

Gamified Coding: Toy Robots and Playful Learning in Early Education

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Abstract—This paper explores the activity of coding with smart toy robots Dash and Botley as a part of playful learning in the Finnish early education context. The findings of our study demonstrate how coding with the two toy robots was approached, conducted and played by Finnish preschoolers aged 5-6 years. The main conclusion of the study is that preschoolers used the toy robots with affordances related to coding mainly in developing gamified play around them by designing tracks for the toys, programming the toys to solve obstacle paths, and competing in player-generated contests of dexterity, speed and physically mobile play.

Keywords—coding, gamification, toy robots, physical play, programming.

I. INTRODUCTION

Coding is becoming the most essential skill for people who want to prosper in this world of the 4th Industrial Revolution time [1]. The importance of coding is accentuated in the necessity to learn 21st century skills, which, according to Trilling & Fadel (2009) are the skills needed to survive and thrive in a complex and connected world [2]. Computational thinking as a 21st century skill involves solving problems, designing systems, and understanding human behaviour, by drawing on the concepts fundamental to computer science. Presently, many European countries are introducing computing and coding as core curriculum topics [3]. With young learners in mind, coding can become a playground, an environment to be creative, to express oneself, to explore solitarily and socially, to learn new skills and problem-solve, while having fun. In a coding playground, children become producers—they are not anymore only consumers of digital artifacts that can be shared with others [4].

Coding as a 21st century skill is accentuated as a part of STEM education that is currently being integrated into early education curricula both in Finland and North America. However, as a new area of education, the tools for teaching coding for kindergarten and preschool-aged children, as well as primary school students, are still diverse and non-standardized. One way of approaching coding in the educational context is through toy-based learning as in this case study presented in the paper at hand. Coding skills are widely considered a crucial skill nowadays and especially in the future business landscape [5]. One example of this are coding toys, which offer tasks related to the learning of basic coding skills either through object play and entertainment (i.e. physical manipulation of the toy), or through content mediated and communicated through various mobile applications including screen-based technologies.

This paper explores emerging play patterns related to coding from the perspective of two smart toy robots, Dash and Botley, which were play-tested in the context of a preschool environment in Finland in spring 2019. The paper reports on unique findings in relation to free play and gamified coding. In this study, preschool children created *gamified play patterns* around coding tasks, for example, by creating rules for collaborative coding competitions for the toys, such as “who is the fastest in building a trail for the Botley robot”.

Developing the MDE model for toy-based learning

The MDE framework developed by Robson et al. (2015) describes how learning can use a novel engaging activity by employing gamified experiences in connection to three abstractions: mechanics, dynamics and emotions [6]. In our research, we have extended this framework with toy-based learning. We suggest that toy-based play experiences in the educational context go through the learning by doing phases (in this case, coding), which is beneficial for children in promoting collaborative learning. We were also able to detect how the preschoolers, unknowingly, besides engaging in toy-based learning, also applied the Flipped Classroom approach, which was supported by the gamification of playful activities around coding. The Flipped Classroom is a teaching method different from the traditional classrooms in terms of its objectives, which include creating a competitive environment where students are entertained, and their interest and motivation levels are elevated [7].

Our study investigates what potential the category of smart toy robots holds when considering playful learning in the preschool context. The presumption is that how the robot is accepted by preschoolers’ and educators may be influenced by factors, such as 1) the role assigned to the toy robot (i.e., how the toy robot functions in play, or part of playful learning), 2) the toy robot’s social capabilities or skills (such as its social intelligence and emotions expressions), and 3) the toy robot’s appearance. In order to find out how toy robots are approached and used as a part of playful learning in the early education context, we conducted a longitudinal study to investigate, understand and identify the potential impact of these factors on preschoolers’ acceptance, adoption of and play with the coding robots and robot toys—Wonder Workshop’s Dash and the Botley robot toy. One of our primary objectives was to understand preschoolers’ motivation to play with the toy robots and to find out, how they employ these toy robots as a part of their free playtime in the context of preschool. We also wanted to find out how the preschoolers employed the coding exercises in their activities with the toy robots and how the

play patterns related to coding evolved during the study period.

A. Gamification and learning

Previous research has explained the relationship between gamification and learning by providing frameworks such as the *theory of gamified learning*. This theory proposes four components: instructional content, behavior and attitudes, game characters, and learning outcomes [8]. Enriching learning environments with game elements modifies these environments and potentially affects learning outcomes. The application of gamification in the domains of coding education has a promising potential in enhancing motivation to extend gamified experiences. One clear example of this is the usage of the Logo programming language. The popularity of Logo continued to grow in the 1990s [9], [10].

Another example is RoboRun, a basic introduction to coding by using a gamification method [11], which proposes to develop key skills and challenge players to come up with better solutions to increasingly more difficult levels. The result of a study conducted by Seow et al. (2017) highlights that starting at an early age, children are exposed to developing Computational Thinking (CT) skills through age-appropriate ways of playing. In the case of preschool, a form of learning was to experience play with coding toys and to understand how children would learn from playing [12].

B. Toyification of educational technologies

Technology-based toys have been reported to have become increasingly popular with children [13]. The educational value of contemporary, digitally-enhanced toys is the main way to emphasize the benefits of using toys outside of their traditional recreational uses, for example, in the learning of computational thinking. In our understanding, both the realms of technology and educational tools are undergoing a toyification. This refers to the process through which an entity is being reinforced with toyish elements through intentional behaviour. More specifically, toyification communicates the idea of an entity (either physical, digital or hybrid) being intentionally reinforced with toyish elements or dimensions; an object, a structure, an application, a character or a technology acquiring a toyish appearance, form or function [14], [15]. The toyification of education means that three-dimensional and interactive toy(-like) objects are becoming increasingly used in the context of pedagogics and lifelong learning. In this paper, toyification of education refers to the situation, in which a robot toy is the learning tool providing an effective learning mechanism triggered by, for example, game elements and facilitating preschool children's gamified coding. Thus, by the toyification of education, we suggest that current toy design of technologically enhanced toys, such as IoT toys and toy robots, is prominently interested in the integration of learning opportunities into toys through robotics and mobile technology.

Previous empirical studies by Eteokleous et al. (2018) examine the potential of a robotics curriculum for developing creative thinking skills in the context of non-formal education [16]. Research has shown that robotics integration in the teaching practices stimulates the development of students' higher-order thinking skills such as application, synthesis, evaluation, problem solving, decision making, and scientific investigation [17]. We believe that for preschool-aged children this learning is prompted by the use of toyified technologies. The study by Eteokleous et al. (2018) suggests,

that throughout the curriculum, the students experience a great variety of education robotics packages and programming platforms: Bee Bots, Botley Robotics Kit, etc. The exercises of the curriculum were developed based on the aforementioned packages and are intertwined with the following: presentation, educational games, documentaries, interactive audiovisual material, hands on activities, unplugged activities, and use of interactive educational software [16]. In this paper, our analysis targets the first mentioned robots and programming platforms. Our study focuses on *programmable coding toys* as toy robots, a subcategory of contemporary smart toys.

C. Robotics and learning

In recent years, studies have attempted to present the potential of robotics education even for young learners [18], [19]. Based on the systematic review article of Jung & Won (2018) [20], there are few existing viewpoints on robotics education that have been addressed in the academic field. Previous research has focused on the effects of robotics education on young children's learning [21]. The studies have also concentrated on the children's conceptualization of robots and systems of robots. McDonald and Howell's study showed that a robotics project positively impacted five- and seven- year-old children's literacy development and numeracy skills [22]. While engaging in robotics activities, the young children expanded their terminology and employed more complex sentence structures to explain robots' behaviors or explain their ideas. Other perspectives that have been studied are children's processes and strategies for learning robotics. Julia & Antoli's (2015) study on kindergarten children's robotics course stated that kindergarteners improved their endurance and ability to concentrate over a certain period along with developing planning and cognitive flexibility to apply to learned abstract rules [23]. Moreover, the theme of assessment of children's robotics learning has been explored [24], [25]. In the study of Mioduser & Kuperman (2012) kindergarten children constructed and programmed robots. As result of the study, they identified the engineering perspective (i.e., children's use of technological language) and the psychological perspective (i.e., children's use of anthropomorphic language to describe robots' behaviors) as a frame to analyze children's verbal statements [ibid.]. Based on Chambers et al. (2008), robotics activities (constructing and programming Lego Mindstorms kits) were effective in helping 4th graders to learn gear functions and mechanical advantages [26]. The main outcome of these studies imply that the use of robotics seems to enhance the logical thinking but also the social encounters within the group settings [27].

II. MATERIALS AND METHODS

A. Toy robots – Dash and Botley

Our study employs technologically enhanced toys with light, sound and movement that, according to their marketers, cater to enjoyment and opportunities for learning—*Wonder Workshop's Dash* and the *Botley* toy robot. See Figure 1. The toys were chosen based on their gender-neutrality as character types of toys (toy robots) and their availability on Amazon U.S. (August 2017 and August 2018). Both toys have been awarded with several prizes in the U.S., such as Parents' Choice Awards 2016: Gold, Seriously STEM Award 2018 Grand Prize Winner, and edTeach Digest's Cool Tool Award Winner 2019 (*Wonder Workshop's Dash*) [28].



Fig. 1. The Dash robot by Wonder Workshop (left) includes sensor-based recognition and play affordances related to lights, sound, and movement. The Botley toy robot (right) operates with remote control and other accessories.

Wonder Workshop’s Dash toy robot is “smart enough to respond to voices and sounds and Dash can dance and sing, which makes for a fun and interactive learning experience for kids.” Dash belongs to the category of IoToys, which means that the toy, when connected online, is constantly being updated with new content, some of it educational and coding related. When considering the IoToys, learning is expected to happen in play through physical and digital manipulation of the toys’ affordances. Connected toys can also contribute to the blurring of the boundaries between formal and informal learning [29]. Along with Dash, the players can use five free mobile apps, one of which is the Blockly App, which is in standard use in elementary schools and recommended for children by Code.org. [30]. Coding with Dash happens through visual coding exercises, enabled by its own simplified coding language based on colors and symbols rather than numbers and words, which are suitable for children between 6-10 years of age. Earlier research on Dash demonstrates how this toy robot invites to physically mobile play, by encouraging the players to employ the toy, for instance, in playing of tag and hide-and-seek [31]. Dash is also used as part of schools’ curricula and coding clubs. According to Kolodny, some 8,500 schools are using Dash and its robot companion Dot around the world today [32]. The Botley toy robot by Learning Resources, suited for ages 5+, belongs to the category of non-connected, and thus screen-free smart toys. “Children as young as five can learn to code with Botley, detecting objects, programming if/then logic, following looping commands and taking on obstacle courses” [33]. The programming of Botley happens with the help of a remote controller provided with the robot toy character. Hence, it represents TCT (Tangible Coding Technology).

B. Participants

We introduced (n=21) preschool children ages 5 to 6 years (9 girls, 12 boys) and their two teachers to the coding toy robots Dash and Botley. Overall, 23 participants joined four playtesting sessions that were observed by the researchers. Furthermore, the robots were made available for the preschoolers to be used in unstructured (or free-form) play over the study period, altogether 6 months. The play sessions were organized in a familiar playroom setting of the preschoolers’ own kindergarten. Preschoolers—in the context of our research, represent Finnish children who are very familiar with mobile technology. For example, in some kindergartens, preschool-aged children are being introduced to the use of tablets on a daily basis as part of early education. Furthermore, many of them have their own mobile phones, which increases their possibilities of using apps that some of the contemporary smart toys, such as Dash, require in order to be fully operational [31]. The participating preschoolers were new to coding exercises meaning that they had no previous experience of coding toys, but they had skills in using tablets, which was required in order to operate the Dash toy robot. Moreover, the preschool teachers did not have earlier experiences of coding with the toys, but they were interested in learning about the educational affordances of the toy robots and their discovered potential to be used in education.

During the six-month study, the teachers observed the preschoolers play with the toys and reported how quickly they gained an understanding of how to program the toy robots by using either the visual programming language on Dash’s app, or the remote control and physical play material used in building paths for Botley. Both toy robots were also reported to give straight feedback to their players, which made the learning easier for the children and motivated them to start to play again by trying out their various coding-related features. In our research design, we have used a multimethod approach to understand the broad dimension of the educational potentiality of the robot toys in the preschool context and their use in play patterns related to coding. We used four play-test sessions, observation, group interviews (with the preschoolers) and thematic interviews (with their teachers) in order to find out how they had used the toys as a part of their free-time play (see Figure 2).

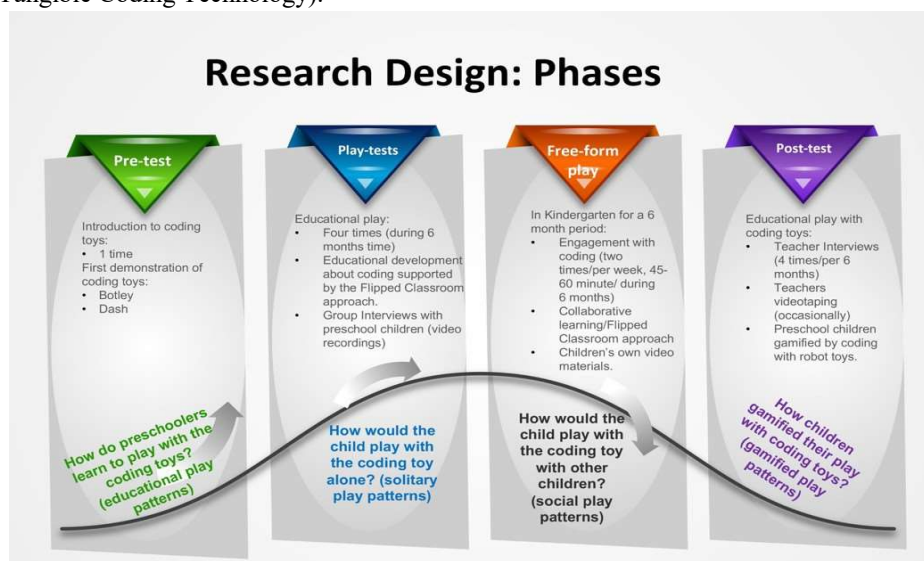


Fig. 2. Research design: Phases.

C. Data Analysis

Altogether, the participating preschool children played with the Dash toy robot for six months and with Botley for 3 months. The toys were part of the daily, unstructured play sessions with a duration of 30-45 minutes per session. During this time, preschool children made videos of their playing with the toy robots. Furthermore, the researchers also organized play-tests, conducted group interviews and observation of the children on four occasions, video-recording all play sessions. Afterwards, all video material (altogether some 160 minutes of footage) was analyzed in order to find out how the preschoolers employed the coding exercises of the toy robots by playing with them. Our data analysis was based on qualitative data analysis methods. The video-recorded interviews were first digitally transcribed by two researchers. After this phase, the data were analyzed using the in-depth content analysis technique (content and thematic analysis).

III. RESULTS

The results show that the interaction of preschool-aged children and coding toy robots takes place in multiple ways. The key affordances— physical, digital, and coding-related, as well as examples of related play patterns detected in our study are summarized in Table 1.

TABLE I. SUMMARY OF DASH' AND BOTLEY'S AFFORDANCES (PHYSICAL, DIGITAL AND CODING -RELATED), AND PLAY PATTERNS (EXAMPLES).

Toy robots	Physical play affordances and related play patterns (Mechanics)	Digital play affordances and related play patterns (through connectivity/ remote control) (Dynamics)	Coding related play affordances and related play patterns (Toy-based learning exercises/ Emotions)
Dash (by Wonder Workshop)	*sound, lights, movement (e.g. storytelling through sound, dancing through movement)	*connectedness through wifi and app *responding to voice/player voice playback <i>Example of finding:</i> <i>Preschoolers recorded their own voice/sounds for the robot.</i>	*functionality as a coding canvas *navigating of objects <i>Example of finding:</i> <i>Preschoolers mobilized the toy.</i> * re-playability <i>Example of finding:</i> <i>Preschoolers engaged emotionally with Dash because there is always new things to learn (updated apps) and it represents a character toy (like a digital friend).</i>
Botley (by Learning Resources)	*sound, lights, movement *trail-building with ready-made pieces	*responding to voice/player voice playback *making of sound effects	*coding structured game-play *making speed building competitions * re-playability by always building new trails (creative activities provoke emotional responses in preschoolers)

Preschoolers, in their unstructured play sessions, demonstrated the following play patterns (examples) with Dash: recording of player's voice/sounds and mobilizing of the toy robot through coding and competing in letting the toy robot chase other players through coding exercises. For example, when playing with the Dash robot, the preschoolers recorded their own voice on the toy robot and made it move and chase other players by programming the robot with the help of the app. Following these leads, it is possible to see how the preschoolers moved on from first, employing the toys sound-related affordances, second, using its coding-related affordances to mobilize the toy, and third, developed gamified play around the coding exercises, making Dash move as well as mobilize the players.

The preschoolers 'gamified' their coding by coming up with contests and other games with rules for Dash. This activity made the preschoolers both mobilize the robot and themselves, by taking turns to program the toy robot's movement, and by engaging in playing together. The preschoolers also gamified coding with Dash by generating chases as one player coded the toy robot to move and the others tried to run away from it. In sum, the key affordances of Dash detected in the play patterns using coding, were a combination of use of digital sound (voice recording and playback) and physical mobilizing of the toy. While observing the play-tests, we found out that more developed (physical and mobile) forms of gamified play emerged around Dash, as some of the playing preschoolers started to use their own bodies to build tunnels of their own legs, and urged the coding preschooler to make Dash navigate through these human obstacles.

With Botley, it was found that preschoolers, in their unstructured play sessions, demonstrated the following play patterns: mobilizing of the toy robot to move along tracks through coding, continuing to build the track while the toy robot was moving and developing a social game of speed and dexterity through coding exercises. The preschoolers first coded Botley to follow a constructed, physical trail, consisting of ready-made cardboard pieces, and continued the trail while Botley was moving. The findings present how preschool children gamified their speed building competition with Botley by building a trail with 5 pieces and repeated the play pattern by building the trail with the same pieces all over again so that the trail did not end. In this game of speed and dexterity, the groups of children competed with each other on who was able to continue the trail as long as Botley was made mobile by other players. As for Botley, it was the physical trail building pieces that were employed in coming up with gamified play patterns, that were used the most. Especially when the players built trails for Botley and when all trail pieces were used, the players started to compete against time and the players built a new track as fast as possible, while other preschoolers video-recorded this gamified coding exercise with a tablet. To sum up, the findings illustrated in the paper represent *gamified forms of play*. The preschoolers developed rules, goals, and ways to measure achievements (for example, by competing against time)—elements familiar from games, to motivate further playful learning through coding exercises with both Dash and Botley. In this way, the toys represent *edutainment*, with a combination of educational content and opportunities for free-form play.

IV. CONCLUSIONS AND FUTURE WORK

It is important to emphasize the difference between teaching a programming language and teaching coding skills as something that profoundly builds understanding towards today's digital technology. [34] Coding skills do this by making the underlying processes and protocols visible. To extract their full potential, young people do not need just programming competence but rather the understanding of how new technologies work [35]. Consequently, it is possible to claim that gamified coding through playful learning with toy robots presents a potential avenue in generating interest towards the development of coding skills in the context of early education. In other words, using gamification in combination with coding it is possible to motivate children to take on coding-related challenges.

Our case study discussed coding toys as an educational, toy-based tool, which invites gamified playful learning by, for example, creating competitive play with coding toys. In this paper, we extended the MDE framework developed by Robson et al. (2015) by conducting a study on two toy robots, which were played by preschoolers in the Finnish early education context. By analyzing the key affordances of Dash and Botley, and by studying play patterns that emerged as a part of free-form play activities among 5-6 year old preschoolers, the scope of our longitudinal study was namely in finding out how preschoolers incorporate these coding toy robots in their playing and to envision, how the toys function as tools in toy-based learning.

Our findings demonstrate how the preschoolers first and foremost, were eager to develop gamified play around the toys by coding them to generate movement. This study shows, how the toyfication of technology with toy-based learning and programmable toy robots, can result in creative, collaborative and gamified play among preschoolers, that also influences players physical mobility and motivation to play again. Therefore, our conclusion is that play activities with coding toys, such as the toy robots Dash and Botley, represent *gamified playful learning*. The use of these toy robots as a part of play increased the participating preschoolers understanding of the logic of programming in a simple and playful way. Simultaneously, the players seemed to engage in physically mobile play, while making the toy robots—and human players—mobile.

We believe that this early introduction to coding through toy-based learning enhances further learning of more complex coding tasks. Furthermore, the results reveal the motivation of players to create gamified play around the toy robots, which provides a fruitful approach to consider how to develop game-based mechanics for future educational materials related to coding. In the future, the aim of our further stages of research is to broaden the scope of investigating, for example, how the insights on the gamified play patterns created by preschoolers around coding activities could be employed by the teachers in designing and achieving more structured learning goals related to coding skills.

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