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# Introduction of Educational Robotics at Secondary School Level in the Latvian Education Curriculum

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## ABSTRACT

The relevance of the present research is justified by the wide range of educational robotics applications and the rapid development of educational technologies in general. Technologies are produced faster than it is possible to develop methodical teaching materials or curricula, especially in the Latvian language. Educational robotics develops various skills and knowledge, such as algorithmic thinking, problem-solving, logical thinking, etc. However, despite the clear achievements in technology education, there are a number of related problems. These include the lack of teachers, the qualifications of teachers, the lack of funding, and the insufficient provision of teaching materials in line with the new approach in the Latvian education curriculum. The study aimed to develop, test, and improve instructional materials for the implementation of the curriculum for the use of digital technology in elementary schools, as well as to create a methodology for evaluating learning achievements in ICT lessons on the topic "What is programming and how to program in a visual environment" and promoting the development of algorithmic thinking (learning with the educational robot Photon). The study uses mixed research methods. The first part was the analysis of the literature on educational robotics and computational thinking. In the empirical part of the action research, both quantitative and qualitative research methods were used. The results obtained are important for a wider and more meaningful introduction of educational robotics in Latvian schools.

*Keywords:* computational thinking, educational robotics, instructional materials, Photon, educational robot

## Introduction

Robotics, science, and techno-scientific practices in general have become increasingly common in individual and industrial contexts. In both social contexts, we see how artificial intelligence (AI) is integrated into various processes, such as security recognition or disease detection and prevention in public health (Salas-Pilco, 2020). Integrating technology, including educational robotics, into the learning process is essential. It is important to implement the technology-enhanced learning process meaningfully, responsibly, and in such a way that technology is a tool to achieve specific goals. Technologies in education are associated with both the technical and organizational support of the educational process, which includes learning management systems, learning platforms, and the management systems of educational institutions (Daniela, 2021), and with learning means, such as educational robotics (devices of various complexity, structure, and functionality), which can be used in the learning process for learning specific achievable results. There are various obstacles to the implementation of educational robotics in practice. One of the main obstacles is the lack of effective instructional materials for the use of educational robotics in classrooms, as well as well-defined curricula and learning materials. These obstacles have created a lack of experienced and professional educators in the productive use of educational robotics (Yang et al., 2020).

Educational robotics is now being widely introduced in learning in schools around the world (at various education levels), including in the general education curriculum in Latvia. However, the amount of instructional materials available in Latvian is very limited. This is a significant obstacle to the introduction of robotics in the learning process. Teaching robotics can be a big challenge for many teachers because, for example, translating materials from another language or creating one's own takes a lot of effort. Another problem is the lack of educators who can teach robotics. Sometimes, educational robots are available at schools, but no one is ready to teach with them.

Currently, there are significant differences in the definitions and implementation processes of educational robotics in educational processes. There are also sometimes noticeably different opinions about the advantages and disadvantages of educational robotics and how to learn it better at different age stages. As such, it is important to use uniform terms, criteria, and guidelines when creating instructional materials for robotics.

## Concept of robotics and robot, their development and importance

The field of robotics is a combination of science, technology, and engineering. The main goal of robotics is to produce intelligent machines (Alici, 2018). On the one hand, robotics could be considered a recent trend, and it is now possible to robotize almost everything. From robots that weld parts on car manufacturing lines to robots that interact with people in the service industry (Staples, 2018), we encounter various robots in our daily life, such as chatbots on the web, self-service checkouts, robot hoovers and lawnmowers in households, etc. Robotic technology is thus emerging as tools with particular purposes that will allow us to improve the quality of our lives in many aspects, whether caring for our loved ones or making our businesses more productive (Hawes, 2021).

Robots can be classified in many different ways. First of all, it is important to point out that robots can be divided into physical robots and software robots. This research focuses on instructional materials in educational robotics, and the materials developed are for working with the physical robot known as Photon. Despite all the advantages that robotics can bring to education, there is still a lack of a clear definition of the purpose of introducing robots into education (Scaradozzi et al., 2019). Although it is difficult to come to a single definition due to the rapid and dynamic development of the robotics industry and the development of the field of technology more generally, it is possible to classify robots according to their functionality, characteristics, and purpose of operation.

## Educational robotics

The beginnings of educational robotics can be traced back to Papert's invention of the LOGO programming language (Papert, 1980), which was suitable for encouraging children's development of their technology and programming skills. Papert's career spanned a trio of influential movements: child development, artificial intelligence, and educational technology. Based on his insights into children's thinking and learning, Papert recognized that computers can be used not only to provide information and instructions but also to allow children to experiment, explore, and express themselves (Resnick & Robinson, 2017).

Robotics in education (hereinafter, RI) covers various applications of robots in the world of teaching and learning, such as replacing the teacher with a robotic device at some stage of learning (reading texts, etc.) or using robots as a support device (communication, motivating students, etc.). On the other hand, educational robotics (hereinafter, ER) is a field that aims to improve people's learning experience, where two aspects (pedagogical and technological) are essential to introduce, improve, and choose appropriate activities, tools (guidelines, templates, etc.), and technologies in which robots play an active role, each activity is pedagogically justified, and the most appropriate methods are chosen (Angel-Fernandez & Vincze, 2018). In short, ER teaches the design, analysis, applicability, and operation of robots, while robotics is used to motivate the learning and acquisition of programming, artificial intelligence, and engineering skills.

Regardless of the classification of robots used and how ER is integrated into the learning process, ER for students aims to achieve specific learning outcomes:

- To improve problem-solving skills, making it easier to understand complex concepts, research, and make decisions.

- To increase self-efficacy: The natural controllability of the robot encourages experimentation, discovery, and rejection, thus increasing the student's self-confidence, as the student feels in control of the machine. It also strengthens students' critical thinking.
- To improve algorithmic thinking: Students learn algorithmic thinking to break down a large problem into smaller ones and then solve it, thus learning to focus on important information and reject irrelevant details.
- To increase creativity by learning with knowledge that conveys play in a more playful form. Learning turns into a fun activity and becomes more attractive and interesting for the student.
- To increase motivation, as ER allows students to engage in a specific activity and stick to it (Evripidou et al., 2020).

There are two basic types of educational robots based on Papert's ideas: *Build Bots*, which students must assemble before use, and *User Bots*, which students can take out of the packaging and use immediately (Catlin et al., 2019 ). Researchers and authors have described various benefits to students using ER with both *Build Bots* and *User Bots* in the learning process. The three most important are the development of computational thinking, problem-solving skills, and creativity. Researchers who are working in the field of educational robotics explain that *black box robots* (or *User Bots)* are ready-made devices that students can work with, but since there is no customizing, joining of parts, or creating a design, the student does not know what is inside the robot and does not develop an understanding of its functioning.

The situation in the field of STEM education in Latvia as a whole can be assessed as quite good and constantly improving. However, one of the biggest problems is related to the availability of instructional materials in Latvian and the lack of teachers in the field of robotics. Therefore, during this research, instructional materials were developed for working with the Photon educational robot.

Photon is a learning tool of the latest generation and can be used both at educational institutions and at home, allowing children to get to know the world of modern technology through their own experiences and experiments. According to the taxonomy described above, the Photon robot is ready-made (*black box, User Bots*) and does not qualify as a toy (Photon Robot for Education, 2021) because it has the characteristics of an educational robot, such as flexibility, digitization, repeatability, humanization, and natural interactivity (Pei & Nie, 2018). With the help of the Photon robot, children can develop their algorithmic thinking, creativity, and logical thinking. In the same way, working with a robot can develop their ability to search for solutions to problems in different ways and promote the acquisition of both programming skills and knowledge of the English language.

By applying appropriate methods in a specific situation, the impact of the robot on the development of children's skills could be divided into four main categories: cognitive, conceptual, language, and social (cooperation) skills (Toh et al., 2016). It is important not to treat ER as the "main" focus of learning where students learn how to play with robots; instead, it should be integrated into a holistic pedagogical strategy to benefit students' learning and development (Tang et al., 2020) to support the formation of knowledge of programming, computational thinking, and creativity.

## Computational thinking

The beginnings of computational thinking in the context of technology can be traced back to the previously mentioned Papert in 1960 when he published his concept and basic principles of computational thinking. He also created and introduced the LOGO programming language in 1967 (Resnick et al., 1988) and coined the term "computational thinking" in *Mindstorms: Children, Computers and Powerful Ideas* (Papert, 1980). The educational team founded by Papert at the Massachusetts Institute of Technology has since developed and researched methods for developing algorithmic thinking in students. According to Papert, there are six essential principles of computational thinking:

- an understanding of human-computer interaction;
- the ability to create algorithms to solve problems;
- abstraction and the ability to find and use information;
- problem analysis: possible solutions and anticipation of other problems;
- communication: one must be able to explain problems and provide possible solutions;
- teamwork: one must actively work with others to solve problems (Papert, 1996).

The principles of computational thinking and the development of related skills are closely related to everyday challenges even today. As such, computational thinking is and will be urgent both in the learning process and throughout life. When considering the definition of computational thinking, it is important to mention that, as is the tendency in the field of technology, there is no single definition for this term. However, the following definitions have been put forward by some of the best-known authors on this topic:

- thinking that solves problems in computer science and that makes one think abstractly. Papert primarily connected this concept with the ability to solve problems in computer science (Papert, 1980);
- thinking processes involved in formulating problems and their solutions so that they can be represented in a form that can be implemented by a human or a computer (Wing, 2017;

- a set of skills that connect basic cognitive skills involved in complex tasks such as abstraction, algorithmic thinking, and data representation (Brennan & Resnick, 2012);
- a way of finding solutions with clearly defined steps).

In scientific articles, conceptualizations of computational thinking are divided into two categories: computational thinking as a code-oriented skill and computational thinking as an interdisciplinary practice. Regardless of whether a code-oriented or interdisciplinary practice is adopted, the computational thinking research community mainly uses the computational thinking construct in the form of programming-based activities (Kite et al., 2021). Relatively few attempts have been made to integrate computational thinking into advanced curriculum programs.

Computational thinking as an interdisciplinary practice can be implemented in any field, but a code-oriented practice can be specifically applied in computer classes because these provide an environment where everyone has access to a computer and a teacher who understands programming. Computational thinking in computer classes is not only related to programming, however. Elementary school students start with logical games in the 1st grade, learn the visual programming environment in the classroom in the 4th-6th grade, and then continue with a text-based programming environment in the 7th-9th grade.

During the last 20 years, methodologies and techniques have been developed that aim to support the development of computational thinking. It was essential to understand how to combine computer capabilities with human capabilities to create the best solution. A key takeaway from these findings is that supporting computational thinking is much more than just programming accessibility (Repenning et al., 2020).

## Methodology

For the purposes of this research, 13 instructional materials were developed on how to work with Photon with 4th-5th grade students. The materials were developed in a sequential mode, meaning that each material was developed before a particular class, and the next one was developed based on the results from previous classes. Knowledge development was evaluated using formative assessment tests that followed four levels of knowledge based on the SCML evaluation system (Started to learn: 0–24%; Continues to learn: 25–49%; Mastered: 50–74%; Learned in-depth: 75–100%) to determine how these materials supported the development of computational thinking. At the end of each lesson, students performed a self-test by answering open-ended questions in the Quizziz tool, which started with simple questions and increased in difficulty (see Table 1). Their answers were evaluated on a scale from 0–4, where 0 = no answer given, 1 = 0–24%, 2 = 25–49%, 3 = 50–74%, and 4 = 75–100%.

*Table 1.* Learning outcome evaluation questions

| Outcome to be achieved | Questions |
|---|---|
| To materialize the idea, you need to understand what actions have to be done. | 1. What is a robot?<br>2. What actions does a robot help us do in our daily lives?<br>3. What do you understand by "robotics in education"? |
| Both computers and humans can perform algorithmic operations.<br><br>Name the differences and commonalities between humans and computers in the action performed by the human. | 1. What is an algorithm?<br>2. Who can perform/execute algorithmic operations?<br>3. Write a short, simple algorithm |
| For each result, the achievement can be described and broken down into a number of smaller and simpler actions.<br><br>Required actions can be written down in different ways. | 1. Who can perform/execute algorithmic operations?<br>2. What commands/actions does the Photon robot perform (write at least 3)?<br>3. What types of algorithm notation can you write down? |
| Describe the algorithm of your idea in words or diagrams.<br><br>Verbally (by making a list) and schematically (by schematic drawing in free form), describe linear and cyclic algorithms in everyday situations. | 1. What are the different types of algorithms?<br>2. How do you rate your work today – write how it went and what was most interesting. Fill in the self-assessment.<br>3. What sensors does the Photon robot have, and why are they necessary? |
| The correctness of the algorithm can be checked by executing the sequential steps specified. | 1. How can you work better in Scratch with a spirit or a robot?<br>2. How do you problem-solve on a daily basis? Describe the steps<br>3. How can you check the correctness of an algorithm? |
| The simple actions that are possible are determined by the environment in which the actions are performed (programming or physical).<br><br>The computer executes the commands given to it verbatim, so the accuracy of the algorithm in the input is very important. | 1. Enter two words that fit into the paragraph in the space provided: "The simple actions that are possible are determined by the environment in which the actions are performed – ... or ..."<br>2. Draw a short linear algorithm.<br>3. Draw a short branching algorithm.<br>4. Draw a short cyclic algorithm. |
| Create a project in a visual programming environment that executes a written or schematically defined algorithm.<br><br>Create a description of the solution and record the sequence of steps. | 1. List two ways how an algorithm can be defined.<br>2. Write down why it is important to analyze and describe an operational algorithm.<br>3. Describe the steps to create a qualitative project in the visual programming environment Scratch. |

*Table 1.* Continued

| Outcome to be achieved | Questions |
|---|---|
| The design solution is targeted and implemented according to a plan.<br><br>The design program is tested for story representation and possible improvements are identified. | 1. What are the features of Scratch's visual programming environment?<br>2. Write down three types of algorithms.<br>3. Describe the steps to create a quality project in Scratch with the Photon robot. |
| Design and visualize an animated story with several characters who perform various simple or cyclical actions to convey the message. | 1. Write down what you did best.<br>2. Write down which part of the test you liked best.<br>3. Write down what didn't go well and what you would like to do next time to improve.<br>4. Write down which part of the test you disliked the most or which seemed redundant.<br>5. How many marks would you give yourself if you were to assess your work according to the criteria? |
| In a programming environment, plan and visualize a story to be represented on a carpet by a Photon robot that performs various simple or cyclical actions to convey the message of the story. | 1. Write down what worked best for you.<br>2. Write which part of the test you liked best.<br>3. Write down what didn't go well and what you would like to do next time to improve.<br>4. Write down which part of the test you disliked the most or which seemed redundant.<br>5. How many marks would you give yourself if you were to assess your work according to the criteria? |
| Demonstrate visual programming stories developed in a programming environment, evaluates classmates' performance, and analyze the results. | 1. Write down your thoughts on whether you prefer working on Scratch with or without the Photon robot. Why?<br>2. Was there anything in your classmates' programs you didn't know how to make? Can you describe what it was?<br>3. Compared to other topics in computer lessons, was this topic different? Did you like it better or not? Why?<br>4. What did you learn about in this topic? |

At the end of the topic, a summative assessment was carried out, consisting of three parts (Scratch, Scratch + Photon, test). The results of 28 students were analyzed in this research; however, this paper only analyzes the final evaluation results.

The materials developed were validated to see whether implementing the developed learning materials improved problem-solving skills, increased self-efficacy, and developed algorithmic thinking, creativity, and motivation.

All procedures performed while involving human participants were conducted in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

## Results

Students' answers to the formative assessment tests were assessed using the SCML principle. Observations show that some pupils did not go into what the question asked or submitted incomplete answers, resulting in a score of 0. The results also depended on whether the question was easy to assess. For instance, naming the types of algorithms has specific correct answers, but answering what a robot is is not so easy to answer, resulting in very different answers.

When assessing the progress of the students, it is evident that the students who answered more accurately at the very beginning ended up with significantly higher marks on the test and vice versa – if they gave no answer or an inaccurate one, their final mark was not very high either. This conclusion is based on the students' scores. After analyzing the data, it can be concluded that almost half (43%) of the respondents have mastered the topic and 25% learned it in-depth for a total of 68%. This is by far the largest part of the respondents. Of the remainder, 25% were assessed at the level of "Continues to learn," while only 7% were assessed as "Started to learn."

The reasons for the low performance indicators could be different, for example, frequent absence from school or the students' light-hearted attitude, e.g., doing everything quickly rather than with better quality. This might have resulted in them not answering the questions at all or answering something completely different from what was asked, thus causing them to get the lowest number of points.

It can also be concluded from the student survey that of robots, algorithms, and the visual programming environment, students knew the most about robots before learning the topic. Similar results also appeared after learning the topic. The respondents knew less about algorithmic thinking and the visual programming environment before learning the topic, but after learning the topic, they knew what an algorithm is.

The visual programming environment performed worst, which was perhaps because it was not talked about as much. For instance, the students knew that the environment they were working in (Scratch) was a visual programming environment, but most did not perceive it. Only a few respondents had previously worked in the Scratch environment or with robots.

This questionnaire proved to be not only a unique and productive experience but also resulted in skills and knowledge being gained, as evidenced in the practical tasks at the end of the survey. The results can be seen in Table 2.

*Table 2*. Students' results in the final test

| | |
|---|---|
| *Scratch* | 81.9% |
| *Scratch + Photon* | 82.3% |
| Tests | 77.9% |
| AVG in class | 80.5% |

Analyzing the students' results after completing the tasks shows that they did the best with the Scratch + Photon part and the worst with the theory test. Overall, the class' grades ranged from 3 to 9, and the average grade was 80.5%, which is very good. The results also vary when comparing the students' individual results, and students who got a failure score did not complete two parts (Photon and test).

## Conclusions

Activities with Photon robots develop creative and logical thinking, other skills in a variety of creative ways, and programming skills. When this is combined with the visual programming environment Scratch, discussions, theories, and, above all, practical tasks, pupils are encouraged to develop their algorithmic thinking.

When creating instructional materials, first of all, the goal for ER's implementation should be set in the learning process in computer classes. Second, the learning content should be clearly defined and have achievable results. Next, teaching methods and pedagogical conditions for achieving the goal and learning outcomes should be determined. Then the structure of the learning module, the lesson, should be divided by subtopics with clear indications of exactly which stages ER is included in during the learning process.

The development of teaching materials using an action research design was a very successful practice, enabling the researchers to plan the overall course based on the lessons' results, observations, and conclusions.

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