Enhancing Computational Thinking Skills using Robots and Digital Storytelling

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Abstract: The need for digital education from an early age is undisputed today. In the years to come, computer science education is to be integrated more intensively into early education and thus find its way into primary school. Since it is planned to be anchored in the Austrian primary school curriculum, research into teaching methods and content suitable for this area is becoming increasingly necessary. For this reason, a research project with programmable robots was developed to support and promote the introduction to computer science education in primary schools. This study is part of a long-term educational design research project. To examine the implementation of computational thinking focusing on using programmable robots and digital storytelling a programming unit with the robot Ozobot for third and fourth graders was developed and analyzed. This contribution is dedicated to the question of how do Ozobots enhance children's computational thinking skills through storytelling activities. Results show that combining educational robotics and storytelling is a promising approach to promote computational thinking.

1 INTRODUCTION

Computer science education, including coding, computer science unplugged activities, and computational thinking, is more and more becoming the key addition to a twenty-first-century education. Many governments across the globe now require that educators teach coding from early education upwards (Rich et al., 2019). As computer science education is anchored in the next Austrian primary school curriculum, the topic of implementation and its didactic principles are becoming increasingly important. Even though researchers see the implementation of computational thinking in education as one of the most important prerequisites to foster problem-solving skills at a young age, only in recent years, this topic has begun to be successively explored with students in grades K-12 (Bers et al., 2014; Botički et al., 2018). Nevertheless, experts agree that playful methods of programming can foster computational thinking skills. One possibility of their promotion is the use of educational robots. Concerning computational thinking skills, during the past decade, the research community has embraced educational robotics with real enthusiasm as an approach to teaching computational thinking to young learners (Atmatzidou & Demetriadis, 2014; Bers et al., 2014, Stoeckelmayer et al., 2011). Besides the traditional approaches to robotics, students become motivated when robotics activities are introduced as a way to tell a story, or in connection with other disciplines and interest areas (Angeli & Valanides, 2020; Benitti, 2012; Rusk et al., 2008).

Therefore, this paper describes the application of the teaching and learning method of digital storytelling in an interdisciplinary approach and its insights into how educational robotics can be combined with storytelling activities to support students' development of problem-solving thinking skills.

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2 CONCEPTUAL FRAMEWORK

2.1 Computational Thinking

Computational thinking (CT), first mentioned by Seymour Papert (1980), inventor of the programming language LOGO and founder of constructionism, is considered as an important aspect of developing problem-solving thinking skills (Lye & Koh, 2014, Wing, 2006). Since the publication of Jeannette Wing's article on computational thinking (Wing, 2006), many other educators and researchers have argued strongly to integrate computational thinking into the education of students at all levels of education as a fundamental 21st-century skill (Barr & Stephenson, 2011; Lee et al., 2014; Shute et al., 2017). Wing's paper describes computational thinking as "problem-solving, system design and understanding human behavior by drawing on the fundamental concepts of computer science" (Wing, 2006). Brennan and Resnick's (2012) framework categorizes computational thinking into three dimensions: "concepts, practices, and perspectives". Another popular definition of computational thinking developed by the International Society for Technology in Education and the Computer Science Teachers Association (ISTE & CSTA, 2011) states that "Computational thinking (CT) is a problem-solving process that includes (but is not limited to) the following characteristics" (Table 1):

Table 1: Characteristics of the problem-solving process.

Characteristics of Computational thinking (ISTE & CSTA, 2011)
(a) Formulating problems in a way that enables us to use a computer and other tools to help solve them
(b) Logically organizing and analyzing data
(c) Representing data through abstractions, such as models and simulations
(d) Automating solutions through algorithmic thinking
(e) Identifying, analyzing, and implementing possible solutions to achieve the most efficient and effective combination of steps and resources
(f) Generalizing and transferring this problem-solving process to a wide variety of problems

BBC Bitesize (2019) formulates "the four cornerstones of computational thinking": First, problems are broken down into smaller ones ("decomposition"), then it is considered whether a solution for a similar problem is available ("pattern recognition"). After that, only the basic information remains ("abstraction"). Next, a solution strategy can be designed ("algorithm").

Researchers declare the importance of implementing algorithmic thinking and fostering problem-solving skills at an early stage to achieve computational thinking successfully, but also to develop an interest in technical professions early on (Bergner et al., 2017; Best et al., 2017; Himpsl-Gutermann et al., 2017; Kong et al., 2019). Developing a definition or approach to computational thinking that is appropriate for K-12 is particularly challenging given that there is not yet a widely agreed definition of computational thinking. However, researchers agree that problem-solving skills, logical thinking, and algorithmic thinking can be learned by K-12 students in a variety of disciplines (Barr & Stephenson, 2011). Furthermore, it is stated that children from the third grade onwards have no problems understanding and using the basic elements of a programming language for controlling activity flows and naming entities (Futschek, 2016; Lee et al., 2014; Weigend, 2009). Lee et al. (2014) described, that many everyday activities can be made more efficient when the person performing them can apply computational thinking.

2.2 Educational Robots

One of the emerging resources for problem-solving thinking skills, as well as students' digital competence, is educational robotics (Atmatzidou & Demetriadis, 2014; Lee et al., 2014). A robot enables to interact with the environment using concrete instructions, but in less abstractly than a computer and it playfully serves as a tool for developing problem-solving thinking skills, creativity and cognitive competencies. The use of robots is not only demonstrated by increasing motivation in the classroom but due to its technological characteristics, it enables solving tasks that promote computational thinking as well as skills related to scientific, and mathematical skills such as social skills, collaboration, and communication (Esteve-Mon et al., 2019; Tengler et al., 2020). The use of programmable robots in education has become more and more important in recent years. It has been shown that robotics can increase the motivation of students because it enables them to work in an integrative way while developing several additional skills (Stork, 2020; Tengler, et al. 2019). "Robotics activities in education offer opportunities for students to explore, create and apply knowledge to solve real-world problems" (Stork, 2020, p.2). Contemporary research studies conducted to investigate this area of research report that educational robotics is an engaging approach to the development of young learners' computational thinking, as children can interact in a hands-on manner with a robot and observe the impact of their interactions on the robot's behavior directly (Bers et al., 2010; Bers et al., 2014; Stoeckelmayer et al., 2011). To date, several studies have investigated that the integration of robotics in education promotes responsibility, collaboration, autonomous learning, and creativity as well as increases interest in technology (Anwar et al., 2019; Arís & Orcos, 2019; Kandlhofer & Steinbauer, 2016). Besides, positive effects of robot activities are observed in the aspects of teamwork and social skills (Kandlhofer & Steinbauer, 2016).

The robot used in this study is the Ozobot (Figure 1). An Ozobot is an approximately 2.5 cm wide robot that moves on two wheels and uses color sensors to follow lines and recognize color codes (Ozobot.com). Working with the Ozobot offers opportunities to achieve competencies playfully in the area of computer science and technology, but also to promote the ability to work in a team, collaboration, and social competence. Due to the easy entry into programming the Ozobot, even younger children, recommended from the 2nd school level, can work with the small robots. The simple handling of the Ozobot makes it possible to use the small robot meaningfully in a single teaching unit and to achieve the learning objectives set (Geier & Ebner, 2017). Since these small robots can be used at different levels, they are suitable for simple programming up to more complex tasks and programming solutions.

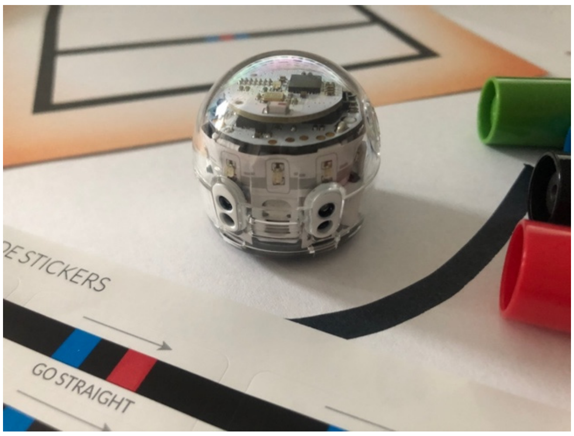

Figure 1: Ozobot.

While tangible floor robots constitute an easy-to-use tool for young students, at the same time, teachers must learn how to use them in an appropriate pedagogical way to maximize their effect on the development of young children's computational thinking skills. As it is well documented in the literature, scaffolding children during learning with educational technology tools is important (Angeli & Valanides, 2020). The didactic principle for the use of this mini-robot very well realizes the important demands for an age-appropriate introduction into working with digital media. The playful approach arouses fascinating and enjoyable, which provides a neurobiological efficient foundation for successful learning (Schachl, 2016). Moreover, it is important that programming in education is designed in such a way that it promotes children's creativity, that algorithmic thinking is encouraged and that one does not stick to reconstruction and deconstruction of existing content (Brandhofer, 2017).

2.3 Digital Storytelling

Digital storytelling is a teaching and learning method that combines the traditional form of storytelling with the use of digital technologies. The aim is to create digital stories based on a combination of different artifacts. Although the digital stories are the result of this process, the added pedagogical value of digital storytelling lies in the process rather than the final product (Otto, 2020). "Digital storytelling involves the combination of technology such as digital audio, video, movies, multimedia images, among others, with story creation by developing one's skills in organizing thinking patterns and pattern recognition" (Stork, 2020, p.44). Robin (2006, p.2) classifies digital stories into three categories: "personal narratives, stories that examine historical events and stories, that are primarily used to inform or instruct". In any category, digital storytelling can be integrated into teaching practice in multiple ways. In fact, four main teaching approaches are proposed: (a) case-based, (b) narrative-based, (c) scenario-based and (d) problem-based (Kordaki & Kakavas, 2017).

Several researchers and educators proposed models for the digital storytelling process. Robin & McNeil (2012) adapted the ADDIE Design Model for the digital storytelling process that consists of the following elements: Analysis-, Design-, Development-, Implementation- and Evaluation-Phase. Morra (2017) presented a rather pragmatic but also very descriptive concept with an eight-step approach to digital storytelling. Kordaki & Kakavas (2017) analyzed the stages of digital storytelling and proposed an initial framework that highlighted the relationship between digital storytelling development and computational thinking skills cultivation.

Digital storytelling allows students to improve their digital skills by creating interactive stories. It allows them to effectively demonstrate what they have learned by technically implementing the story they have created. "Digital storytelling can encourage creativity" (Robin, 2016, p.19) as well as it contributes to fostering other 21st century skills such as collaboration, communication, and critical thinking as each group of students shares their knowledge with the others and reflects on the outcome (Stork, 2020).

Digital storytelling activities that promote computational thinking create a link between the real world and the classroom, making learning more entertaining and additionally enhancing student motivation (Parsazadeh et al., 2020). Padilla-Zea et al. (2014) as well found that including storytelling in learning activities promotes students' motivation. To date, several studies have shown that the combination of storytelling and technology enables deeper learning through the synthesis of what is presented and how it is verbalized (e.g. Kim et al., 2015; Mayer, 2003). "Students make decisions about what content to include and what is the most effective format to get their message across. […] The use of technology allows students to gain a better conceptual understanding of the technology they are using" (Stork, 2020, p.45).

3 METHODOLOGY

3.1 Description of the Learning Environment

As this study is part of a longer-term study based on design research in education (Bakker, 2018), which aims to investigate the implementation of computational thinking focusing on using programmable robots and storytelling in primary school, the participants were already familiar with programming the Ozobot. Nevertheless, the functioning and coding of the Ozobot were repeated at the beginning of the storytelling unit. After that, the students were divided into groups of four and given a worksheet with a problem-based task. The students' assignment was to create a fairy tale based on the given characters (princess, dragon) and some facts (e.g., cross over the river, ...). The task was to depict the story graphically and to program the story's plot accordingly and to carry it out with the Ozobot (Figure 2). Students should use appropriate codes and lines when drawing the story that the Ozobot changes color, spins, or changes speed. Finally, the story was filmed using tablets and presented to the other groups. Then the students had the opportunity to give feedback.

Figure 2: Storytelling with Ozobots.

3.2 The Study

This exploratory sub-study of the longer-term educational design research study, which is parted into several cycles (Bakker, 2018), was conducted at an Austrian primary school with 16 third grade students (aged 8-9 years), 5 girls and 11 boys, who already had experience with the basic functions of Ozobot programming.

Literature review, classroom experiences and insights gained from the authors' previous studies led to the following research questions:

- Which components of the computational thinking process can be identified through storytelling combined with programming activities?
- How do Ozobots enhance children's computational thinking through storytelling activities?

Classroom observations, teacher interviews, student reflections, and student-created artifacts provided the data for this cycle of the research project. The competencies identified and defined by the computational thinking framework (Bitesize, 2019; ISTE & CSTA, 2011) relevant to using educational robots to design stories were the basis for developing the data collection instrument.

The qualitative research methods used in this study included the following: interviews, observations, data collection procedures and data analysis (Döring & Bortz, 2016). During the data collection phase, the interview and observation data were analyzed, coded, themes for the problem-solving process developed and interpreted (Mayring, 2015) about the computational thinking framework. Two key environmental components, educational robots and digital storytelling were used to influence the building and enhancement students' computational thinking skills through an interdisciplinary approach. Classroom observations provided data on the stages of the problem-solving process and indications for communication and collaboration. Interviews delivered data to answer the question of how do Ozobots enhance children's computational thinking through storytelling activities. Finally, student-created artifacts provided data on creativity and problem-solving skills.

4 RESULTS

The Ozobot offers a simple way to teach the basic concepts of programming or computational thinking playfully and to build problem-solving skills. Above all, precise work when drawing the lines is essential so that the robot can interpret the color codes correctly.

The research questions of the study will be answered in more detail in the next chapters.

4.1 Components of the Computational Thinking Process

The first step was to investigate whether stages of the computational thinking process (Bitesize, 2019; ISTE & CSTA, 2011) could be identified in storytelling activities in combination with Ozobot programming. The data based on the observation and the interviews were assigned to the stages of the computational thinking process and listed in the table below (Table 2).

As shown in Table 2, there seems to be a relationship between the computational thinking components and the development of the problem-solving process supported by Ozobots and digital storytelling. The steps of the problem-solving process during the storytelling unit show characteristics of the computational thinking process. Therefore, the results indicate that combining educational robotics and storytelling seems to be a promising approach to develop and promote computational thinking skills.

Table 2: Evaluation of the problem-solving process.

Stages of the CT-process (Bitesize, 2019; ISTE & CSTA, 2011)	Description (Bitesize, 2019; ISTE & CSTA, 2011)	Observed stages of the problem-solving process during the storytelling unit
data collection and analysis	the process of gathering appropriate information, making sense of data, finding patterns, and drawing conclusions	identifying the problem, analyzing which characters and details are relevant to create the story
decomposition	breaking down a complex problem or system into smaller parts that are more manageable and easier to understand	defining which sequences are necessary to create the plot of the story
pattern recognition	finding the similarities or patterns among small, decomposed problems that can help to solve more complex problems more efficiently	thinking about how to represent certain storylines
abstraction	reducing complexity to define main idea	graphic representation of the story based on a plan for the Ozobot
algorithm	series of ordered steps taken to solve a problem or achieve some end	coding of the sequences of activities, use of the corresponding codes
evaluation	a process that allows making sure the solution does the job it has been designed to do and to think about how it could be improved	filming and telling the story, checking that the codes fit the plot of the story, presentation of the video to the other groups

4.2 Enhancing Computational Thinking with Ozobots

Based on the observation, the interviews, and the created artifacts, the research question of whether Ozobots enhance computational thinking through storytelling activities can be answered as follows.

The easy handling of the Ozobot robot and its simple functioning contribute strongly to motivation and committed performance. The students were very excited about the “small, spacy” robot, and they were “able to solve any tasks without problems”. The division into smaller groups effectively fostered communication as well as successful collaboration, as each student had the opportunity to contribute story ideas and try out the programming of the robot. Furthermore, they had to think carefully about which action sequences occur in their story and how these should be represented and programmed. By using the programmable robot, the problem-based task is broken down into smaller parts and the development and writing of the story become more structured.

The following aspects, referred to as MOSAIC-aspects by the authors, enhancing computational thinking during the robotics-based storytelling activities were identified:

Motivation and Enthusiasm. Due to working with the fascinating robot, the students were motivated to work on their problem-based tasks, and enthusiasm for the storytelling activities as a result could be observed.

Orientation. Due to the programming of the robots when creating the story graphically systems of order are built up and spatial abilities are fostered.

Structuring. The students worked in a structured manner by drawing the plot and by programming the Ozobots. The task is broken down into individual work steps and executed one after the other which corresponds to sequencing in programming. An exact sequence of action in broad strokes should be planned first.

Abstraction. The graphic representation abstracts the plot of the story and by telling the story through the path of the Ozobot and the codes, the story is decoded again. Programming and transferring the plot into a graphic representation stimulates algorithmic and logical thinking enormously.

Interactivity. An essential aspect is also that of interactivity. The pupils can intervene at any time in the presentation and design of the story and change details. As a result, the process of evaluation is constantly carried out.

Communication and Collaboration. Communication and collaboration are important aspects to achieve a common goal by developing a problem-solving strategy, discussing details of the story and its realization, and having an internal agreement within the group where responsibilities are defined and accepted.

Furthermore, two other competencies could be identified in this study. These were, firstly, social competence, the ability to work in groups and to divide, assign and fulfill different roles in the process. The second was technological competence, the ability to use educational robots and digital media to record the story. Besides, it was possible to see that the graphic representation of the story particularly encouraged creativity, since the groups had special ideas for the realization of the story.

5 CONCLUSIONS AND FUTURE WORK

It is well known that technology has the potential to increase learner engagement and interest in young students’ learning environments. This study aimed to investigate how the use of robots enhances computational thinking skills by designing and building an interactive story using the robot Ozobot. The results of this study show that the use of educational robots as support to digital storytelling is a good possibility to implement computer science education in primary education in an interdisciplinary approach, and it supports and promotes the development of computational thinking skills in the process. Through the simple introduction to programming Ozobots, primary learners can easily work with the little robots and thus gain first insights into problem-solving skills. Their appearance and ability to follow lines are fascinating and motivating for the students. This could be a good way to arouse interest in programming and computer science already at the primary level. Due to its diverse applications and tasks from the children's everyday life and environment, the Ozobot can be integrated well into lessons in various subjects. The interdisciplinary robotics-based approach presented is thus a good example of implementing computer science in primary school and developing computational thinking skills at the same time.

As previously mentioned, this sub-study is one cycle of a larger educational design research study, so it is planned to extend the implementation of the learning environment to several primary school classes and conduct further research. In a future approach, it would be interesting to investigate to what extent digital storytelling is feasible with other programmable robots, what insights emerge, and whether there are differences compared to the use of the Ozobot.

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