through hands-on projects covering key science topics such as physical-, life-, earth- and space sciences, engineering and technology. Improve problem solving, critical thinking, communication, collaboration and integrate the use of relevant digital tools to improve computational thinking skills. (WeDo 2.0 Core Set, Software and Get Started Project, <https://education.lego.com/en-us/products/wedo-2-0-core-set-software-and-get-started-project/45300>)

Dash & Dot robots are being implemented in schools to help teach 21st-century skills, such as creative problem-solving and computational thinking. Coding experience is quickly becoming a differentiator in today's workforce. Data from the U.S. Bureau of Labor Statistics project there will be 1.4 million computer science jobs available by 2020 with only 400,000 computer science graduates qualified to apply for them (Papallo 2015). Other projections from the Bureau of Labor Statistics show 1 million high-paying computer science jobs likely going unfilled over the next five years due to the current lack of qualified graduates.

Dash & Dot Pack: 2 companionable robots for teaching robotics to children. Dash & Dot are the 2 mobile, interactive and programmable robots designed by Make Wonder. Their job? To serve as a truly useful and fun educational tool as part of a first robotics workshop for children from the age of 5.

- Dash is the adventurer in the team. It can detect objects and obstacles and perform actions accordingly. It has a 360° head and three wheels to move around both easily and smoothly.
It also comes with various accessories, allowing it to lift and pick up objects, draw or play music, plus much more besides!
- Dot is its little friend. With just one wheel and perfectly round, it can detect when it's been caught, lifted or shaken. And it's also a very clever sidekick, able to pass orders on to Dash, or to tell stories while flashing and emitting sounds.
(<http://www.generationrobots.com/en/402097-dash-dot-pack.html>)

SELECTED LEGAL REGULATIONS

The Council for the Informatization of Education at the Ministry of National Education (Poland), on 18 June 2015, presented proposed changes to the current core informatics curriculum.

The Council adopted the final form of its proposal at its meeting on 10 December 2015. Account was taken off all the opinions submitted during the consultation and raised at several meetings with teachers across Poland and at meetings of experts abroad.

According to the Council for the Informatization of Education, one of the goals of universal informatics education is to improve the relevance and importance of

computer science as an independent discipline as perceived by students and society (...). Early contact at school with computer science and programming should give learners the idea of richness of this field and its applications in other subjects and areas, and to stimulate interest and motivate the choice of future education and a future career in this direction.

The most important skills acquired by a student in the course of general education in primary school should also be the ability to solve problems creatively with various objects methods derived from computer science. This new proposed provision indirectly also points to robotics and the ability to solve problems of border technology and computer science.

Members of the Council are proposing to replace certain specific requirements (relating to computer classes) for the first stage of the current educational curriculum with their proposal, which (among other things) includes provisions favouring classroom robotics.

For example, the proposal states that the student:

- creates a command (command sequence) for a specific plan of action and to achieve the objective; in particular, performs or programmes these commands in a computer application;
- programmes visually simple situations (...) according to her/his own ideas and the ideas developed together with other students;
- uses programming for robot control (...) in the physical world outside the computer;
- observes other students as they work, exchanges with them ideas and experiences, competes with other students.

Furthermore, the Council proposes changes to the curriculum, which relate to computer classes in grades 4-6 of elementary school. Among these proposals there are suggestions in favour of “invasion” of robots to schools. The student at this stage:

- formulates, in the form of algorithms (...) commands that make up the (...) to control a robot or other device;
- in algorithmic problem solving distinguishes basic steps: defining goal to achieve, finding a solution to the problem for sample data, developing a solution, programming solutions and testing the correctness of program examples;
- designs, creates and saves in a visual programming language (...) solutions to problems and simple algorithms using sequential commands, iterative and conditional and simultaneous events;

- tests, on the computer, programs in terms of compliance with the assumptions about the effects of their actions, explaining how programs operate;
- creates a control program for a robot or other device (...);
- identifies and recognizes the benefits of cooperation on joint problem-solving, as well as benefits from healthy competition.

The entry into force of these proposals would be a direct indication that robotics and visual programming of robots as a student activity is highly recommended (desirable) in the educational process, at the stage of primary school. What would also be significant would be the team nature of work during the implementation of projects in robotics.

So solid anchoring of classes with the use of robots in the core curriculum of general education could help learners to overcome barriers which sometimes involve the perception of learning and fun as two completely separate worlds of children's activities.

The proposals of the Council for the Informatization of Education confirmed the advisability of the use of robots (more broadly, creative toys) in the teaching process.

GOOD EXAMPLES OF THE USE OF ROBOTICS IN POLISH SCHOOLS

Workshops, using kits to build and program robots, are a modern form of interdisciplinary education of children and youth.

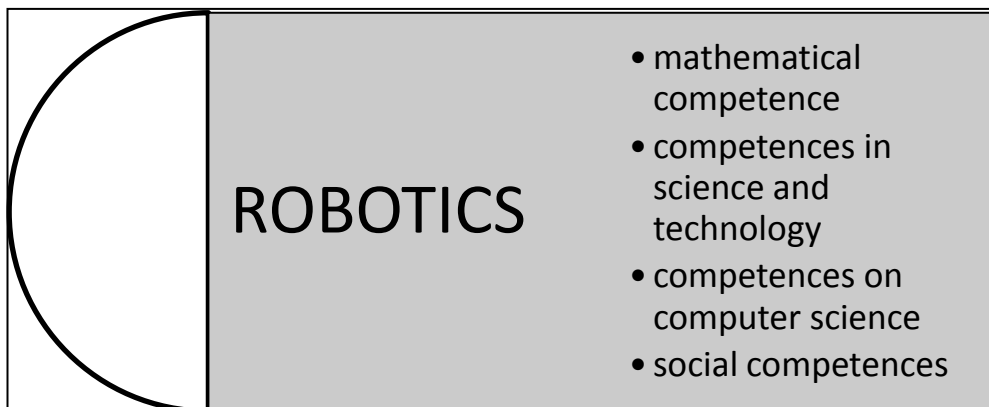


Figure 1. Robotics and training on key competences.

Source: Own work

The rationale for conducting such activities in schools is found in the European reference framework in the context of training of key competences.

Classes in robotics – properly taught – will have an impact on the development of mathematical literacy and scientific-technical information and social competences (see Figure 1). At the same time competence is understood to mean a combination of knowledge, skills and attitudes appropriate to the situation.

The position of the course of robotics (including elements of design, construction and programming of robots) in modern teaching in Polish schools will be presented, using as an example the experience of teachers working in Bielsko-Biala (Silesia region).

Lessons (mandatory)

In elementary school, you can use robots:

- during design and technology classes – models of equipment and vehicles,
- during computer classes – elements of visual programming – controlling a robot,
- during science classes – e.g. sensory perception and sensory reception, construction of simple electric circuits.

Due to the specific nature of individual subjects the scope of the proposed use of robots in class will be varied: (see Table 1)

Table 1.

Evaluation of the possibility of implementation of selected activities while working with robots in class in primary school.

Item	Activity (action) in class	Design and technology classes	Computer classes	Science classes
1.	presentation of activities of robots already built (robot's interaction with the environment)	possible	possible	possible
2.	construction work according to the plan	possible	possible to some extent – simple structures	almost impossible – lack of time, other learning content
3.	construction work according to one's wishes	possible and recommended	more difficult (lack of time for the test phase and design)	almost impossible – lack of time, other learning content

			modifications, other teaching content)	
4.	design changes	possible and recommended	possible to a certain extent – simple modifications	almost impossible – lack of time, other learning content
5.	design changes – using other sensors (e.g. mobile robots)	possible and recommended	possible and recommended	almost impossible – lack of time, other learning content
6.	creation and testing of a simple input-output systems (sensor- display, sensor- motor)	possible and recommended	possible and recommended	possible and recommended
7.	programming simple input- output systems (sensor- display, sensor-motor)	possible, although it is not the main objective of the course	possible and recommended	possible, although it is not the main objective of the course
8.	programming a robot already built	possible	possible and recommended	practically impossible – lack of time, other learning content
9.	designing a robot in a 3D environment	possible and recommended	possible and recommended	practically impossible – lack of time, other learning content

Source: Own work

Lessons (mandatory) in lower secondary (middle) schools can be taught with the use of robots in two school subjects:

- design and technology classes,
- informatics (computer science).

In both cases, students are actively involved in classes - working with robots individually or in teams. Due to the specific nature of the subject (including the

number of hours of instruction in in the curriculum) the range of student activities will be varied.

Proposals of activities are presented in Table 2.

Table 2.

Evaluation of the possibility of implementation of selected activities while working with robots in class in lower secondary (middle) school.

Item	Activity (action) in class	Design and technology classes	Computer science
1.	presentation of activities of robots already built (robot's interaction with the environment)	possible	possible
2.	construction work according to the plan	possible	possible to some extent – simple structures (models)
3.	construction work according to your wishes	possible and recommended	more difficult (lack of time for the test phase and design modifications, other teaching content)
4.	design changes	possible and recommended	possible to a certain extent – simple modifications
5.	design changes – using other sensors (e.g. mobile robots)	possible and recommended	possible and recommended
6.	creation and testing of a simple input-output systems (sensor-display, sensor-motor)	possible and recommended	possible and recommended
7.	programming simple input-output systems (sensor-display, sensor-motor)	possible, although it is not the main objective of the course	possible and recommended
8.	programming a robot built before	possible, although it is not the main objective of the course	possible and recommended

9.	design a robot in a 3D environment	possible and recommended	possible and recommended
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Source: Own work

The currently applicable core curriculum for D&T classes at middle school contains the following learning objectives (general requirements) for the subject:

- I. Recognition of items of technical equipment and understanding how they work.
- II. Developing the concept of solutions to common technical problems and examples of design solutions.
- III. Planning work of varying complexity, with different forms of work organization.
- IV. Safe use of tools and devices.

The core curriculum does not lay down specific teaching content (specific requirements). There is, therefore, the opportunity for teachers to create their own curriculum for example, in robotics and computer-aided design.

Extra-curricular activities (optional)

Extra-curricular activities in elementary school or high school may take the form of robotics workshops run by student interest clubs (computer / computer or technical clubs). Such activities are characterized by strong interdisciplinary nature, which is sometimes difficult to achieve in a class of an individual subject.

Kits for the design, construction and programming of robots will also prove their worth when students work using the method of a group project of research nature. Full exploitation of this method involves the creation of new knowledge by students (on the basis of findings from the conducted experiments, own work) and sharing it through the public presentation of the results.

Classes with robots can contribute to the development of students' new interests, in the context of organization of their leisure time. They are also an opportunity to learn about the specifics of the jobs of tomorrow, such as a mechatronics engineer and an IT specialist.

Open classes (demonstration)

In elementary school, one can consider running extracurricular workshops with robots for teams made up of a parent and child or parent and 2 children. In this formula there is a chance for active participation in classes of younger children, working under the care of a parent.

Lower secondary (middle) school students can help teachers in teaching classes for pupils of local primary schools (e.g. during the Open Day). These activities contribute to the promotion of a given school in the local community, helping to shape the image of an open school, sharing knowledge and experience with others.

THE METHODOLOGY AND SELECTED RESULTS

The study was carried out with the participation of 91 primary school teachers and future teachers in the province of Silesia and the University of Silesia Poland and Ukraine, and Borys Grinchenko Kiyv University. The survey contained 15 questions about the pedagogical research “Robotics and children”. The study was carried out to determine the needs of modern education to introduce the basics of robotics in the educational process of primary school.

Question 1. At what age should children learn the basics of robotics?

Respondents were allowed to choose one or more options.

- A. before the age of 5
- B. aged 5 to 7 years
- C. ranging in age from 7 to 10 years
- D. aged 10 to 15 years
- E. over 15 years of age

The research results of this question are presented in Figure 2.

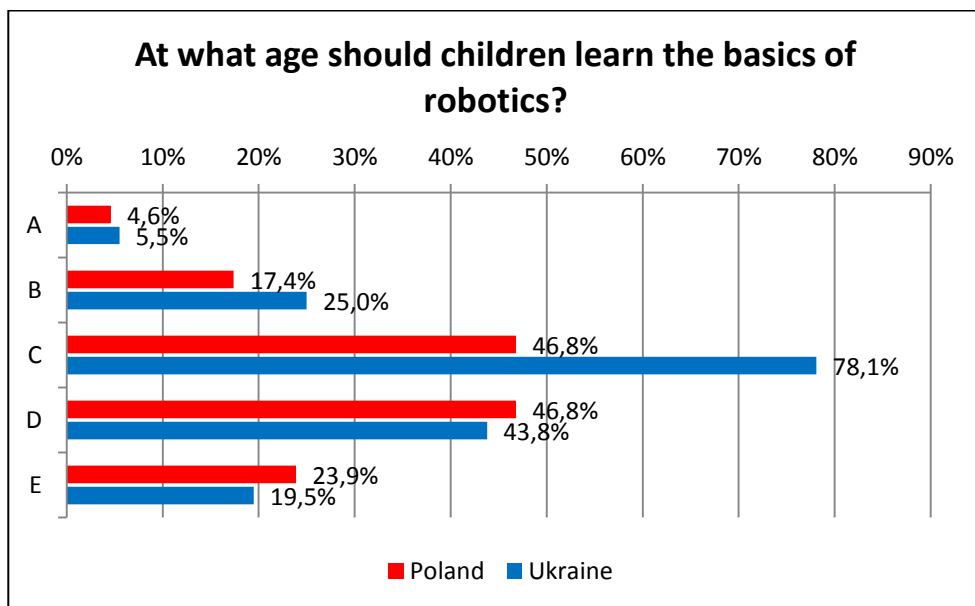


Figure 2. The results of responses on Question 1

Source: Own work

Almost half of the respondents in Poland chose the range of 7 to 10 years (C), and from 10 to 15 years (D), which corresponds to the current elementary school and current junior high school, or planned eight-year primary school.

The interval from 7 to 10 years (C) was selected by almost 8 in 10 respondents in Ukraine.

Question 2. Do you think it is possible to teach students robotics in class at school or is it a more of out-of-school education process?

Respondents were allowed to choose one answer.

- A. Robotics can be taught in the classroom, as a mandatory part of the curriculum
- B. You can implement robotics classes in school if the school provides appropriate conditions and equipment
- C. You can implement robotics classes in selected schools or for selected students
- D. It is rather a process of school education, including some students

Research Results of answers on this question presented on Figure 3 and 4.

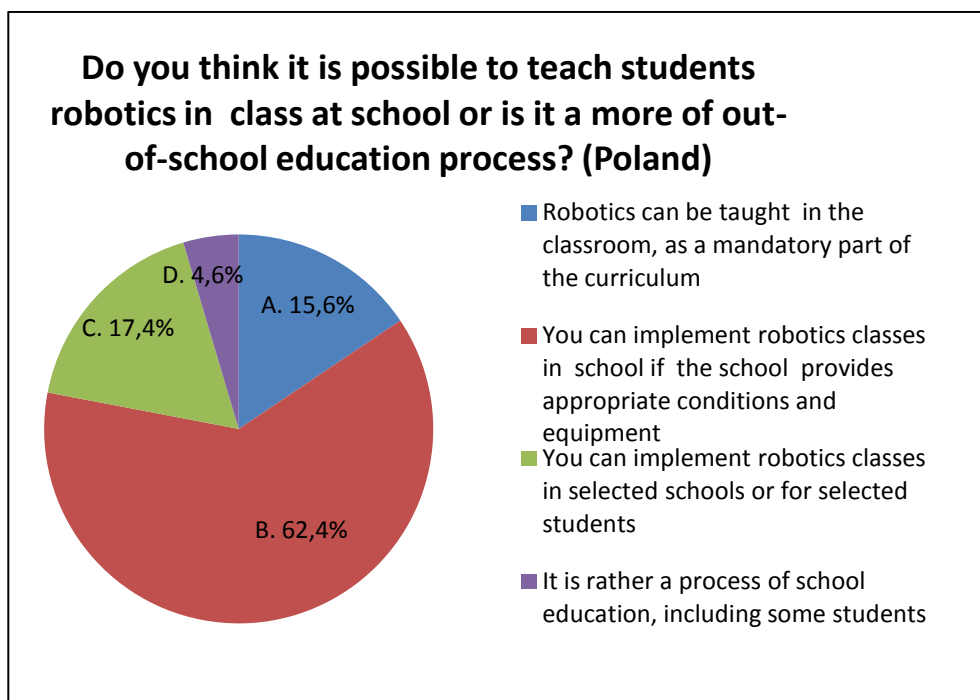


Figure 3. The results of responses on Question 2 (Poland)

Source: Own work

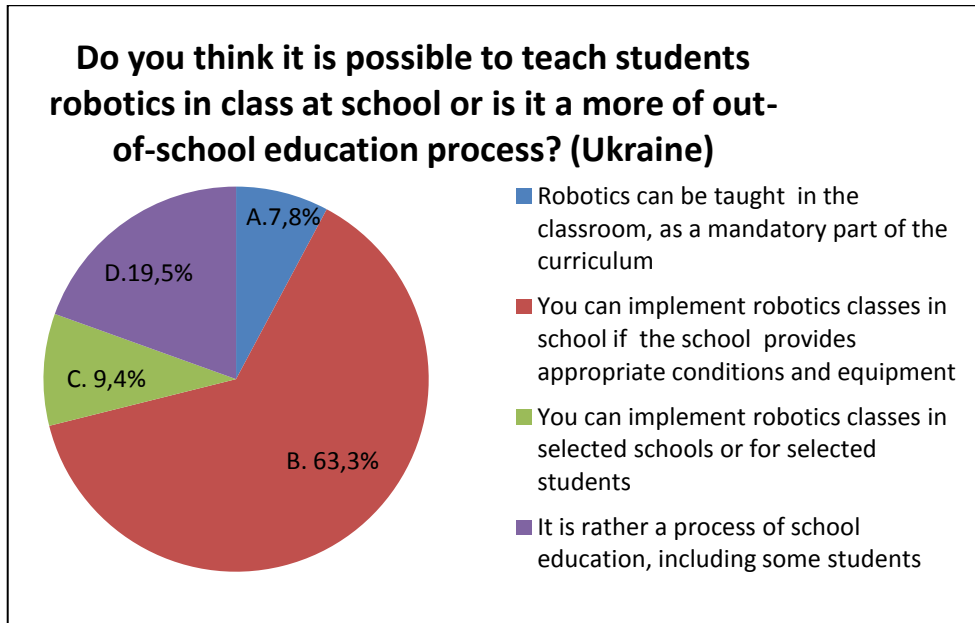


Figure 4. The results of responses on Question 2 (Ukraine)

Source: Own work

Over 62% of respondents in Poland said that robotics classes can be taught in school when the school provides appropriate conditions and equipment.

Only one in 20 of those polled sees robotics as a process of school education, covering only some of the students.

More than 63% of respondents in Ukraine (as in Poland) said that robotics can be taught in school when the school provides appropriate conditions and equipment.

Almost 20% thought that robotics is a process of school education, covering only some of the students. That is almost 15 percentage points more than among the respondents in Poland.

Question 3. How many hours of classes in robotics should be included in the primary school curriculum?

Respondents were allowed to choose one answer; they were allowed to provide their own answer - by selecting "another answer".

- A. 1 lesson per week
- B. 1-2 lessons per week
- C. more than 2 lessons per week
- D. as separate topics in computer science (computer classes) and in design and technology classes

- E. as a matter of combining elements of computer science (computer classes), activities of technical design (modelling)
- F. another answer

The results of this question are shown in Figures 5 and 6.

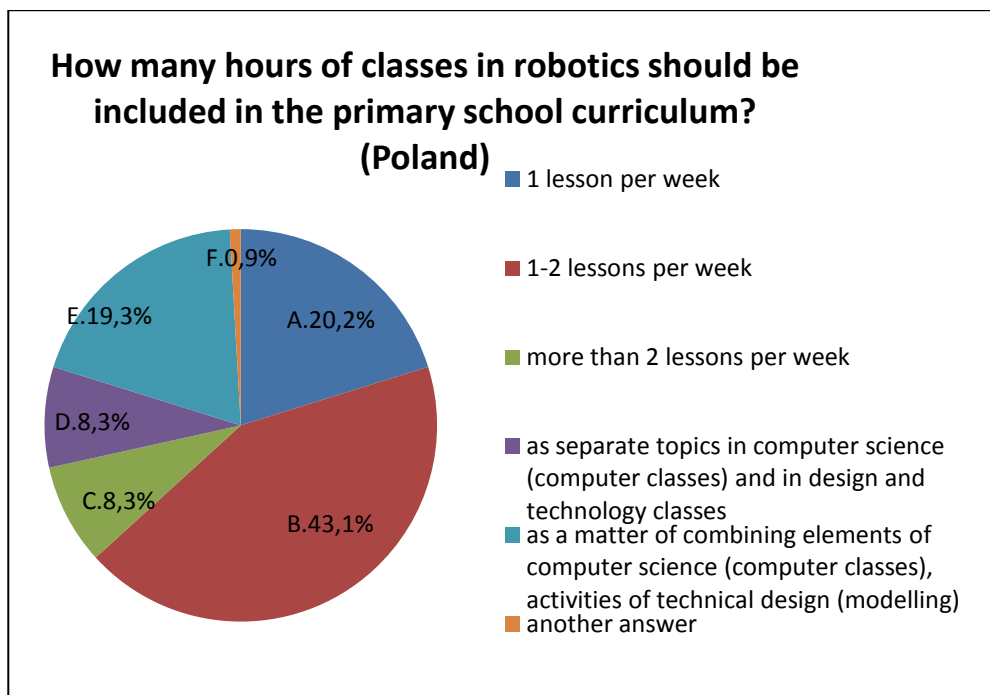


Figure 5. The results of responses on Question 3 (Poland)

Source: Own work

Respondents in Poland usually chose 1-2 hours per week of classes in robotics.

The only “other answer”: This should be extra-curricular activity, free-of-charge.

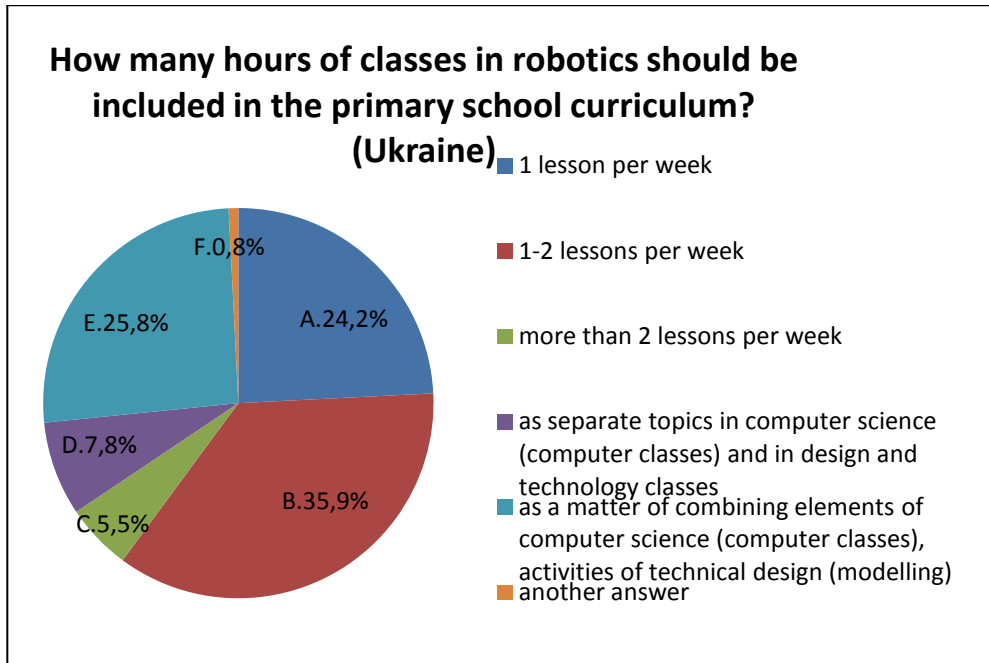


Figure 6. The results of responses on Question 3 (Ukraine)

Source: Own work

The respondents in Ukraine (as in Poland) usually chose 1-2 hours per week of robotics classes.

Question 4. Do you want to learn the basics of robotics?

- A. With pleasure
- B. No, I think it is inappropriate
- C. Another answer

Respondents were allowed to choose one answer. Results of answers on this question presented on Figure 7 and 8.

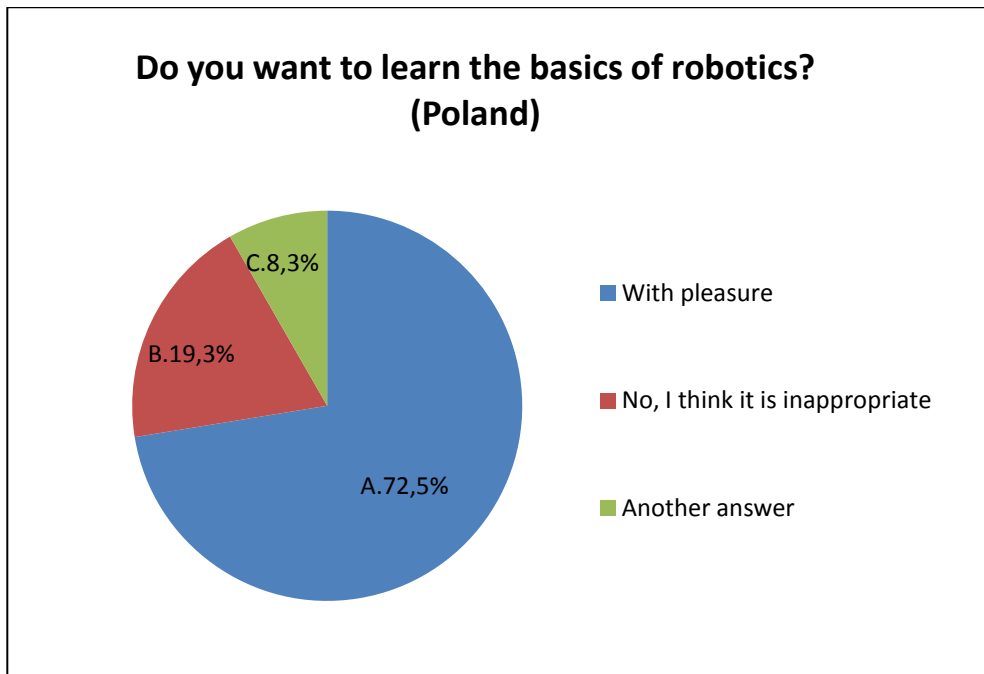


Figure 7. Do you want to learn the basics of robotics? (Poland)

Source: Own work

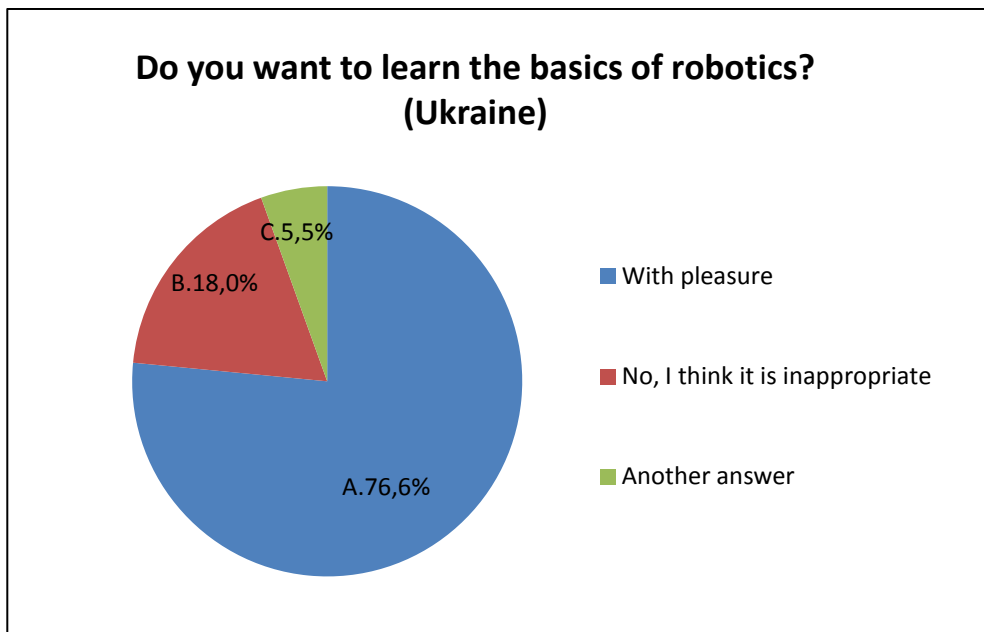


Figure 8. Do you want to learn the basics of robotics? (Ukraine)

Source: Own work

CONCLUSIONS

The article describes a number of aspects concerning the use of robots in primary school as an object and subject of learning. The authors conclude, based on an analysis of earlier research and literature as well as their own study that educational robots can stimulate learners' learning motivation. Compared with other media, programmable bricks provide children with the opportunity to create their own product and, through this process, to express creative thinking. Studies have found that learning robotics or integrating programming bricks into courses can help to develop students' problem-solving abilities and enhance their learning performance. Smart robots helps teach students the basics of coding, while providing an enriching process that creates both an interest and foundation in its basic concepts. In elementary school, one can use robots during design and technology classes, computer classes and science classes.

Besides, an analysis is presented of basic legal regulations in this matter, primary school curriculum as well as some results of a survey conducted in Poland and Ukraine among in-service teachers and prospective teachers. In respect of Question 3 "How many hours of classes in robotics should be included in the primary school curriculum?", the majority of responses were 1-2 hours per week. As for the question "Do you think it is possible to teach students robotics in class at school, or is it a more of out-of-school education process?", the vast majority of respondents in Poland chose the answer "You can implement robotics classes in school if the school provides appropriate conditions and equipment". In respect of the question: Do you want to learn the basics of robotics? - "With pleasure" accounted for 72,5% of Polish responses and 76,6% of Ukrainian ones.

The authors will continue research in the area of developing key and other competences in learners during robotics education, and increasing of effectiveness of learning and teaching young learners in conditions of the 21st century.

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