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Educational Robotics: Development of computational thinking in collaborative online learning

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Abstract

In the previous study the work experience on organization of teaching Robotics to secondary school students at school lessons and in study groups was introduced. This study which was conducted within 2019 and 2021 covered the period of distant learning caused by COVID-19 pandemic and even post-pandemic period, when a part of school students continued learning online. The study deals with the problem of developing school students' computational thinking in online learning. We consider computational thinking as a set of cognitive skills of solving educational and cognitive problems. The research questions raised were aimed at solving the problem of the influence of Educational Robotics on developing computational thinking. During the research we have found out that due to the adaptability of robots, Educational Robotics, the development of individual learning programs, and the arrangement of collaborative online learning are instruments and a solution to the problem of developing computational thinking. The main components of computational thinking, which were studied within those 3 years, are the following: algorithmic thinking, ability to program, and efficiency in team work. The influence of the learning strategy we chose enabled us to determine the level of computational thinking and its dependence on learning Robotics. We used statistical criteria in order to summarize the results of our research. The statistics provided suggests progress in the indicator tracked. Based on the experimental data received we approximated reliability (R^2) and relevant exponential equation (trend lines). The research we carried out also has led to the general conclusion that Educational Robotics helps to create synergistic learning environment for stimulating students' motivation, collaboration, self-efficacy and creativity.

Keywords Online learning · Collaborative online learning environment · Robotics · Educational Robotics · Computational thinking · Virtual simulator of robots

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1 Introduction

Robotics in education is an instrument of involving students in the process of scientific and technological creativity, developing technological knowledge, information and communication competences, and ability to work in teams. Nowadays, when not just mechanical electronic robots but humanoid robots as well are created, school children demonstrate increasing interest in Robotics.

The scientific analysis of 69 articles introduced by Lorenzo et al. (2021) proves that most studies on problems of robotic interference with communication and social interaction based on “social robots” deal with Robotics. Robotics is used as a part of the compulsory educational process in the informal educational activity. (Daniela & Lytras, 2019; Filippov et al., 2017; Encarnação et al., 2017). Robotics in the sphere of education shows children’s personal and psychoemotional development (Kozima et al., 2009; Lin et al., 2008; Fitter & Kuchenbecker, 2020).

Educational Robotics is an important resource, which can be used to help solve educational problems by increasing opportunities and students’ learning level (Patiño-Escarcina et al., 2021). The use of social robots has a certain positive effect on human-robot interaction (Duquette et al., 2008; McColl et al., 2011) and implementation of robots into social and cognitive therapy (Rasouli et al., 2022). The current discussion about Virtuous Robotics approaches lets us consider advantages and disadvantages of the application of robotic systems (Cappuccio et al., 2021; Vianello et al., 2021) to personal enrichment and self-realization. Robotics can be effectively integrated by means of professional development programs (You et al., 2021) aimed at changing “self-efficacy of teachers’ technological-pedagogical-and-content knowledge” and improvement of their content knowledge of Robotics in order to apply Robotics to teaching other subjects such as Mathematics or science.

The study in the simulation environment aimed at studying the influence of different signals which robots send to people increases opportunities of modeled robots and raises expectations about learning outcomes (Sun et al., 2021). When teaching Robotics the problem of training teachers becomes particularly important (Schina et al., 2021). Educational Robotics (ER) is an educational resource the use of which helps achieve the aims connected with the development of digital technologies, abilities and skills. Student engagement has been described as active involvement in learning activities that significantly affects learning achievements (Verner et al., 2021).

Our study considers how to solve the problem of developing computational skills when learning Robotics. The tool for solving this problem is organization of collaborative online environment. The study results proved that a specially organized online environment when learning Robotics has a positive effect on developing students’ computational thinking.

The objective of this study is to show what role the collaborative online learning played in organizing learning Robotics and how it affected the development of students’ computational thinking.

It is certainly only one of possible solutions to this problem, but its aim is to look for other effective tools, methods and means.

2 Related work

There are extensive and versatile works which investigate issues of learning Robotics and developing students' computational thinking. Investigation of robotic systems is represented by a number of works aimed at the raise of the productivity of labor in the production (Yang et al., 2022). Educational Robotics has a positive effect on developing students' computational thinking (Ioannou & Makridou, 2018). The authors believe that it is necessary to develop computational thinking from primary school age, and they emphasize the necessity of developing practical framework for expanding computational thinking through learning Robotics.

Learning programming through Educational Robotics affects students' understanding and motivation (Fegely & Tang, 2022). The study results prove that Educational Robotics helps students understand concepts of programming. Complex systems methods (such as agent-based modeling) and computational methods (such as programming) provide powerful ways for students to understand new phenomena (Berland & Wilensky, 2015). The scientists suggest models of integration of Computer Science and Robotics (El-Hamamsy, et al., 2021).

Integration of Robotics into preschool education through LEGO Mindstorms and "ROBOLAB" engage students in studying concepts and ways of thinking (Bers et al., 2002). There is a relationship between the qualities of the developed curriculum and the development of preschool children's computational thinking (Bers et al., 2014). Computational thinking is one of the main learning skills in the XXI century. Computational thinking which implies the ability to solve problems algorithmically and logically is one of the factors in digital learning. Computational thinking is extended when children imitate a robot's movements using both perceptual and formal strategy of multiplicative thinking (Kopcha et al., 2021; Chan et al., 2021) investigate the evaluation of the abilities of computational thinking among Singapore secondary school students using the Rasch model. The conducted tests showed that the elements under investigation had functioned differently depending on students' sex and learning level. The modification of the curriculum and technology results in students' greater interest in learning Robotics and programming, and, thus, in developing computational thinking.

3 Background

Education in the XXI century is a process of communication, critical thinking, collaboration, and creativity. Computational thinking, which implies the ability to solve problems algorithmically and logically, can be called another factor in e-learning. The collaborative online learning organized in practice enabled us to use effectively advantages of traditional full-time education and distant learning technologies. In collaborative learning students focus on their aims while remaining fully aware of the fact how their activity affects other students from their group or team.

Online collaborative learning requires the implementation of intercultural online learning using seamless and effective strategies, common interactive learning activities that embrace cultural diversity (Yang et al., 2014; Kumi-Yeboah et al., 2017). Such environments perform representative and interactive design functions for collaboration; create a sense of community and collaboration (Sullivan et al., 2011). Synchronous and asynchronous online environments act as the design of multi-user virtual environments for collaborative learning. Collaborative learning offers tremendous benefits in relation to the use of educational technology (Zheng et al., 2019). There is some gender difference in the development of computational thinking in collaborative middle school Robotics program (Ardito et al., 2020).

Introduction of courses on Educational Robotics is a positive tendency for spreading technological knowledge and promoting engineering and technical specialties. In the current realities online learning proved to be a productive approach to organize teaching Educational Robotics.

Originally our thematic study was aimed at revealing the nature of educational technologies in collaborative online learning with the application of robotic systems. In order to organize the study of collaborative online learning we had to strike a balance between theory and practice. This problem and the research questions related to it can be solved using the methodology introduced in this study.

4 Methodology

4.1 Characteristics of participants and thesaurus field of study

The students who were taught according to the curricula of comprehensive schools took part in our study. Collaborative online learning was conducted in the group of 25–30 students. The same number of students attended extracurricular activities. Study groups consisted just of 6–8 students. Collaborative online learning was organized for students of 3–4, 5–6 and 7–8 grades. The total number of students participated in the experiment was 120 students. The experiment covered three academic years, and it enabled us to draw objective conclusions, which illustrated the role and importance of collaborative online learning in the development of computational thinking.

The logic of our study was to realize the following stages: determination, search, forecasting, forming and analyzing. At the experimental stage of determining the status of the problem under study we studied peculiarities of technologies in collaborative online learning and their influence on the development of computational thinking at Robotics lessons.

Among other things, the study included harmonization of terms and concepts in the sphere of collaborative learning involving Robotics. First of all, let us decide on the concept of collaborative online learning that we use in the study.

Collaborative online learning is a learning strategy which is based on team work using distant technologies in order to achieve the general objective. In collaborative learning, students work together at a certain problem or project. The positive side of collaborative online learning is the fact that students gain their own abilities and skills, develop their personal responsibility and can manage their own activity while working in teams. The impact of such work occurs in organizing independent activities when one of the participants is able to take up the leadership role in teams.

VanOostveen et al. (2019) suggest that significant reforms have been slow to take hold in educational systems around the world. Much of the reluctance can be attributed to a widely-held misconception of the nature of learning. Collaborative learning directs traditional transmissible learning under the guidance of a teacher to active learning focused on students (Ouyang et al., 2020). Collaborative online learning has a positive effect on the processes of students' self-regulation (Yilmaz & Yilmaz, 2020).

In collaborative learning on Educational Robotics students work together in teams but each of them has his/her own problem he/she should focus on. Students have the opportunity to increase their skills at the same time seeing how their activities impact all other team participants. All this can be seen in team work during competitions on Robotics. Students' communication during their work in teams helps them strengthen the spirit of friendship and contributes to strengthening links between teams. At the same time it is an opportunity to get to know each other and understand strengths and challenges of other participants. In this regard collaborative learning helps to develop interpersonal skills, such as solving problems together, communication and collaboration. Before we raised the following questions: What is the role of collaborative online learning in developing computational thinking in teaching Robotics? How do abilities and skills of designing, constructing algorithms and programming influence the development of computational thinking?

Computational thinking covers thinking processes which participate in problem statement and providing its solution in the form which can be effectively realized by a human or a computer. Children can learn how to use computational thinking without a computer (Kuo & Hsu, 2020), for example, while playing a board game, which corresponds to structural programming. Preschoolers' computational thinking can be improved by the use of card-coded robots (Nam et al., 2019). This study indicates that an enhanced planning experience using card-coded robots was beneficial for improving young children's thinking skills. The implications for designing appropriate curricula using robots for kindergarteners are addressed. Project-based learning activities and programming problems develop seniors' skills of computational thinking (Saritepeci, 2020). The results of this study showed correlation between design-based learning (DBL) and teaching computer programming, and skills of computational thinking.

4.2 Learning environment in collaborative online learning

Before getting to carrying out the empiric part of the study we developed the model of learning environment in collaborative online learning. Our conception of such environment was built on the problem of arranging teaching in the context of synchronous and asynchronous learning. Teachers had to apply such methods and technologies which enabled them to conduct lessons both offline (traditional learning) and online without any negative impact on the quality of the material gained.

The experience showed that collaborative online learning enabled us to effectively organize the learning process with the continuing social cooperation. In collaborative learning various work activities were arranged, such as team work on Robotics and participation in project activities. Collaborative online learning enabled us to conduct lessons both synchronously and asynchronously.

We carried out a questionnaire in order to find out how much the children were satisfied with the learning process in the distance format.

Collaborative robotic learning, which takes place with computer support, contributes not only to learning, a robotic app is a motivating activity for students that fosters collaboration between them, has a positive effect on learning and the emotional state of students, when a synergistic effect can be observed between participants in the educational process (Tang et al., 2020; Kerimbayev et al., 2020; Ribeiro & Lopes, 2020; Yang et al., 2020; Ospennikova et al., 2015; Lubold et al., 2021).

In collaborative online learning teachers face a lot of problems. There are increasing requirements on teachers' knowledge and qualification level.

Teachers should undertake different activities in collaborative online learning. Figure 1 shows the analysis of teachers' activities concerning organizing collaborative online learning.

The study we carried out proved that the academic achievements of the students who were working together in teams in order to solve problems they faced were much higher. Competition and rivalry with other teams is required for developing computational thinking and forming certain patterns of thinking and behavior.

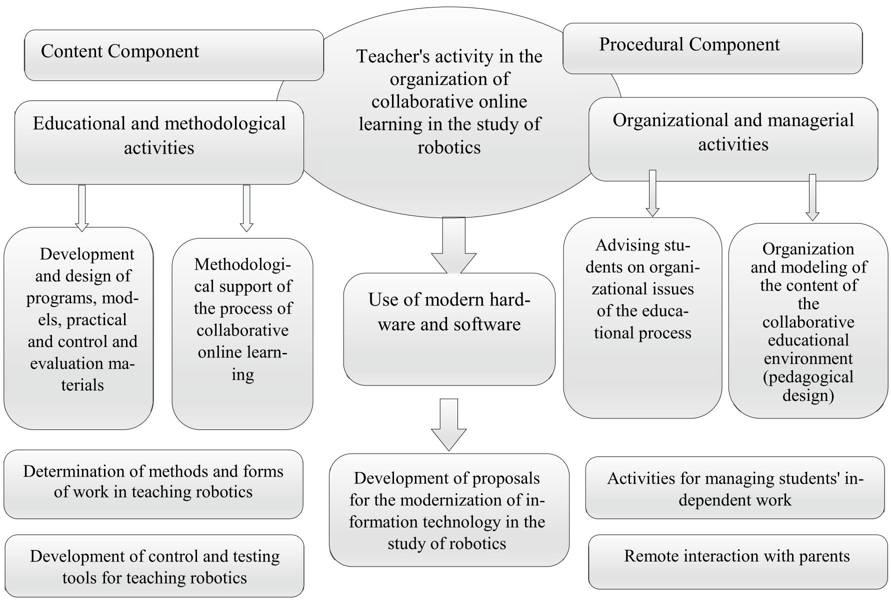


Fig. 1 Teachers' activities concerning organizing collaborative online learning aimed at the development of computational thinking

Some research scientists proved the connection of students' coding and programming ability with their computational thinking, creative thinking and working memory (Wang et al., 2021); the influence of application of different tools to teach students to program on their computational thinking when they solve problems (Yildiz Durak, 2020); the influence of robotic programming on students' computational thinking and creative abilities (Noh & Lee, 2020).

There is a number of researches studying the linkage between the creativity and learning Robotics. Cassone et al. (2021) consider problem solution using module Robotics in computer-supported collaborative learning (CSCL). According to the scientists, those participants who spend more time on solving problems are involved not only in more interactions while solving problems but in building more innovative figures.

While realizing the learning process teachers work at simplifying difficulties in the processes of verbal and logical thinking, analyzing and synthesizing, classifying, and generalizing; fight with communicative difficulties including mono-logic and dialogic speech and enrichment of vocabulary. Teachers help overcome difficulties in developing students' attention and memory, and develop their positive emotions and motivation.

4.3 Visual robot assembling

4.3.1 Virtual robot simulator

Educational Robotics has a wide range of opportunities to create motivational conditions for involving educational space subjects in the development of natural science and mathematics and technological education.

In collaborative online learning school students not only study program material but also study fundamentals of Robotics and learn to program.

For example, children's construction kits help children develop independent flexible creative thinking and adequate social behavior.

Educational Robotics at schools and out-of-school institutions uses different forms of organizing academic activities: a study group, an elective course, a lesson, and a lab (Fig. 2).

In collaborative online learning new approaches are used for dealing with motivated children. For instance, modern educational environments present a very wide range of opportunities for organizing construction environments like LEGO kit.

For primary school children LEGO WeDo, and LEGO Mindstorms construction kits and models were used to create a programmable robot. Using such construction kits one can organize highly motivated learning activities for space construction, designing and automatic control.

For senior school students instead of ordinary constructor robots a virtual robot simulator was used. In educational Robotics, simulators offer higher flexibility and precision of visual robot modeling (Camargo et al., 2021; Teixeira et al., 2015).

Involvement of school students in research in the sphere of Robotics, in sharing technological information and basic engineering knowledge, and in developing new

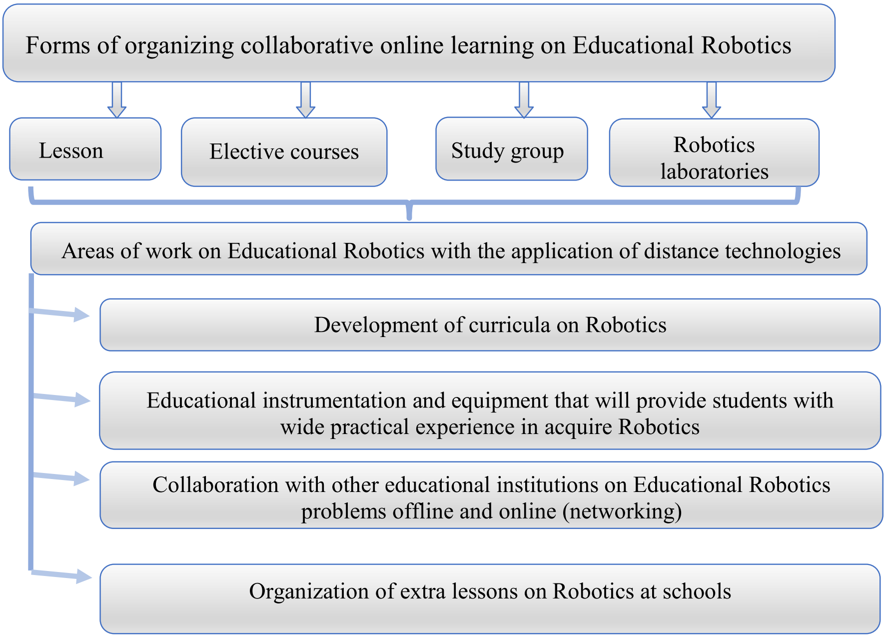
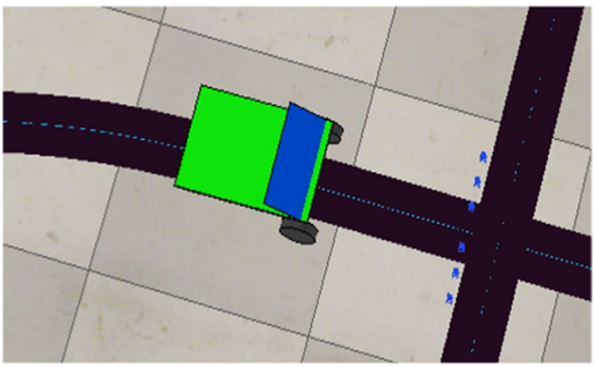


Fig. 2 Main forms of organization and fields of study for Educational Robotics

scientific and technological ideas enables to create necessary conditions for a high quality of education through using new pedagogical approaches in education and application of new information and communication technology. Understanding of technology laws helps school-leavers match current needs and find their place in modern life.

In modeling a robot simulator the construction of which consists of 6 vision sensors was used. The construction of the robot is shown in Fig. 3. The robot is located in the start-finish zone, in front of the cross line, not intersecting it at all, and the sensors are not contacted with the line.

Fig. 3 Virtual robot at the start position



Vision sensors are numbered from left to right in the direction of the robot: the leftmost one with local coordinates (+0.4, +0.14) - sensor 1. Sensor 6 - the rightmost one has coordinates (+0.4, -0.14). Initially 1, 2, 5, 6 sensors are located above the bright area of the field; the read values are close to one. Sensors 3 and 4 are above the black line - their readings are close to zero. A simple algorithm is used for calculating the control action depending on the readings of the sensors.

All 6 vision sensors are located along a transverse line at a distance of 400 mm from the axis of the drive wheels - this is the “X” axis. On this transverse line, the sensors are positioned symmetrically about the centerline of the robot in 50 mm increments inside each triplet of sensors on the left and right, between the two central ones (between these triplets) – 80 mm. (respectively, the extreme left ~ 140 mm along “Y”), and the entire measuring base is 280 mm. The dimensions correspond to the local coordinate system - tied to the middle of the axis of the robot’s drive wheels (Fig. 4).

During the development and modeling of the visual robot, the following parameters were taken into account:

1. The number of changes in the states of each sensor was counted - when the transitions of the read values from white to black and vice versa occurred.
2. The angles of turns of the left and right wheels were determined - in fact, the changes in the speed of rotation and the length of the paths that each wheel passed at a frequency of 20 Hz was recorded.

The obtained values - in the form of changes in the rotation speeds of the left and right wheels - are given in two variants of the nominal speed: 35 and 45 units. The graph clearly shows straight sections when the speeds of the motors are the same (Figs. 5 and 6).

Interactive learning environments are paid a particular attention in teaching Robotics. Children are very receptive to new information. This had a positive effect on the development of common abilities and skills: work with a computer and computer instructions, and acquirement of elementary computer programs.

The research based on simulators covers different robotic technologies offering students a simple method of interaction with virtual robots (Tselegkaridis &

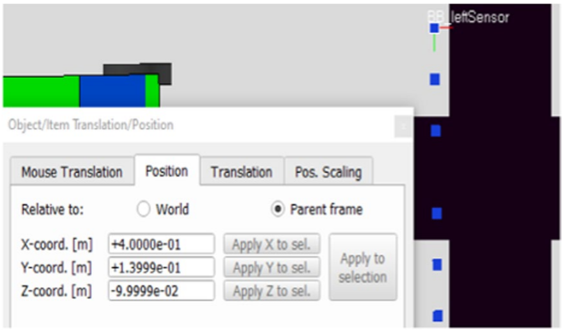


Fig. 4 Setting the position of the virtual robot

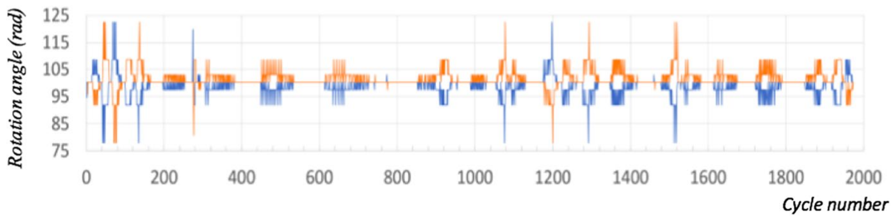


Fig. 5 The ratio of the change in the rotation speed of the left and right wheels (speed 35)

Sapounidis, 2021). At Robotics lessons children learnt to construct models and write programs for them. The work started with LEGO construction kits, then students got down to more advanced versions of virtual robot simulator, ”CoppeliaSim”, Edu version. Modeling of robot behavior in CoppeliaSim environment provided with the results comparable with their real behavior in accordance with physical laws.

The development of a robot project in the virtual robot modeling environment requires some knowledge in the sphere of constructing and programming, including understanding the essence of physical processes.

Collaborative online lessons develop children's logical and creative thinking, attention and patience. When children work with construction kits and their items their hand fine motor skills are developed, which has a positive effect on their mental development. Children have an opportunity to combine their study with an exciting game.

The children who had already learned the basics of robotics moved on to more complex topics. The 8-9th grades students started learning the basics of modeling. Robot modeling became the next step to acquire Educational Robotics and to develop computational thinking.

4.3.2 Advantages and disadvantages of collaborative online learning

There are many advantages and disadvantages in collaborative online learning. Our work experience gained during three years has showed that teachers must be prepared for any change which can happen in the society and in the whole world. Mobility, ability to reconfigure work, and readiness to meet challenges of the contemporary world became main “attributes” of teachers' professional qualities. Collaborative online and offline learning proved to be an optimal and productive

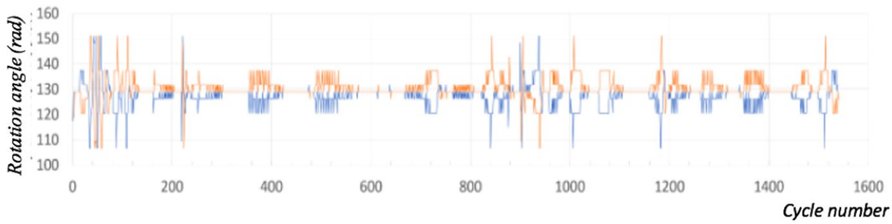


Fig. 6 The ratio of the change in the rotation speed of the left and right wheels (speed 45)

solution. It can be conducted both to one student and to a group. When working with elementary school students, a distant teacher or coordinator attends a lesson and helps children in complicated situations.

It is worth noting that we conducted collaborative online learning in the virtual learning platform we developed ourselves. Figure 7 shows how a student demonstrates the movement of the robot he/she assembled in synchronous online mode. The main advantage of the platform we used in collaborative online learning is providing every student with a personal board. A teacher could monitor all the activities in real mode.

Let's highlight the main, in our opinion, advantages of joint online learning:

1. Teaching is flexibility, individuality and adaptability. Lessons are conducted at a convenient schedule and pace. This not only improves the quality of education, but also allows for virtual communication on a computer network, helping children express themselves in society using Internet technologies.
2. The lesson can be conducted online through MS Teams, Zoom and other programs that allow students to work in distance, show the screen, make voice and video calls, exchange files for reading, and send instant messages.
3. It can be conducted synchronously and asynchronously, without time and space limit in training.
4. Promotes enrichment of students' and teachers' communicative environment.

Disadvantages of collaborative online learning:

1. Low level of computer skills of students with special needs, especially children of primary school age.
2. There is a low speed of the Internet, disconnections.

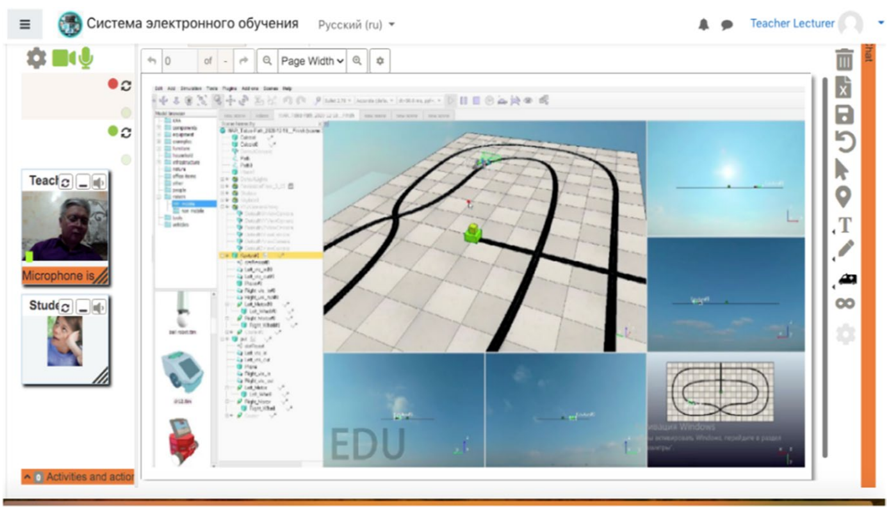


Fig. 7 Synchronous online classes

3. It is an absence of an “instructor-assistant” like parents, guardians or other adults who can provide the assistance.

At a certain stage of the experimental study it was revealed that the majority of children with special needs were not ready to work in the conditions of distance inclusive education. In order to organize online collaborative learning it is necessary to have a basic knowledge of the nature of special features in the development of such children, and in accordance with it to organize a new type of education.

5 Results

5.1 Logic of the study and realization of experiment stages

The study offers the hope that properly organized collaborative online environment contributes to the fact that children gain necessary knowledge independently of external conditions, such as the place and time, and there is no need to be tied to physical participation in real time.

We used interviews, questionnaires and tests in the experimental study. We developed individual thematic calendars and tasks for each student (Table 1).

During the collaborative online learning on Robotics with the third and forth grades students we obtained noticeable results. Children learned to use virtual robot simulators of different types. In the first quarter children faced a lot of difficulties in learning the material under study. Three of them had trouble assembling two- and three-wheeled robots in virtual robot simulator.

In collaborative online learning, connecting to a remote computer and providing timely assistance we achieved early successes. It encouraged the children to move forward. By the end of the forth quarter, that is by the end of the academic year, the children much “caught up”, and it was easier for them to understand learning material (Fig. 8). A possibility to witness their outcomes and teachers’ encouragement inspired the children for new achievements.

The given statistical information shows the increase of the subject we study, i.e. computational thinking. The methods and technologies we developed enabled us to successfully realize collaborative online learning, to apply technologies based on artificial intelligence, which have a direct impact on students’ computational thinking. Also it has led to social and emotional “saturation” of the learning process. As a result we witnessed students’ increased motivation, and improving achievements in many school subjects. The progress the children made when learning Robotics had a positive effect on their psycho-emotional development and information and communication skills. They enjoyed using a computer, playing and communicating in virtual environment, which contributed to the development of their communicative competences.

The indicative and final stages of our experiment showed the dynamics of such components of computational thinking as decomposition, abstraction, pattern identification, creation of algorithms, and analysis. In teaching Robotics, these

Table 1 A part of adapted program topics on learning Robotics

№	Topic	Developed competencies	Number of hours	
Organization of classes and initial acquaintance with robotics – 9 h			Theory	Practice
1	Introduction to Robot Simulator	The concept of simulators and why they are needed. Overview of the program and features of Coppelia Sim.	1	2
2	Introduction to the environment of computer simulation Simulator	Scene view in Coppelia Sim. The main elements of the Coppelia Sim interface.	1	2
3	Robot control in the Simulator	Scripts and programming languages in Coppelia Sim. What is a script, what is it for and how to create it.	1	2
Funny mechanisms – 9 h				
4	Construction of static objects in the Simulator	First project. Scene creation. Adding primitive objects (sphere, cube, etc.) and ready-made objects (wall, tree, corner, etc.). Changing properties. Moving objects around the scene. Saving a project.	1	2
5	Construction of moving objects in the Simulator	Control of simple robots. Creation of the simplest robot with motors - Robot-machine. Motor control script.	1	2
6	Preparing students for robotics competitions	Ability to listen and understand others; ability to build a speech statement in accordance with the tasks.	1	2
	Total		6	12

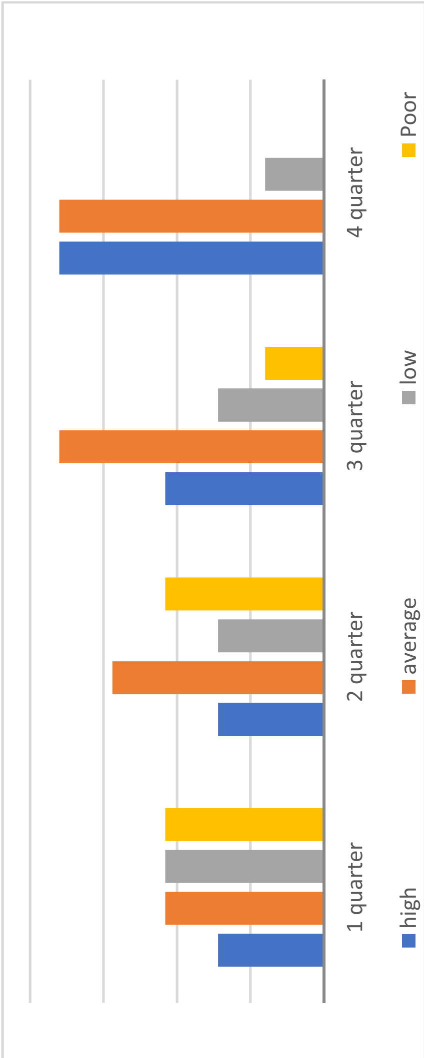


Fig. 8 Results of online collaborative learning in Robotics

components of computational thinking can be seen in the ability to divide tasks into parts, establish connection between them, and build algorithms and flowcharts.

In collaborative online learning, when developing a limited-respond robot, children discuss problems together sharing their opinions and abstracting program inputs and outputs. Automation enables to debug the program.

Currently computational thinking in a broad sense is a set of cognitive skills and processes of problem solution, which include (but are not limited by them) the following characteristics:

Using abstractions and pattern recognition for introducing a problem using new and different methods;
Logical organization and data analysis;
Dividing a problem into smaller parts;
Approach to a problem using program thinking techniques, such as iteration, symbolic representation and logical operations;
Restating a problem into a set of ordered steps (algorithmic thinking);
Identification, analysis and realization of possible solutions in order to achieve more effective combination of steps and resources;
Extension of the certain process of problem solution to other problems.

Our experimental study environment consisted of school lessons and 18 two-hour out-of-school lessons on Robotics. The class we chose for the experiment (sample) consisted of 23 students. In Table 2 there are descriptive statistics.

We calculated the average “Time spent on problem solution in seconds”. It is 163.783. Variability is within the norm, sigma is equal to 45.037. The median is 159. High, medium and low values are very close to the normal distribution (A=0.287). The excess is negative (E= – 0.893). A lot of values in the sample are at the edge minimum and maximum values. Minimum is 95, maximum is 267.

The average of the “Intelligence level” is 80. This scale shows a low variability relative to the average (sigma = 14.161). It means that this indication varies a little in the sample. Median value is 81. High, medium and low values are very close to the normal distribution (A= – 0.087). The excess is negative (E= – 1.526). A lot of values in the sample are at the edge minimum and maximum values. Minimum is 57, maximum is 100.

According to the preliminary results, we witness a positive dynamics at $p < 0.001$. For the accuracy of the study, we used statistical criteria of calculating correlation coefficient that is Spearman correlation test in R.

Table 2 Principal descriptive statistics concerning the sample

	Arithmetic mean	Standard deviation	Median	Asymmetry	Excess	Min	Max
Time to solve abstract problems in seconds	163.783	45.037	159	0.287	-0.893	95	267
Intelligence quotient	80.000	14.161	81	-0.087	-1.526	57	100

We considered the linkage between such features as the level of computational thinking and ability to solve abstract problems within a certain time. As among the values of the features there were some identical ones, we formed related ranks and calculated using the following formulae:

$$p = 1 - \frac{\Sigma 6d^2 + A + B}{n^3 - n} \tag{1}$$

The formula of correction for identical ranks of intelligence level is the following:

$$A = \frac{1}{12}\Sigma(A_j^3 - A_j) \tag{2}$$

The formula of correction for identical ranks of the time spent on solving abstract problems is the following:

$$B = \frac{1}{12}\Sigma(B_k^3 - B_k) \tag{3}$$

Where d^2 are squares of differences between ranks; A, B are corrections for identical ranks; N is the number of features participating in ranking.

Using above-mentioned formulae we calculated rank correlation values, p=0.663.

The table shows correlation coefficients of the scales on intelligence level (IQ) with the time spent on solving a set of abstract problems (X) for 14 students from one class (Table 3).

In the special table we find the critical value of the rank correlation coefficient for the sample of 14 people and for the significance level $p<0.05$. The critical value of Spearman's correlation coefficient R_{cr}= 0.532.

The value obtained $p=0{,}663$ shows positive and moderate relationship, which proves dependence of computational thinking on the ability to solve abstract problems.

In the process of working at a project, a close personal relationship between a teacher and a student based on the principal of equal partnership appears, which means communication of a more experienced teacher who does not impose his/her will and a student who acts with a reasonable independency. The project-based method involves a student in the activity where the objective is to achieve the result of the project this student is interested in, which is a powerful motivator.

It can be assumed that even in the projection period the nature of change will not change significantly. Using obtained experimental data we approximated reliability (R^2) and related exponential equation (trend lines).

At the beginning of the experiment, the level of children's mastery of learning material was rather low (Fig. 9a, gray hatched line), reliability was $R^2 = 0.526$, and the exponential equation was $y=e^{-0.159x}$. At the end of the experiment we faced the process of more effective mastery of learning material and as a result the indicators were higher (Fig. 9b, gray hatched line), reliability $R^2 = 0.9088$, and the exponential approximation equation is $y=e^{-0.225x}$.

Table 3 Correlation coefficients of the level of dependence of intelligence (IQ) and the time of solving a series of abstract tasks (X)

	Correlation	Indicators	
Dependence of intelligence level (IQ) on the time spent on solving abstract problems (X)	Spearman's rank correlation	Middle-ranking value −9.06	Rank-sum 124.40
	Value	Bilateral −0. 550	
	$p=0.663$		
	N	14	

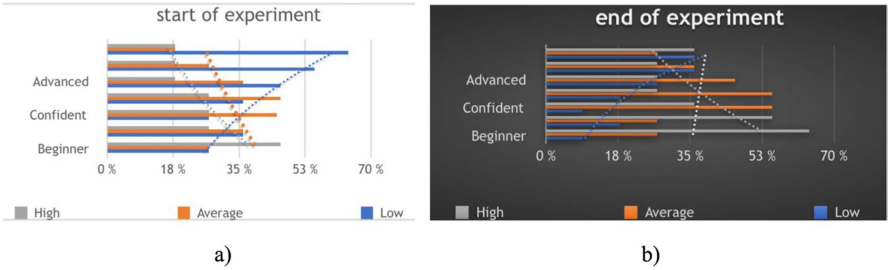


Fig. 9 Experiment results and trend lines

Thus, we can conclude that there is a significant difference in learning outcomes at the beginning and at the end of the experiment, which proves effectiveness of the model developed.

The results of the diagnostics obtained at the final stage of the experiment show the positive trend in the development of willingness for collaborative online learning which is reflected in values-based, motivated, cognitive and active readiness for realization of learning principles.

6 Restrictions and perspectives of the research

Despite positive trends obtained in this study, there are some restrictions the solution of which will enable to expand the research area. Some problems regarding the influence of robotics programming upon students' computational thinking in a specially organized environment still remain unsolved. We used collaborative online learning at Robotics lessons as such special environment.

Access to digital technology and its introduction to the learning process provide all the students regardless of their social, ethnic, gender and other differences with equitable opportunities to gain knowledge (Mavrou & Loizou-Raouna, 2017) as the creation of the special learning environment ensures equity of teaching and educating children (Burke & Hughes, 2018).

The tasks, which we gave to the students in order to see their ability to solve abstract problems, to program in robotics environment while creating constructions and mechanisms, helped us identify their level of proficiency in computational thinking. The development of metacognitive abilities in collaborative learning environment, where children reveal themselves from a completely new point, is the subject for further study. However, it is evident that learning Robotics proved to be an enabling environment for realizing collaborative learning, which enables to develop students' computational thinking if it is organized properly.

During the study the following characteristics and limitations influencing both the study itself and its experimental part were identified:

Complexity in the organization of the experiment on collaborative learning in online environment;

Logic and strategy of the study including objects and subjects of the experiment (establishing the relationship, proving correlation between them): computational thinking, collaborative learning, educational Robotics;
Limited nature of the experiment and involving a researcher in the experimental situation.

Knowledge of appropriate teaching methods enables to effectively influence collaborative learning and achieve positive results (Flem et al., 2004).

7 Discussion

In answering the questions raised in this study we can confidently say that collaborative online learning has clear advantages in education. Teaching Robotics to children has a number of features which must be taken into consideration. Developed computer skills and gained knowledge of Robotics served as a starting point for further development of computer skills and further knowledge of Robotics fundamentals. Properly organized collaborative learning, online mode of lessons, fast and effective feedback, and specially selected tasks proved that all these are a good prerequisite for developing computational thinking.

Interactive learning environment has had a positive educational effect: computer skills improved, and interest in learning Robotics increased. The task of developing algorithmic programs and creating abstract models and real constructions was solved. The structure itself and the design and organization of collaborative learning, arrangement of practice, monitoring and assessment materials for distant learning courses were developed under taking into account different variants of tasks. Joint activities with teachers and psychologists have had expected positive results in students' socialization and personal development. Collaborative online learning and digital integration at school bring down social barriers and enable to improve children's abilities to participate in different life activities (Mariën & Prodnik, 2014).

8 Conclusion

In the study we tried to introduce the scenario of collaborative online learning in educational Robotics using computer support. This study is important because there is a need for creating a flexible learning system aimed at developing computational thinking as one of the most necessary qualities modern students have to possess. Educational Robotics has been the subject of our work with mainstream school students and our field of study for several years. One of the ways to solve rising research and organizational problems is collaborative online learning. And we would like to share our experience of working in collaborative online learning with the readers who are interested in this problem.

The collaborative online environment we organized consisted of learning different courses on Robotics. Students' outcomes depended on the fact which methods and forms of work their teacher applied. That is why the tasks were designed so that they arouse children's keen interest; develop their computational thinking, ability to solve abstract problems, ability to program, including their creative activity and ability to work in a team.

During the experiment such indicators as the level of learning study material and developing computational thinking increased. Reliability of the experiment results is confirmed by the approximation exponential equation, $y = e^{-0.225x}$ at the following values: $R^2 = 0.9088$ and $R^2 = 0.526$. The fact that the students learned to use computer operators and to program contributed to improve the level of their mathematical and computational thinking.

We believe these results are achievements in the sphere of our study. Besides, they help to solve problems we face now concerning the development of computational thinking, arrangement of collaborative online learning, and development of students' motivation to study Robotics.

We do hope the conclusions and results obtained in this study will serve us as a starting point for continuing the work on the development of computational thinking when learning Robotics and for searching further prospects of developing the problem we chose.

In future studies one can consider other factors and conditions of organizing learning environment, which can be very important for developing children's computer skills while teaching them Robotics.

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Data availability The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest None.

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