AN EXPLORATORY STUDY OF YOUNG CHILDREN'S SPATIAL SKILLS IN THE CONTEXT OF EDUCATIONAL ROBOTICS

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in the Context of Educational Robotics

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DECLARATION OF ORIGINALITY

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ABSTRACT

An Exploratory Study of Young Children’s Spatial Skills

in the Context of Educational Robotics

This qualitative study explored young children’s spatial skills in the context of educational robotics. The study aimed to investigate two research questions: (1) How do 5-year-old pre-school children’s spatial skills emerge when they engage with programmable robot toys? (2) How do 5- year-old pre-school children use spatial vocabulary while interacting with programmable robot toys over a semester?

Data were collected through video recordings of young children participating in an 11-week robotics curriculum that included both unplugged and plugged-in activities. These video recordings were analyzed through multimodal analysis with the lens of embodied learning. Five themes emerged from the data analysis: (a) Robotic activities encourage preschool children’s use of spatial skills while planning their robotic programming; (b) Designing tangible materials for plugged-in robotic activities supports preschool children’s use of spatial skills; (c) Robotic activities enable preschool children to use spatial skills while solving problems in the programming phase; (d) Unplugged robotic activities that focus on different spatial concepts prepare preschool children for plugged-in activities more; (e) Providing a context, robotic activities facilitate preschool children’s frequent use of specific spatial vocabulary. The findings suggest that engaging with educational robotics in the context of embodied learning not only enhance preschool children’s spatial skills but also enriches their spatial vocabulary.

ÖZET

Eğitsel Robotik Kodlama Bağlamında

Okul Öncesi Çocukların Uzamsal Becerilerinin İncelenmesi

Bu nitel çalışma, eğitsel robotik kodlama bağlamında küçük çocukların uzamsal becerilerini incelemiştir. Çalışma, şu iki araştırma sorusuna incelemeyi amaçlamaktadır: (1) 5 yaşındaki okul öncesi çocukların uzamsal becerileri, programlanabilir robot oyuncaklarla etkileşim sürecinde nasıl ortaya çıkar? (2) 5 yaşındaki okul öncesi çocuklar programlanabilir robot oyuncaklarla etkileşimde bulunurken uzamsal kelime dağarcıklarını nasıl kullanırlar? Veriler, çocukların hem dijital (plugged) hem de dijital olmayan (unplugged) etkinlikleri içeren 11 haftalık bir robotik müfredata katıldıkları video kayıtları aracılığıyla toplanmıştır. Bu video kayıtları, bedenlenmiş öğrenme perspektifiyle çok modlu analiz yöntemi kullanarak incelenmiştir. Veri analizleri sonucunda şu beş tema ortaya çıkmıştır: (a) Robotik etkinlikler, okul öncesi çocukların programlama sırasında uzamsal becerilerini kullanmayı teşvik eder; (b) Dijital (plugged) robotik etkinlikler için somut materyaller tasarlamak, okul öncesi çocukların uzamsal becerilerini destekler; (c) Robotik etkinlikler, okul öncesi çocuklarının programlama aşamasında sorunları çözmek için uzamsal becerilerini kullanmalarını sağlar; (d) Robotik etkinlikler, okul öncesi çocuklarının uzamsal kelime dağarcığını kullanmalarını destekler; (e) Farklı uzamsal kavramlara odaklanan dijital olmayan (unplugged) robotik etkinlikler, okul öncesi çocuklarını dijital etkinliklere daha iyi hazırlar. Bulgular, eğitsel robotik etkileşimin, bedensel öğrenme bağlamında, okul öncesi çocuklarının uzamsal becerilerini geliştirmekle kalmayıp, aynı zamanda uzamsal kelime dağarcıklarını da zenginleştirdiğini göstermektedir.

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CHAPTER 1

INTRODUCTION

In early childhood education, there is an increasing acknowledgement of the significance of developing spatial skills in young learners during robotic activities (Angeli & Valadines, 2020; Brainin et al., 2021; Palmér, 2017; Shumway et al., 2023). Teachers can modify their educational programs to incorporate robotics to instruct children on various subjects such as numbers, shapes, colors, language skills, and handwriting (Bers et al., 2019). Research has shown that educational robotics can effectively teach programming concepts to children from kindergarten through elementary school (Kopcha et al., 2021; Sullivan & Bers, 2016). Programmable toys designed for guided play help preschool children explore spatial concepts by offering a multimodal interface for manipulating and embodying the movements of a robot (Bakala et al., 2021; Bers, 2020). In guided play, educators offer scaffolding and guidance to assist children in their exploration and purposeful activities. Through guided play, children investigate, experiment, and solve problems within a supportive environment (Baykal et al., 2018; Berson et al., 2019).

Concurrently, spatial skills involve perceiving visual images accurately, creating and imagining mental representations of visual data, and understanding and manipulating the spatial relationship between objects (Khine, 2017). Moreover, spatial skills are categorized into various components, including spatial perception, spatial visualization, mental rotation, spatial relations, and spatial orientation (McGee, 1979; Lin & Peterson, 1985). Previous studies (e.g. Uttal & Sheehan, 2014; Verdine et al., 2016) indicate that spatial reasoning is rarely taught in early childhood, partly because it involves internal thought processes that are hard for educators to observe and assess during play. In the study of Pollit et al. (2020), play-based spatial reasoning assessment strategies were suggested for preschool children. According to Pollit et al.'s study (2020), both plugged and unplugged robotic activities should involve tasks that require identifying shapes, patterns and using directional language. Furthermore, researchers evaluated children's understanding of geometric concepts, including the creation and identification of 2D and 3D shapes, symmetry, patterns, and spatial reasoning through tasks that involve making shapes, recognizing patterns, mapping pathways, and using directional language (Pollit et al., 2020). The findings suggest that play-based interventions may be used to observe young children's spatial skills. In the current study, instead of using different spatial terminology, young children's spatial skills in the context of educational robotics were focused in a playful and engaging environment.

Aligning with the literature, the current study focuses on exploring children's use of spatial skills and vocabulary during the robotic tasks. Pruden et al. (2020) underlined the role of spatial language to predict children's later spatial skills. Similarly, Casasola et al. (2020) note that diverse use of spatial labels improves children's understanding of spatial concepts, including shapes, the arrangement of objects, spatial characteristics, direction, and places. Moreover, researchers emphasized the difficulty of understanding the concepts of left and right for preschool children as they usually lack the ability to visualize and transform objects mentally (Austin & Sweller; 2014; Scott & Sera, 2018; Turan et al., 2020). These findings are important to understand children's use of spatial skills in the context of educational robotics.

Gestures help convey meaning and clarify verbal communication among preschool children especially for abstract concepts. Pollit et al. (2020) argue that children frequently demonstrate their thinking and understanding in diverse non-verbal ways-including gesture, movement, and art, especially in the context of their play. Furthermore, gestures enhance communication and comprehension of spatial information, encouraging the use of spatial strategies in problem-solving (Alibali, 2005). Previous studies (Brainin et al., 2022; Di Lieto et al., 2017; González-Calero et al., 2019) on the development of spatial skills in early childhood indicate the complexity of spatial skills, its adaptability, and the importance of spatial language.

1.1 Purpose of the study

The main objective of this study is to explore young children's spatial skills when they engage with educational robotics. In the programming tasks with an educational robot, children plan and execute sequences of movements (Di Lieto et al., 2017). This process encourages them to hold multiple pieces of spatial information in mind, such as the robot's current position, the target destination, and the necessary commands to reach that destination (Di Lieto et al., 2017). Furthermore, this programming process involves planning robot movements, coding these plans, and evaluating the outcomes, thereby enhancing vital skills such as problem-solving, spatial reasoning, and mental rotation (Angeli & Valadines, 2020; Bers et al., 2019; Gonzalez-Calero et al., 2019). Educational robotics also creates a meaningful context for preschoolers to develop their understanding of spatial relationships (Misirli et al., 2019). Kindergarten children employ their spatial reasoning skills to program toys and agents to move within a specified area, particularly in tasks involving navigation and movement through grid (Clarke-Midura et al., 2021).

After an extensive literature review, this qualitative study aims to understand the role of educational robotics on preschool children's spatial skills through their physical interaction with robots. The guiding theoretical framework for this study is based on embodied learning which emphasizes the interconnectedness between the body and cognitive processes (Abrahamson & Lindgren, 2014). The overarching research questions of the study are as follows:

1.2 Research questions

- How do 5-year-old pre-school children's spatial skills emerge when they engage with programmable robot toys?
- How do 5-year-old pre-school children use spatial vocabulary while interacting with programmable robot toys over a semester?

1.3 Significance of the study

This study addresses a critical gap in the research on early childhood spatial skill development and the potential of educational robotics. While the importance of spatial skills for STEM success is well-documented (Reilly et al., 2017), and the influence of environmental factors like education on these skills is recognized (McGee, 1979), longitudinal studies exploring the long-term impact of programmable robots on young children's spatial abilities remain scarce (Brainin et al., 2022). This research study, as one of the few studies conducted in Turkey, offers a unique contribution by focusing on the impact of educational robotics on preschool children's spatial skills. The extended data collection period of this study (11 weeks) would provide valuable insights into the developmental trajectory of spatial skills as influenced by young children's physical interaction with programmable toys.

Another significant contribution of this study is its utilization of two distinct types/levels of educational robots. By exploring the nuances of interaction with these different robots, the study can offer valuable guidance for educators in selecting and implementing robotic tools in the classroom. Furthermore, developing a robotics curriculum grounded in the embodied learning framework is a key deliverable of this research study. The concept of embodied learning highlights the connection between physical actions and the acquisition of abstract concepts, particularly in STEM education, where gestures and bodily movements play a crucial role in comprehension and communication (Abrahamson & Lindgren, 2014; Meadow & Beilock, 2010). This curriculum, incorporating two types of educational robots, could provide educators with a practical and theoretically sound resource for integrating robotics into early childhood education. The framework-driven design of the curriculum ensures that the activities are intentionally structured to promote embodied learning and the development of specific spatial skills. For instance, children can better navigate programming tasks and develop spatial awareness through embodied activities that simulate robot movements (Kwon et al., 2022). Studies have shown that using physical robots in educational settings helps children grasp geometric concepts and improves their spatial reasoning skills (Clements & Battista, 1989; Francis et al., 2015). This tangible outcome of the current study offers a valuable tool for educators seeking to effectively utilize robotics to enhance spatial skills and prepare young children for future STEM learning. Therefore, this study employs embodied learning as a theoretical framework to explore how educational robotics impacts preschool children's spatial skills, and multimodal analysis to capture their experiences effectively.

Overall, by examining the literature on educational robotics and their role in children's spatial skills, this study has a two-fold goal. Firstly, it aims to explore young children’s spatial skills in the context of educational robotics through their physical interactions with programmable toys. This study also seeks to examine how young children pre-school children use spatial vocabulary while interacting with programmable robot toys over a semester. This was a 11-week study to observe young children's use of spatial skills in the context of educational robotics and to gain deeper insights into their physical interactions with two different types of programmable toys.

CHAPTER 2

THE LITERATURE REVIEW

This chapter includes an extensive literature review outlined under five topics. First, we explored educational robotics within the context of early childhood education. Secondly, we examined research on the development of spatial skills during the early childhood period. Thirdly, we delved into the role of gestures in supporting spatial skills. Fourth, we specifically reviewed studies focusing on integrating spatial skills within robotic-based activities. Finally, the theoretical framework of the study which drew upon embodied cognition is described in this chapter.

2.1 Educational robotics in early childhood education

The inclusion of computer science education in early childhood has been growing in the last years. However, it is insufficient to simply replicate models from older children's curricula, primarily derived from STEM disciplines. There is a need for designing programming curricula that align with the developmental stages of young children (Bers, 2019). It is possible to create opportunities for young learners to learn computer science in their classrooms by incorporating programming activities into various academic subjects and fields, such as math, literacy, science, engineering, and arts, through a project-based learning environment (Bers et al., 2019; Otterborn et al., 2019).

Prior studies demonstrated the feasibility of teaching programming concepts to young children, from kindergarten to elementary school by the use of educational robotics and block-based programming languages (Kopcha et al., 2021; Sullivan & Bers, 2016). Most of the educational robots used in early childhood education primarily focus on spatial movement commands, such as go forward, go backward, turn right, and turn left. Students typically program the robot's route by organizing codes, which demonstrates their understanding of symbolic representations in the computational tasks (Di Lieto et al., 2017; Kopcha et al., 2021). Programming robots requires students to translate physical actions into a symbolic context (e.g. a programming platform). These actions include planning robot movements, coding these plans, and then evaluating the program's outcomes (Bers et al., 2019; Elkin et al., 2016). Therefore, the integration of programming activities in early childhood education, improve vital skills such as problem solving (Bers et al., 2014), spatial skills (Angeli & Valadines, 2020), and mental rotation skills (Gonzalez-Calero et al., 2019). Moreover, it becomes evident that fostering problem-solving skills, analytical thinking, and concrete thinking is a social responsibility to prepare children for today's technological advancements (Demir & Demir, 2021).

Studies indicate that incorporating educational robots into early childhood activities enhances various learning outcomes for children (Gonzalez & Munoz-Repiso, 2018). Educational robotics offer an interactive approach for young learners to cultivate programming skills. Through hands-on experiences with robots and unplugged activities, children can gain insights into programming and problem-solving skills effectively. Programmable toys and robot construction kits can be valuable educational tools for integrating STEM fields into early childhood education. These kits also provide opportunities for children to engage in programming and robotics activities and build interdisciplinary knowledge (Çetin & Demircan, 2020).

In early childhood education, a balanced approach to robotics education, incorporating both plugged and unplugged activities, is crucial for fostering deeper learning of related skills. Unplugged activities help children to understand abstract concepts in a concrete way, enabling them to develop solutions based on logical thinking and understand computer science principles by applying them in their daily lives (Battal et al., 2021; Wang et al., 2016). Furthermore, Saxena et al. (2020) suggest that unplugged activities should be implemented to enhance children's ability to program educational robots as they provide concrete experiences for children and support their programming skills in plugged activities. This aligns with the perspective of Relkin (2018), who highlights the importance of hands-on play through robotics activities for young children's full engagement. Batı (2021) also concluded that both plugged-in and unplugged applications improved children's programming skills. Unplugged applications are more effective in early childhood education because it focuses on concrete experiences of young children (Batı, 2021). Expanding on this, Lin et al. (2023) concluded that well-designed unplugged activities propose positive experiences because it activates young children's thinking processes by transitioning abstract concepts into concrete experiences.

Moreover, engaging in collaborative digital play with programmable robots enhances children's social emotional growth, and activities involving robots promote essential interpersonal skills such as turn-taking, sharing resources, effective communication, and making responsible choices to reach shared objectives (Bakala et al., 2021; Bers, 2020; Çetin & Demircan, 2020). Beyond these cognitive and socio-emotional advantages, programmable robots also function as communication tools, offering visual signals and prompts that may also have a role in developing spatial skills (Arnott & Yelland, 2020).

In conclusion, integrating computer science education through robotics in early childhood is essential for nurturing foundational skills that prepare children for a technologically advanced future. By employing both plugged and unplugged activities, educators can create a rich learning environment that not only introduces programming concepts but also fosters critical thinking, problem-solving, and spatial skills. Therefore, the primary goal of this case study is to explore young children's spatial skills in the context of educational robotics through the lens of embodied learning.

2.2 Spatial skills in early childhood

Historically, several efforts have been made to define spatial skills and identify the foundational elements. Previous research studies (e.g., Eliot, 1987; Linn & Petersen, 1985; Maccoby & Jacklin, 1974) mainly focused on developing different frameworks and describing the relationships among various spatial skills. The term *spatial skill* refers broadly to a set of interconnected abilities involving the mental handling and manipulation of information about objects around us and the spaces we occupy (Uttal et al., 2013).

On the other hand, there is no agreed-upon definition of spatial skills in the literature, and different terminologies exist. For instance, while Khine (2017) argues that spatial ability refers to accurately perceiving visual images, creating mental representations and imaginings of visual data, and comprehending and manipulating the spatial relationships between objects, Newcombe and Shipley (2015) and Berson et al. (2023) claim that spatial reasoning, as multidimensional cognitive ability, involves problem-solving through manipulating objects, constructing spatial arrangements, and navigating paths, whether involving oneself or other objects.

In the current study, spatial skills were deliberately adopted as an inclusive and practical umbrella concept to encompass the broad range of spatial skills observed, such as visualizing, manipulating objects, and using spatial language. This terminology aligns with the study's aim to capture the multifaceted nature of young children's physical and verbal engagement with programmable toys without restricting the data analysis to a single theoretical lens.

Notably, spatial skill is not fixed; it is malleable and can be significantly enhanced through targeted training activities (Khine, 2017; Newcombe, 2017; Uttal et al., 2013). Delving deeper into the complexities of spatial skills, McGee (1979) identified various components, including spatial perception, visualization, mental rotation, spatial relations, and spatial orientation. Further refining this classification, Linn and Petersen (1985) organized spatial skills into three primary domains: spatial perception, which involves recognizing and interpreting spatial relationships; mental rotation, the ability to manipulate two- and three-dimensional figures mentally; and spatial visualization, the skill to visualize and draw conclusions about spatial arrangements. Researchers evaluate spatial skills by observing preschool children's use of positional or directional language and gestures, their ability to name three-dimensional shapes and their attributes, their use of two-dimensional symbols to document directions as a code sequence, and their proficiency in guiding others through pathways (Pollit et al., 2020). Together, these elements form a comprehensive picture of the multifaceted nature of spatial skills.

Understanding children's cognitive development, particularly their spatial transformation skills, has become a focal point in the developmental psychology. Research showed that children's spatial transformation skills start to develop earlier than Piaget claimed (Newcombe & Frick, 2010). Furthermore, engaging in active exploration of objects enhances the growth of mental rotation for toddlers and infants (Möhring & Frick, 2013). Additionally, developmental research on mental rotation has revealed that children as young as 4 or 5 years old not only exhibit the ability to manipulate objects mentally but also demonstrate spontaneous usage of mental rotation strategies (Frick et al., 2009). As they continue to develop, children also progress in the efficiency and speed of their mental rotation skills through early childhood, and these skills improve significantly with age (Frick et al., 2009).

To effectively support young children's spatial learning, exploring innovative approaches and methodologies in education is essential. For instance, Baykal et al. (2018) highlight the importance of identifying appropriate tools and methodology for designing Computer Tangible Interaction scaffolding to support young children's spatial learning. In light of this, there is a need for change in traditional educational methods for teaching early geometry, where children use their spatial skills often, by using interactive learning techniques, guided play, and comparative language in describing shapes (Newcombe, 2024).

In this study, one of the aims is to explore the use of spatial vocabulary to understand preschool children’s spatial skills. A growing body of research pinpoints the importance of children's spatial language development in early childhood education. Cohen and Emmons (2016) suggest that using more direct scaffolding of spatial words increases the frequency of spatial language children hear and use. This finding aligns with the research by Pruden et al. (2020), which emphasizes the role of parents' spatial language use on children's spatial language skills. They found that conversations about space in the early years predict their later spatial thinking.

In the study, Pruden et al. (2020) categorized spatial words: a) shape terms such as circle, triangle, and octagon; b) dimensional adjectives such as big, little, tall, tiny, small, and long; and c) spatial features terms such as curvy, edge, side, line, and corner. In addition, Casasola et al. (2020) note that different spatial labels can improve children's understanding of spatial concepts, including geometric shapes, the arrangement of objects, spatial characteristics, direction, and places.

In the study conducted by Turan et al. (2020), preschool children in Turkey had difficulty both in using and understanding the concepts of left and right. This affected their ability to visualize and transform objects or positions mentally (Turan et al., 2020). Scott and Sera (2018) also explain that people usually learn the terms left and right later than they know other spatial words. This is because *left* and *right* are connected to our bodies and require a more complex understanding of how things relate to each other in space, unlike simpler terms such as, *above* and *below*. Furthermore, Austin and Sweller (2014) found that children typically acquire movements verbs later in their language development. Besides, children with a substantial vocabulary of nouns are more capable to remember the locations of objects than to understand how things move (Austin & Sweller, 2014).

In summary, although spatial skills are a common part of our everyday experiences, it has often been overlooked or neglected in both informal and formal educational environments (Clements & Sarama, 2011). Through targeted interventions and play-based activities, there will be a potential for enhancing spatial skills which is relevant to the primary goal of this study.

2.3 The role of gestures in young children’s spatial skills

Gestures can play a key role in developing spatial skills, especially in mental rotation tasks, and may assist children in concentrating on the changing elements of spatial transformations (Ehrlich et al., 2006). Gesture also plays a vital role in organizing and structuring thoughts before they are translated into language and in cognitive processes, including thinking, memory, and problem-solving (Alibali et al., 2000).

Furthermore, Frick et al. (2009) found that 5 and 8-year-olds showed a difference in their mental rotation performance depending on whether their hand rotation was compatible or incompatible with the mental rotation they were performing. This suggests that their motor actions interfered with their cognitive process of mental rotation. That is, the ability to separate motor actions (hand movement) from visual cognitive processes (mental rotation) develops over time. Younger children have a harder time keeping these processes separate, while older children and adults are better at isolating them. Goldin and Meadow (2014) examine the role of gestures in the learning process, and they found that learners can be encouraged to use gestures when describing a problem.

Building on the understanding of how gestures facilitate cognitive processes, the study by Austin and Sweller (2014) emphasizes the significance of using representational gestures involving various gesture types to improve spatial learning. Notably, they found that gestures particularly encourage children's learning and memorization of spatial information, especially when it comes to navigating route directions. To break this down further, gestures can be categorized into four types: beat, deictic, iconic, and metaphoric (Austin & Sweller, 2014). Specifically, beat gestures provide rhythmic accompaniment to speech, while deictic gestures guide attention. In contrast, iconic gestures depict concrete ideas visually, and metaphoric gestures convey abstract concepts through physical representation (Austin & Sweller, 2014).

In addition to these findings, Novack et al. (2015) highlight the critical role of iconic gestures in early childhood learning and development. Consequently, these gestures serve as valuable tools for teaching young children new skills and concepts. Moreover, Goldin-Meadow (2015) concluded that gestures not only indicate a child's readiness to learn but also reflect unique thought processes that may not be easily articulated in words. Importantly, active participation in gesture production has been shown to promote a deeper understanding and better retention, particularly in mental rotation tasks (Goldin□Meadow et al., 2012). Focusing on evaluation of non-verbal communication among children, Pollitt et al. (2020) emphasize the importance of utilizing play-based approaches. That is, this study advocates for an understanding that includes gestures and movements, recognizing their significance in children's spatial skills.

Alibali (2005) further provides a comprehensive framework to examine how gestures contribute to expressing, communicating, and thinking about spatial information. Notably, when expressing spatial information, learners tend to gesture more frequently in discussions about spatial topics compared to abstract or purely verbal subjects (Alibali, 2005). In addition, learners use gestures more when they want to support their understanding and demonstrate their intention to communicate (Alibali, 2005). Importantly, gestures that either repeat verbal information or introduce new information can significantly influence the listener’s grasp of accompanying speech (Alibali, 2005). Consequently, gestures play a vital role in cognitive processes, especially when thinking about spatial information. They assist speakers in retrieving words, particularly those related to physical actions or spatial concepts (Alibali, 2005). Ultimately, gestures encourage the application of spatial strategies in problem-solving activities, such as mental rotations and spatial reasoning (Alibali, 2005).

In light of these findings, in early childhood, when verbal expression may still be developing, gestures offer an embodied tool through which children can externalize spatial thinking, organize ideas, and solve problems (Goldin Meadow, 2015; Alibali, 2005). In the context of this study, young children's use of gestures during robotic activities revealed rich insights into their use of spatial skills, especially in tasks involving planning, navigation, and mental rotation (Austin & Sweller, 2014; Novack et al., 2015). Therefore, recognizing and analyzing gesture use is critical for gaining a holistic understanding of how young children use spatial skills while engaging with programmable toys.

2.4 Spatial skills in the context of educational robotics

Tangible computing tools, including programmable robots, have demonstrated potential in enhancing children's learning by offering multimodal interfaces that enable children to physically interact with and embody robot movements (Bakala et al., 2021; Bers, 2020). Such tools uniquely integrate physical and digital experiences (Clarke-Midura et al., 2021), providing opportunities for young learners to cultivate computational thinking and spatial reasoning skills. Furthermore, existing literature indicate that educational robotics can enhance children's mental rotation skills, offering a valuable learning opportunity to develop related skills. Educational robotics might be an important tool for considering relationships among different cognitive domains, such as visuospatial, computational, and mathematical (Diago et al., 2021).

Moreover, educational robotics provides a meaningful context for developing preschoolers' spatial relations (Misirli et al., 2019). It is also important to consider guidance and scaffolding of designing a teaching environment to foster spatial skills by using programmable toys (Misirli et al., 2019). For instance, Brainin et al. (2022) revealed that children who used programmable robots demonstrated improved performance in spatial relations and mental rotation tasks. The research study of

González-Calero et al. (2019) similarly presents results on the effectiveness of robotics-based instruction for developing mental rotation abilities among primary school students in the context of map reading.

In the existing literature, researchers underline the specific spatial skills which are encouraged through robotics education. In the research studies conducted by Di Lieto et al. (2017), it was observed that educational robotics training with Bee-Bot positively affected the development of executive functioning skills which cognitive flexibility, inhibitory control, and working memory of preschool children aged 5. In the implementation phase, preschool children planned the correct commands based on the location of Bee-Bot by actively manipulating the relevant information in their visuo-spatial working memory. They actively used executive function skills such as mentally anticipating the robot's action, selecting appropriate commands and continuous updating of programming planning for reaching predetermined goal.

As a result of this study, preschool children showed a steady progress in their ability to use Bee-Bot and complete tasks that required mental anticipation. Initially, they relied on the physical robot to help them understand how to program movements. This "concretism" phase involved them working with tangible support. Over time, children began to grasp the concepts more abstractly, enabling them to mentally visualize each Bee-Bot action without support and they also learned to mentally rotate the movements, such as turning right or left (Di Lieto et al., 2017).

In programming activities, children demonstrated the skill to mentally compare both paper and grid maps, along with their symbols and the movements depicted (Palmér , 2017). They were also capable of visualizing and conceptualizing actions and the relationships among paper maps, grid maps, and symbols in their minds (Palmér , 2017). There were noticeable changes in how children perceived arrows as symbols in the programming tasks. They employed terms such as *forward*, *backward*, *rotate*, and *turn* when interpreting the arrows' meanings despite their limited usage of *left* and *right*. Alongside using these words, they incorporated gestures with their hands and body movements to demonstrate the robot's potential movements corresponding to the various symbols (Palmér, 2017).

Spatial knowledge plays a crucial role in the behaviors and discussions of young learners as they observed and interacted with robot movements (Shumway et al., 2023). Young learners made observations of the robots' movements and positions, planned and built programs, and debugged programs as they built (Shumway et al., 2023). They also engaged in orientation, spatial visualization, spatial language, and representing spatial knowledge in codes. Young learners needed to understand and describe the robot's movements by using spatial terms and gestures to facilitate their understanding throughout robotic tasks (Shumway et al., 2023). Young learners demonstrated their spatial knowledge using spatial language, such as *turn*, *move, forward*, *right*, *left*, *then here*, and *this way*. Also, they used gestures with their hands, such as pointing direction, tracing a path, and moving the robot with their hands, such as simulating linear or rotational movements (Shumway et al., 2023).

In light of these findings, spatial skills can be applied to problem solving in many domains, including programming activities described above. Spatial knowledge was fundamental to learning how to program robotic toys and influenced multiple aspects of the computational thinking process (Francis et al., 2016; Palmér, 2017). The purpose of this study is to reveal young learners' spatial skills by focusing on their spatial vocabulary use and physical interactions with educational robots.

2.5 Theoretical framework of the study

The concept of embodied learning emphasizes the connection between the body and the process of acquiring abstract concepts. Fundamental STEM knowledge is influenced by the embodied nature of the human mind. Numerous studies about how people gesture while speaking and solving problems provided that thinking is embodied (Abrahamson & Lindgren, 2014). Tools that facilitate embodied learning employ analogies to connect concrete actions with abstract concepts (Meadow & Beilock, 2010). That is, embodied learning allows us to build upon our existing, easily understood physical experiences and use them as a foundation for grasping more abstract concepts. We leverage our body's understanding of the world, grounded in movement and sensation, to make sense of more complex and intangible ideas. In the study of Burte et al. (2017), they also examined the benefits of embodied tasks in math learning for elementary school students and they found that spatial training, thinking three-dimensional, paper folding, and origami tasks emphasize and improve spatial skills.

An effective approach to exploring embodiment is through gestures. STEM fields are particularly compatible with the incorporation of gestures, actions, and body-related metaphors because they often depend on abstract or arbitrary symbols system and involve the exploration of complex, dynamic processes (Weisberg & Newcombe, 2017). Besides, Hostetter and Alibali (2008) suggested that an embodied perspective on gestures is crucial for understanding their role in communication and cognition, and it helps explain the origins of gestures and how they reflect real-time thinking. Furthermore, gestures have a potential to bring actions into our mental representations. It can contribute to the process of change in two distinct manners; firstly, when we observe others' gestures, it can facilitate learning; secondly, when we produce gestures ourselves, it can also enhance our own learning process (Goldin-Meadow, 2015).

Additionally, Hostetter and Alibali (2008) concluded that people use gestures to convey spatial and motor information when describing mental images. For instance, when giving directions, a speaker might say "take a left" while gesturing leftward, directly expressing the spatial concept through movement, rather than translating it into verbal form (Hostetter & Alibali, 2008). Furthermore, Meadow and Beilock (2010) also explored the unique role of gesture, suggesting that actions primarily intended to represent ideas with gestures may have a more profound impact on thinking than actions with direct physical consequences. That is, gestures are not directly tied to physical actions but instead serve as symbols or representations of abstract thoughts and play a crucial role in shaping our thinking. Through the perspective of embodied learning, it is aimed to examine how people comprehend the significance of gestures in communication. Listeners are more likely to understand the meanings expressed by speakers when conveyed through gestures (Alibali & Nathan, 2012). In the study of Nemirovsky and Ferrara (2019), the term *utterance* was defined as all forms of bodily activity that occur in a particular conversation. The interpretation of these utterances highlights multimodal elements, such as facial expressions, gestures, tone of voice, eye movement, body posture and gaze.

Papert (1980) focused on not only what people are thinking but also how earning relates to our bodies and physical objects. The Turtle robot's action in response to commands such as *left* of *right* are based on its own orientation, so learners take the perspective of the Turtle, embodying the view of the screen to navigate the robot (Papert, 1980). The robot became an embodied artifact for children to simulate its actions and convert into a block-based program by acting out the robot's movement (Kopcha et al., 2020). Furthermore, Alibali and Nathan (2012) pointed out that the use of objects and tools in a learner's surroundings can impact how they process and understand their thoughts.

In the study of Kwon et al. (2022), they designed embodied learning activities with high motoric engagement through simulating the robot's movement for primary school students. The learning tasks included making multiple turns, avoiding obstacles, passing missions, and rotating perspectives. At first, children solved programming tasks by walking on a mat themselves in the embodied learning activities. As a result of the study, students gained spatial awareness through the embodied activities because the learning tasks required spatial awareness in finding paths, deciding on the path, and sequencing steps (Kwon et al., 2022). In addition to these, physical robots enable children to understand geometric shapes which are related to spatial skills. In the Logo-learning environment, children demonstrated a better understanding of the parts that make up geometric shapes (Clements & Battista, 1989). Furthermore, they were more inclined to think about geometric shapes in terms of how they are made or the steps needed to draw them, suggesting that their programming experience influenced their understanding of geometric construction (Clements & Battista, 1989).

Francis et al. (2015) shed light on the specific ways children's spatial reasoning skills improved as they worked through the programming activities, providing a rich understanding of developmental process. According to Francis et al. (2015), observations of children engaging in programming tasks indicated that three modes of representation, such as action, visuals, and symbols, do not necessarily develop one after the other. Instead, they appear to grow simultaneously, constantly interacting with and shaping each other. Therefore, it is critical to explore learners' interaction with technology and the meaning behind such interactions by emphasizing the complementarity of different modes of human interaction (Kopcha et al., 2020).

Spatial skills also allow individuals to organize, interpret, manipulate, and understand spatial relationships within both real and imagined environments. During early childhood, conversations about spatial concepts such as spatial features, relationships, and orientations support children's development of spatial understanding, particularly important for visualizing movements and navigating their surroundings. Additionally, active participation in spatial activities further promotes young children's spatial learning and improves their performance on spatial tasks (Newcombe, 2013). Spatial skills are critical for daily life activities, and as children explore spatial relationships, they enhance their receptive vocabulary, spatial perception, executive function, and visual-spatial and language abilities (Zhang, 2016).

Aligning with the primary objective of this study, embodied learning was employed as a theoretical framework to design and implement the robotics curriculum to explore young children's spatial skills by addressing their physical interactions with programmable toys. To put the perspective of embodied learning into practice properly, multimodal analysis method was used, and children's physical experiences with educational robotics were captured in an enriched way.
Upon this extensive literature review, the present study aims to investigate the following research questions:

1) How do 5-year-old pre-school children's spatial skills emerge when they engage with programmable robot toys?
    i) How do 5-year-old pre-school children demonstrate their spatial skills during the pre-programming stage of the robotic tasks?
    ii) How do 5-year-old pre-school children demonstrate their spatial skills during the programming stage of the robotic tasks?
    iii) How 5-year-old pre-school children use their spatial skills during unplugged and plugged robotic activities?
2) How do 5- to 6-year-old pre-school children use spatial vocabulary while interacting with programmable robot toys over a semester?
    i) Which categories of spatial vocabulary are predominantly used by preschool children during robotic activities?

CHAPTER 3

METHOD

The purpose of this study is to explore young children's spatial skills in the context of educational robotics in light of their physical interactions with programmable toys. In this chapter, the following sections are covered: (1) research design, (2) the research site, (3) the research context, (4) the case, (4) data collection procedures, and (5) data analysis, (6) researcher position, and (7) trustworthiness.

3.1 Research design

This study employed a qualitative single case study design (Yin, 2009). The case involved six pre-school children aged 5-year completing unplugged and plugged robotic activities. The aim of this study is to explore the young children's spatial skills in the context of educational robotics based on their physical interactions with programmable toys. Creswell and Poth (2013) concluded that conducting qualitative research requires complex and detailed understanding. The dataset included 11 video recordings of the sessions where the robotic activities were implemented.

Yin (2008) asserts that a case study includes an empirical investigation of a current phenomenon in its real-life context. This study allows for an in-depth investigation of the role of educational robotics on preschoolers' spatial skills and embodied interactions. Case studies are effective for understanding complex and multi-faced phenomena like the integration of educational robotics in early childhood education, which enables researchers to explore the unique experiences and context of participants. This depth analysis is crucial when studying the development of spatial skills in this context, where the boundaries between the phenomena and its context are not always clear. Therefore, the case study design provides a comprehensive understanding of spatial skills within the intricate dynamics of these educational robotics settings.

3.2 The research context

This study was conducted to explore preschool children's spatial skills in the context of educational robotics at an Early Childhood Education Center in Istanbul. The selected research site was chosen based on several criteria. Firstly, Early Childhood Education Center was known for its emphasis on child-centered, play-based, developmentally appropriate learning environments. Secondly, the presence of a special technology classroom equipped with screen-free programmable robots made it an ideal setting for conducting the robotic curriculum. Thirdly, the researcher had professional familiarity with the center's philosophy, staff, and routines, which facilitated access, prolonged engagement, and deeper contextual understanding. Finally, the single 5-year-old classroom consisted solely of five-year old children, all residing in the same urban district, enrolled for similar durations, coming from middle-to-upper SES backgrounds, allowing for focused exploration of age-relevant spatial skills.

The participants included 5-year-old children from one classroom at the center because there was only five-year-old classroom at the center. These children shared common characteristics such as age, duration of school enrollment, and residence in the same city. Participants were selected through purposive sampling ensuring that they shared key characteristics relevant to the study's focus (e.g., age, school environment, exposure to robotics curriculum).

During the children's regular class hours, the sessions were conducted weekly on Wednesdays between 10:00 am and 11:00 am. While the participating group attended the robotic sessions in the technology classroom with the researcher, also served as the activity facilitator, the other children continued in their regular class schedule. During the extra-curricular club hours, the same activities were repeated by classroom teachers with non-participating children to ensure they had similar learning opportunities. The structured 11-week curriculum consisted of five unplugged activities and six plugged-in activities using Bee-Bots and Bubble-Bots. An introductory session was also offered to familiarize children with the robots before the program started. The unplugged sessions included gamified tasks and group activities to introduce spatial concepts through play-based learning approaches. In the robotics sessions, children used Bee-Bot and Bubble-Bot robots to apply spatial skills in hands-on, technology-supported activities. During the introductory session, the researcher presented the physical components and basic functions of the robots, such as the directional buttons and how each input command corresponded to the robot’s movements. The session was designed to be exploratory and child-centered, allowing children to interact freely with the Bee-Bot and Bubble-Bot. Children were encouraged to explore freely, press buttons, and observe the robot’s responses at their own pace.

Data for the study were primarily collected through video recordings of the activity sessions. Two fixed cameras were strategically placed in the technology classroom to capture both audio and visual data, focusing on the children’s verbal expressions, gestures, and interactions with peers and materials. These recordings served as the primary source for analyzing the participants’ spatial skills throughout the program. After each session, the researcher reviewed the video recordings and created detailed transcripts, which included verbal utterances and non-verbal cues such as body language and facial expressions. The researcher in this study was also the homeroom teacher of the participants. This dual role of the researcher enabled her to conduct a deeper analysis and interpretation of the children's engagement during robotic activities

3.3 The case

This qualitative case study explores the young children's spatial skills in the context of educational robotics concerning their physical interactions with programmable toys over a semester at an Early Childhood Education Center in Istanbul. According to Yin (2009), a well-defined case must have clear boundaries to distinguish it from other cases and to prevent the scope of the inquiry from becoming too broad. The case is a group of six 5–6-year-old preschool children at early childhood education center in Istanbul, engaging in an 11-week educational robotics curriculum designed to reveal their spatial skills through unplugged and plugged activities. The designed curriculum was based on embodied learning principles and enabled young children's to interact physically with programmable toys.

The boundaries of this qualitative case study are clearly defined to ensure analytical focus and manageability, as recommended by Yin (2009). The study is bounded by its participants, setting, time frame, and the specific educational context. According to Yin (2009), "a case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident" (p. 18). Yet, for the research to be analytically meaningful, the case itself must have clearly defined boundaries—such as the who, where, and when of the investigation.

The study focused on a group of six preschool children aged 5–6 years, enrolled in an early childhood education center at Boğaziçi University in Istanbul. The study was conducted over an 11-week period during the Spring 2024 semester, with one 40-minute session held each week. The setting was a designated technology classroom equipped with programmable robots—specifically Bee-Bots and Bubble-Bots and materials for unplugged activities. The goal of the study was to explore how young children's spatial skills emerge through their physical interactions with programmable toys. Besides, the robotics curriculum was specifically designed based on embodied learning principles. These boundaries help define the case precisely, prevent the scope of inquiry from becoming too broad, and enhance the study's credibility and transferability.

In the Early Childhood Education Unit, children start the day at 8.30 a.m. with breakfast and continue with morning circle routine. Children take several specialized courses such as English, chess, art, and robotics education. Children regularly attended robotics education once a week in their program. The educational robotics curriculum designed for this study was integrated into this routine schedule at this education unit. To avoid any disruptions in the regular program, the robotics curriculum was conducted once a week, and it was implemented in specifically designed technology classroom by the researcher. Participants attended the program about the educational robotic curriculum which included the unplugged and plugged-in activities (activities that could be completed without and with a computer). The 11-week educational robotics curriculum was implemented in the semester of Spring 2024, and it took 11-week.

Children were selected from the classes at Boğaziçi University Early Childhood Center (see Table 1). The participants were six children, all aged 5, from a single classroom. All had been enrolled in the same school for four years and shared similar developmental backgrounds by the time the study was conducted. The socioeconomic status of participants can be considered middle to upper-middle class, and it serves civil-servant and academic parents who worked at the Boğaziçi University as shown in Table 1. At Boğaziçi University, civil servants are administrative, or support staff employed by the university, such as secretaries, librarians, maintenance personnel, and other non-academic staff who contribute to the daily operations of the institution. On the other hand, academic parents are faculty members engaged in teaching and research activities, such as professors, associate professors, assistant professors, and lecturers across various departments. Moreover, the study focused specifically on young children's spatial skills in the context of educational robotics through their physical experiences with programmable toys over a semester. The study analyzed 11 video-recorded sessions as the primary dataset. It did not include any follow-up assessments beyond the intervention period.

Table 1. Characteristics of Participants

Nicknames	Age	Gender	SES
Uriel	5	Boy	Upper-Middle (Academic)
Yuma	5	Boy	Upper-Middle (Academic)
Emily	5	Girl	Middle (Civil Servant)
Olivia	5	Girl	Middle (Civil Servant)
Sophie	5	Girl	Middle (Civil Servant)
Hazel	5	Girl	Upper-Middle (Academic)

Below are brief narrative profiles of the six participants—Emily, Olivia, Hazel, Sophie, Uriel and Yuma—based on the homeroom teacher's observations prior to the current study. In depth-analysis of participant's characteristics, we expected that children who can articulate their thoughts and feelings are more likely to use spatial vocabulary and reflect on their thinking during robotic tasks. They also tend to engage more confidently in group discussions, which reinforces shared spatial understanding (Palmér, 2017). However, children who are emotionally sensitive or shy, might develop spatial skills through observation rather than action (Newcombe, 2010). In this research, participant's gestures, verbal dialogue among their peers are part of multimodal analysis to explore their spatial skills during robotic tasks.

Emily was a self-aware and verbally expressive child who confidently states her feelings during the robotic tasks. She frequently used spatial vocabulary and confidently explained the robot's movement, sequences, and directions. She was highly persistent and does not easily give up when faced with challenges in the robotic tasks such as debugging, route planning which require use of spatial and planning skills. Emily was good at managing group discussions and was willing to support her friends during the group tasks in the present study.

Olivia was a calm and talkative child who can easily express her feelings and ideas during the robotic tasks in the present study. However, she became sensitive when she had a difficulty during the robotic tasks. She could easily focus on robotic activities, and she wanted to be successful in completing them properly. Despite facing difficulties, she focused on robotic activities and showed a desire to succeed in these activities.

Sophie was confident, solution-oriented, and collaborative, making her a key contributor to problem-solving in group tasks. She encouraged her peers, engaged with spatial challenges such as route direction, use of spatial vocabulary to discuss the robot paths. Her leadership and empathy also promoted peer dialogue, helping others clarify spatial concepts during the robotic tasks. Shortly, she thrived on challenges and actively sought solutions, encouraging her friends to remain engaged and productive, as well.

Hazel was a quiet observer who preferred to watch and listen rather than act immediately. She was generally an observer during the group tasks. She liked to listen and observe her friends and express herself only if needed to complete the task. During the robotic activities, she mostly listened and observed her friends.

Uriel was also a self-aware and verbally expressive child who confidently explains his ideas during the robotic tasks in the present study. For instance, Uriel used gestures and language effectively to explain robot paths and directions, indicating strong communication skills. He also liked to solve problems and finds solutions in the robotic group tasks. His tendency to over-support peers suggests a collaborative spirit but may have occasionally limited opportunities for others to independently explore spatial solutions.

Similar to Uriel, Yuma was a confident and articulate child who enjoys explaining his thoughts and feelings during most of the robotic activities. However, he adopted more of an observer's stance during the robotic activities. He generally matched with Uriel during the group tasks. His participation in the group tasks increased when he was paired with Uriel.

In summary, each child’s personality and interaction style shaped how they approached robotic tasks and developed spatial skills. Children like Emily and Sophie thrived in leadership roles and used rich spatial language, while Hazel and Yuma used their spatial skills through peer interaction and observation. Olivia's and Uriel’s behavior during the activities showed that a child’s motivation, ability to manage their emotions, and social interactions with peers may affect how actively and successfully they engage in robotic tasks. Therefore, it is important to use multimodal analysis that focuses on verbal dialogue, gestures, and physical actions. By analyzing these different forms of communication and interaction, we can better grasp the different ways children use spatial skills while they interact with programmable robot toys.

3.4 Data collection instruments

Participants' experiences with educational robotics concerning spatial skills were video recorded. The study used video recordings of participants who agreed to participate in educational robotics activities within the scope of the study. The videos captured the participants' engagement with the educational robotics activities, including their embodied interactions with the robots, their use of spatial skills, and their verbal dialogues. The researcher observed and video-recorded the robotic activities implemented in the classroom for at least 40 minutes per session once a week.

3.5 Data collection procedures

Before the data collection started, ethics approval was obtained from the Institutional Review Board (see Appendix A). Before the study started in the semester of Spring 2024, a consent form (see Appendix B) detailing the purpose of the study and the significance of participation was sent out to parents via email or handed out. Participation in the study was entirely voluntary. At the semester's onset, the research objectives were communicated to both parents and the school administration, and necessary permissions were taken to conduct the study which included video recordings of pre-school children. After obtaining consent forms from parents, the researcher outlined the planned activities for participants and introduced a child-friendly consent form for children who participated in the study at the beginning of the activity. Participants were asked to color a happy face to indicate their desire to continue participating in the robotic activities (see Appendix C).

The educational robotics curriculum was designed to take place over one semester focusing on programming, building robots, and engaging in problem-solving tasks that require spatial skills (see Appendix D for the curriculum). The 11-week intervention program was conducted in this education unit. Participants attended maximum 40-minute activities once a week. In the first four weeks, unplugged activities prepared preschool children for plugged-in activities designed with educational robotics. Following four-week, participants attended plugged activities designed with BeeBot. In the last two weeks, the activities designed with Bubble-Bot were implemented. The timeline of the data collection can be seen in Figure 1.

Consent forms were collected	Week 1: My Robotic Friend *(20 minutes)*	Week 2: The Floor is Lava *(15 minutes)*	Week 3: Create Your Dance Steps *(23 minutes)*
Week 4: Origami Plane *(18 minutes)*	Week 5: Follow Leader *(25 minutes)*	Week 6: Meeting Bee-Bot *(33 minutes)*	Week 7: Drawing with Bee-Bot *(25 minutes)*
Week 8: Travelling with Campus *(38 minutes)*	Week 9: Lego Maze *(35 minutes)*	Week 10: Meeting with Bubble-Bot *(28 minutes)*	Week 11: Bubble-Bot Adventures *(29 minutes)*

Figure 1. Timeline of data collection process

Bee-Bot, an educational robot that is capable of storing a series of up to 40 instructions in its programming, was used in this study. Young children can control the BeeBot by inputting a series of uncomplicated instructions for movement or rotation by using seven brightly colored buttons located on its back. There are four orange buttons that facilitate forward, backward, right, or left motion. There is a central green button (GO button) that initiated the programmed sequence. There is a blue button for memory clearance (CLEAR or X) and another blue button for introducing a brief pause in the robot's motion (PAUSE or II). This current study also used Bubble-Bot educational robot that introduces children drawing and coding in an intuitive and enjoyable way through the medium of illustrations. To create drawings with Bubble-Bot, children need to press the colorful buttons on the keypad. The sequence of selected buttons forms the drawing, and the robot replicates it on paper. There are cards that assist children in their initial steps in programming, offering various combinations for creative drawing possibilities. Besides, the Bubble-Bot can respond children's sounds and blowing in its free mode.

3.6 The robotics curriculum

This section outlines the design and theoretical underpinnings of the robotics curriculum developed for this study, which aimed to foster spatial skill development in young children through educational robotics. Grounded in research on embodied learning and developmentally appropriate pedagogical frameworks, the curriculum was informed by Bers' *TangibleK Robotics Program* (2010) which emphasizes the importance of integrating physical interaction, problem-solving, and child-centered approaches into early computer science education.

The curriculum was designed by the researcher, who drew upon her expertise in early childhood education and her interest in robotics to create an 11-week program that combined unplugged and plugged-in activities using programmable toys, such as Bee-Bot and Bubble-Bot. Through a combination of hands-on tasks, structured lesson planning, and reflection-based discussions, the curriculum provided opportunities for children to use their spatial skills during the robotic tasks.

3.6.1 The embodied approach in robotic tasks

Bers' Coding as Another Language pedagogical framework (2019) emphasizes using concrete tools to allow young children explore coding through tangible or visual block-based programming. Moreover, Bers (2008) highlights that robotics education encourages students to engage in three-dimensional thinking and visualization, as they build and design robots. This process inherently demands the use of spatial skills and the ability to mentally simulate the robot's movements during programming. Building on this understanding, in the robotic curriculum, unplugged and plugged-in activities were designed to foster targeted spatial skill in the context of educational robotics.

Moreover, programming tasks provide a foundation for problem-based learning and support the engineering design process, which includes repeated cycles of testing and refining solutions (Bers, 2008; Resnick et al., 1999). Although many robotics programming tools exist for educational use, only a limited number are tailored specifically for young children–such as Bee-Bots and Bubble-Bots. In this study, these tools were integrated into the curriculum to explore how embodied learning principles shape young children's spatial skills through robotic activities.

The embodied approach in robotics education emphasizes the role of physical interaction and movement in helping young learners internalize spatial concepts through direct bodily engagement. While learning abstract concepts, it is essential to link knowledge representation with bodily experiences that are grounded in perception (Barsalou, 2008; Johnson-Glenberg et al., 2014; Lindgren, 2014; Lindgren & Johnson-Glenberg, 2013). In the context of robotics programming, studies have shown that physically enacting programming commands is more effective for understanding programming ideas than simply visualizing them (Black, 2010; Fadjo et al., 2009; Lu et al., 2010). These findings highlight that increased physical involvement can enhance perceptual learning by offering learners tangible, real-world experiences.

Furthermore, solving problems with robotics involves designing, building, and programming a robot in ways that require a deep conceptual grasp of how the system works. Embodied robotics tasks encourage learners to physically simulate the robot's actions using their own bodies (Lu et al., 2011). This shift in perspective—from programmer to robot—allows children to visualize and act out the robot’s motions, which can lead to a more thorough understanding of the robot's functioning and more accurate programming.

In conclusion, the robotics curriculum developed in this study integrates developmentally appropriate programming tools and embodied learning principles to support young children’s spatial skill development. Basically, the curriculum combined unplugged and plugged-in activities using Bee-Bots and Bubble-Bots to offer young children concrete opportunities for spatial skill use. This approach not only aligns with current research highlighting the importance of physical interaction in learning abstract ideas (Barsalou, 2008; Lindgren & Johnson-Glenberg, 2013) but also underscores the potential of educational robotics as a meaningful pathway to foster spatial skill development.

3.6.2 The design of the robotic lesson plans

The design of the robotics lesson plan structure was based on the Bers' (2010) TangibleK robotics program which integrates developmental characteristics of young children into programming education. As a curriculum designer, our role is to understand how programmable toys used in the early childhood classroom. Bers' (2010) TangibleK robotics program guided us to design the structure of the lesson plan which included targeted skill, learning objectives, teacher preparedness before the activity, opening/closing technology circles, warm-up activities, main activities.

In this study, targeted spatial skills and learning objectives were included at the beginning of the lesson plan. Furthermore, each lesson contained a variety of activities, including warm-up activities to introduce topics, closing technology circles to discuss and reflect on activities and concepts. According to Bers (2010), technology circle plays a significant role for promoting problem-solving in programming by leading interpersonal connection among peers and adults. Initiated by the teacher, technology circles involve children's showcasing their projects and engaging in discussions around who at worked, what did not, and the objectives they aim to achieve (Bers, 2010). In the present study, the technology circles occurred in every activity at the project's outset and at the end of the activity, tailored with children's needs and teacher's goals.

The robotic curriculum's main activities were designed for the study included eleven activities: five unplugged and six plugged activities for promoting children's spatial skills. In this study, we designed a series of tasks that varied in difficulty, ensuring that both plugged-in (technology-based) and unplugged (hands-on) activities catered to participants' spatial skills. By thoughtfully balancing the complexity of each activity, it was aimed to keep the children engaged and eager to tackle new challenges with confidence throughout the robotic curriculum.

In the unplugged activities, participants were introduced several activities tailored with specific spatial concepts such as spatial awareness, spatial visualization, mental rotation, and spatial vocabulary. In the plugged-in activities, programmable toys were used to facilitate young children's spatial skill development with providing learning environments in which young children can manipulate tools and construct knowledge. For instance, participants were introduced two different types of programmable toys which enable them to engage in planning programming phase, designing tangible materials for programmable toys such as grid, maze, and map design, drawing shapes and figures with programmable toys.

In summary, the robotics lesson plan in this study was structured around the principles of Bers' (2010) TangibleK robotics program, which emphasizes the developmental needs of young children in early programming education. The curriculum was thoughtfully designed to include targeted spatial skills and clear learning objectives, along with structured components such as teacher preparation, warm-up tasks, main activities, and reflective technology circles.

3.7 Data analysis

In this research study, the multimodal social semiotic approach was used to understand young children's embodied interactions with educational robotics. According to Bezemer and Mavers (2011), as the use of video recordings grows in social research, it brings forth methodological questions related to multimodal transcription. This includes challenges in transcribing non-verbal elements. To accurately represent social interactions in transcripts, various modes shaped by social and cultural factors are translated to convey meaning, including speech, gestures, and images (Bezemer & Mavers, 2011). Bezemer’s framework (2014) offers a tool for researchers to analyze embodied interactions with technology by video data (Kopcha & Ocak, 2020). Bezemer (2014) created a framework that involves five common steps: (1) Choose a methodological framework, (2) Define purpose and focus of transcript, (3) Design transcript, (4) Read transcript, and (5) Draw conclusions. The dataset was analyzed based on this framework through multimodal transcriptions in this case study.

3.7.1 Choose a methodological framework

Within the scope of this study, social semiotic approach was used to understand children’s spatial skills in the light of embodied interactions with the educational robotics activities. This framework is particularly suitable because it allows for a detailed analysis of how meaning is constructed through the interplay of multiple modes of communication. Bezemer and Mavers (2011) argue that transcripts should be understood not as neutral records, but as constructed artifacts that reflect the transcriber's analytical choices and theoretical perspective. They emphasize that social semiotic transcription involves recognizing and analyzing the meaning-making principles at work when transcribers represent interactions. This is crucial for this study, as it necessitates a rigorous approach to capturing the nuances of children's interactions with robots, where meaning is conveyed not only through speech but also through actions, gestures, and manipulation of the robotic tools. Bezemer (2014) identifies different parts of the body as resources for making meaning that are visible on the recordings such as head, upper body, arms, and hands. This is highly relevant to the study of children's spatial skills, where embodied actions such as pointing, manipulating objects, and using gestures are integral to demonstrating and developing spatial understanding. By attending to these embodied dimensions, the analysis can provide a more holistic and nuanced understanding of how children interact with and learn through robotics activities.

Overall, the social semiotic approach, informed by Bezemer and Mavers (2011) and Bezemer (2014), provides a robust methodological foundation for this research study. It enables the researcher to move beyond a solely linguistic analysis and to systematically examine the complex interplay of various modes of communication, including speech and embodied actions, that contribute to children's developing spatial skills within the context of educational robotics.

3.7.2 Focus and purpose

The aim of this study is to explore young children's spatial skills in the context of embodied interaction with educational robotic activities. According to Khine (2017), Spatial ability is the skill of accurately perceiving visual information, forming mental visualizations, and understanding as well as altering the spatial relationships among objects (Khine, 2017). Importantly, this ability is not static; it can be developed and improved through specific training exercises (Khine, 2017; Newcombe, 2017; Uttal et al., 2013). Therefore, the aim of the study was to understand the complicated nature of spatial skills, we focused on young children's use of spatial vocabulary and gestures during the educational robotics activities. To reveal participant's use of spatial vocabulary, we categorized spatial vocabularies based on Canon et al. (2007) eight categories of spatial vocabulary for examining the language used by children and caregivers when discussing space in both structured and unstructured settings. In this study, pre-school children's use of spatial vocabularies was analyzed based on these categories. The categories basically include spatial dimensions, shapes, location/direction, spatial orientations or transformations, continuous amounts, deictic terms, spatial features/properties, and patterns. However, focusing only on verbal utterances is insufficient to understand spatial skills so that we will focus on children's gestures.

3.7.3 Design the transcript

According to Bezemer (2014), multimodal transcripts not only represent multimodal interaction, but also multimodal transcripts used multimodal modes in the transcript, including a combination of writing, typography, image, and layout. In this study, we focused on both verbal and non-verbal interactions such as gestures, bodily actions, and mimicry. Our selected images emphasized on moments where the participants interacted with each other and learning tool through gesture. Arranging the images and dialogue encourage us to understand nuanced meaning revealed through the participant's gesture, verbal utterances, and the elements of the environment over time (Kopcha & Ocak, 2020). The design of the transcript includes verbal utterances, gestures, and transduction part. Bezemer (2014) concluded that when you read a transcript, you must read, mark, annotate, and refine it. In the transcription stage, there is a need to select and highlight interactional features for the audience and describe what you see in the visual representation of the transcript. In the study of Kopcha et al. (2020), the transduction section appears in the third column of their transcript, and it entails constructing a single narrative that explains how different modalities encourage participants' computational thinking skills.

3.7.4 Read the transcript

In this study, we aim to describe different modalities and their effect on participants' spatial skills. With this purpose, dialogue and image columns were considered a single unit of analysis, meaning they were analyzed together rather than separately as you can see in Table 2.

Table 2. Example of Multimodal Organization of the Video Data

Dialogue	Embodied Interaction	Transduction	Spatial Skills Observed
Ms. Hill (Teacher): Uriel where are you going? Uriel: To Forest, One, two, three, four, five, six and gooo.	 [He firstly holds the bee-bot and counting its steps to reach Forest in the South Campus. Then, he presses the forward button to reach there.]	He physically interacts with the Bee-Bot, moving it step by step. He assigns a numerical value (the number of steps) to the physical movement of the robot.	Spatial visualization for planning the route for the robot by measuring the distance by holding bee-bot among his hands.

In the first column, verbal exchange between the teacher, the child and among children. It includes direct quotes that reveal how children express their intentions, use spatial vocabulary, and respond to guidance. The second column documents the child's physical actions and gestures while using the robot. The third column of our transcript (see Table 2) presents the transduction, which was achieved by constructing a single account of how different modalities shaped the participant's spatial skills. In other words, transduction (third column) involves the researcher actively examining multiple modes of interaction to gain a deeper understanding of the research question (Kopcha et al., 2020). Therefore, the dialogue (first column) and related images (second column) were treated as an integrated analytical unit, examining them together rather than in isolation (Kopcha et al., 2020). In the fourth column, there are specific spatial skills observed during the interaction with robotic tasks. These may include skills such as spatial visualization, mental rotation, spatial orientation, measurement, or route planning. In the present study, we analyzed both verbal and visual data as a combined unit to make an interpretation about participant's embodied interaction with the programmable toys.

In this study, consensus on codebook was established through two cycles of reading the transcripts by researchers to determine consistent patterns that were present in the data. To ensure reliability in the coding process, the codebook and datasets were shared with a researcher fellow specializing in this field, who was tasked with conducting the coding as an interrater. This researcher is a teacher at the school where the study was conducted and is also a master's student in the Educational Technology program at Boğaziçi University. Subsequently, a validation meeting was held with an expert in the fields of educational technology and qualitative research. During this meeting, the original framework-based codebook, the dataset, and the refined codebook from the previous meetings were critically reviewed.

To aid consensus building, we drew upon Alibali (2005) comprehensive framework to analyze how gestures contribute to expressing, communicating, and thinking about spatial information. We divide the gesture use for spatial concepts into three main categories based on Alibali (2005) framework. In the first category, the role of gesture for expressing spatial information was examined. We categorized gestures to express spatial information regarding geometric relations and spatial transformations during the robotic tasks as shown in Table 3.

Table 3. Gestures for Expressing Spatial Information

Gestures	Their Meanings
Interlocking	Using fingers or hands to interlock or overlap.
Separating	Using hands or arms to split or divide objects.
Relative position gestures	Holding one hand above another indicates one object is above another.
Pointing	Directly pointing at a location, object, or direction (e.g., Pointing at a robot to indicate where it should go.)
Indicating Direction	Using a hand to indicate a direction (Above/Below, In/Out, Near/Far, Left/Right, Front/Back)
Tracing	Tracing a path or shape in the air
Size	Using hands to indicate relative size
Distance	Using hands to indicate distance.

Note. These gesture categories were adapted from Alibali's study (2005).

In the second category, we tried to understand the role of gesture for communicating spatial information as shown in Table 4. Learners often use gestures more when they support their understanding and demonstrate their intention to communicate (Alibali, 2005). Importantly, gestures that either repeat verbal information or introduce new information can significantly influence the listener's grasp of accompanying speech (Alibali, 2005). Children were more successful at choosing the right block when the gestures used by the person giving instructions simply what was being said (Alibali, 2005). That is, if the words and the gestures conveyed the same information, the children understood and acted on the instructions more accurately. Essentially, when the message was reinforced by redundant or matching gestures, it was clearer for the children. It suggests that redundancy in communication, at least in this context, is helpful for children's comprehension and performance. According to Alibali (2005), both redundant and non-redundant gestures affect how learners understand the spoken words they accompany, and learners can also pick up information uniquely expressed through gestures.

Table 4. Gestures for Communicating Spatial Information

Gestures	Their Meanings
Redundant	Gestures that conveyed information that was redundant with (or matched) the information conveyed in the accompanying speech.
No-Redundant	Gestures communicate information that is not conveyed in speech.

Note. These gesture categories were adapted from Alibali's study (2005).

In the third category, we tried to understand the role of gesture for thinking spatial information as shown in Table 5. Consequently, gestures play a vital role in the cognitive process, especially when thinking about spatial information. They assist speakers in retrieving words, particularly those related to physical actions or spatial concepts (Alibali, 2005). Ultimately, gestures encourage the application of spatial strategies in problem-solving activities, such as mental rotations and spatial reasoning (Alibali, 2005). Embodied learning suggests that gestures may affect learner's thinking about spatial information (Alibali, 2005). Gestures are bodily movements, and they occur learners talk about spatial information (Alibali, 2005).

Table 5. Gestures for Thinking Spatial Information

Gestures	Their Meanings
Mental Imagery	Using gestures to visualize or represent spatial concepts (e.g., making a small, circular motion with a finger to represent a ball the robot should avoid).
Bodily Representation	Using body movements to represent spatial relationships (e.g., stepping forward or backward to describe movement in those directions).
Spatial Skills	Using gestures to help solve spatial problems (e.g., tracing a path on the floor to plan a route for the robot).

Note. These gesture categories were adapted from Alibali's study (2005).

3.7.6 Draw conclusion

When we completed the multimodal analysis, we address our research questions and drew our conclusions about our data analysis. During this process, we first formed categories that included code clusters. And then, we generated themes based on those categories. The findings, discussions, and conclusion sections are presented below.

3.8 Trustworthiness

Qualitative researchers should be aware of trustworthiness criteria before analyzing the data they gather. Creswell (2003) suggests using one or more strategies in a study to illustrate that findings are trustable. Prolonged engagement is one of the credibility strategies to decrease the researcher's biases toward the qualitative data and increase their understanding of the culture of the studied group (Lincoln & Guba, 1985). This study lasted for eleven weeks. A triangulation strategy was also used to increase the study's dependability. Triangulation is using multiple data sources or methods to improve the credibility of the findings (Creswell & Poth, 2013). This triangulation process involved bringing together various perspectives and approaches to provide a more comprehensive understanding of the data. During the analysis phase, two researchers meticulously examined the collected data via a thorough review process. Also, clearly describing all the steps from the beginning of the study to the end of the reporting findings improves confirmability (Lincoln & Guba, 1986). Thus, the researcher constantly took notes about her progression during this study with clear and transparent writing. The final criterion is the ability to transfer research findings to other contexts or settings (Lincoln & Guba, 1986). In this study, the researcher provided thick descriptions of the case and findings so that other researchers could easily observe similarities with their studies and replicate the study in different contexts.

3.9 Researcher's position

It is essential to articulate how the researcher's positionality and experiences may have influenced this study. In this research, I occupied multiple interconnected roles, which I will outline below. By acknowledging the dual role and how my background could influence interpretations. This kind of self-situated transparency is essential in qualitative researcher (Berger, 2015).

My academic background includes a bachelor's degree in early childhood education and a master's degree in educational technology, both from Boğaziçi University. My engagement with children began during my undergraduate studies and has continued throughout my professional development. I have prior experience as a teacher within the research setting; specifically, I completed an internship at the Boğaziçi University Early Childhood Education Unit, which is also the site where this study was conducted. Since my graduation, I have been employed as a preschool teacher at the same institution. As a result, I was already familiar with the environment, daily routines, and staff at the unit, which facilitated the implementation of the study and helped establish a naturalistic research setting. However, this level of familiarity also presented a potential ethical concern.

Being in a position of authority and familiarity with the children could create a risk of perceived coercion, where participants might feel obligated to take part in the study due to the existing teacher-student relationship. To mitigate this, several ethical precautions were taken. Prior to conducting the study, I obtained official permission from the Board of Directors of the Boğaziçi University Early Childhood Education Unit. The study was then registered and approved by the Boğaziçi University Ethics Committee. Following this, informed consent forms were distributed and collected from all participating children's parents.

To ensure that children themselves were given a genuine choice about participation and to reduce the risk of implicit pressure, I also implemented a child-friendly consent procedure. Children need to know the purpose of the research, what it involves, what activities they will participate in, and how long it will take (Einarsdóttir, 2007). Before the start of the study, the purpose of the robotic activities was explained to the children using age-appropriate language. Each child was then asked to color a happy face if they wished to participate in the activities, or an unhappy face if they did not. This visual method of voluntary participation respected the children's autonomy and helped ensure ethical engagement in accordance with best practices in early childhood research (Einarsdóttir, 2007).

Consequently, in this study, I took on both the researcher and teacher roles. Prior to the data collection, I also developed the 11-week curriculum by meticulously designing each activity to integrate programming concepts and foster spatial skills. My two years of experience working with 5-year-old children, including the implementation of educational robotics activities, equipped me with the pedagogical expertise necessary to create developmentally appropriate lesson plans using programmable toys. However, being both the curriculum designer and the teacher who implemented the activities posed the risk of interpret participant's behaviors in ways that confirmed pre-existing assumptions or goals. As both the curriculum designer and implementer, my challenge was to observe participant behaviors that confirm the intended learning goals. Moreover, observing whether the curriculum was affective or not objectively was also a challenge due to my emotional investment. To address these challenges, we grounded the curriculum in research-based pedagogical models, Bers' (2010) TangibleK Robotics Program and embodied learning principles. Besides, I explicitly outlined the targeted skills and aligned them with observable learning objectives to minimize subjective interpretation. Also, I shared and co-developed parts of the curriculum with colleagues, mentors and field experts to gain external input and reduce a potential designer bias. While implementing the curriculum, I focused on teaching fidelity rather than interpreting the data. After each session, I recorded reflective memos and notes, as it is a practice that supported reflexivity and contributed to transparency and rigor during the later stages of data analysis (Finlay, 2002; Pillow, 2003).

During the data collection phase, I assumed the role of the children's teacher, implementing the designed activities. This involved the logistical setup of cameras within the classroom, the initiation of recordings, and the facilitation of the activities themselves. The robotics activities were conducted in a dedicated space within the Early Childhood Unit, specifically designed to support children's exploration of programmable toys and related materials. To minimize reactivity and promote authentic behavior, I endeavored to maintain a typical classroom environment. The children demonstrated comfort and readily engaged in the activities, perceiving them as part of their regular classroom routine. This dual role of researcher-teacher can be considered a significant strength of the study, affording unique insights into the children's learning within a familiar and naturalistic context.

However, there were several concerns in the data collection procedure in relation to my dual role. One concern was the potential for reactivity, wherein the children’s behavior might be altered by the presence of cameras or their familiarity with me as both a teacher and a researcher. Another challenge was maintaining objectivity, as my direct involvement in delivering the activities could influence how I interpreted participants’ responses and behaviors.

To mitigate these concerns, several strategies were employed. First, I endeavored to maintain a typical classroom environment, ensuring that the activities were seamlessly integrated into the children's existing routines. This helped reduce the novelty of the setting and supported authentic engagement. Second, the video recordings enabled me to distinguish between my roles temporally: I acted as the teacher during real-time facilitation and later reviewed the video footage as a researcher. This approach allowed for repeated and unbiased analysis of the children’s interactions, independent of real-time classroom demands. Third, the camera placement was deliberately unobtrusive, allowing children to move freely without distraction.

Following the data collection, I transitioned to the role of researcher as a data analyst. This involved repeated and detailed reviews of the video recordings and the production of comprehensive transcripts. These transcripts then served as the primary data source for subsequent analysis. To mitigate this risk and enhance analytic credibility, a series of structured and collaborative steps were taken. First, a codebook was developed prior to the analysis, based on the research questions, theoretical framework, and observed patterns during initial viewings. The data were then subjected to two independent cycles of coding, involving researchers from distinct yet complementary disciplines—early childhood education and educational technology.

In the first coding cycle, a research fellow from early childhood education and I independently coded the video data from the eighth week using the shared codebook. After completing our separate analyses, we met to compare coding outcomes, discuss discrepancies, and refine the interpretations collaboratively. This process helped ensure that the codes were not solely shaped by my personal interpretations or expectations. In the second coding cycle, a new expert from the field of educational technology independently analyzed the same eighth-week data, again using the same codebook. The involvement of an interdisciplinary outsider served as an important external validity check and brought a fresh lens to the interpretation process. After this second round, the final version of the codebook was revised and finalized based on inter-rater discussions and observed overlaps in coding patterns. Using this refined codebook, I then proceeded to code the entire dataset, ensuring consistency and analytical coherence. To further strengthen the trustworthiness of the findings, an external expert review was conducted after the full analysis was completed. This final step provided an additional layer of validation for the themes and interpretations drawn from the data.

Overall, my dual role as both researcher and teacher presented unique opportunities and challenges throughout the study. My background in early childhood education and educational technology, combined with my teaching experience, enabled me to design and implement a developmentally appropriate robotics curriculum grounded in established pedagogical models. However, this insider position also introduced risks related to bias, subjectivity, and reactivity. During data collection and analysis, efforts to maintain objectivity were supported by strategies including unobtrusive video recording, role separation, multi-phase coding with interdisciplinary researchers, and expert validation. This reflective and transparent approach not only enhanced the trustworthiness of the study but also contributed to a deeper understanding of young children's engagement with educational robotics in a naturalistic early childhood context.

CHAPTER 4

FINDINGS

As a result of the data analysis, five themes emerged: (a) Robotic activities encourage preschool children's use of spatial skills while planning their robotic programming; (b) Designing tangible materials before plugged-in robotic activities supports preschool children's use of spatial skills; (c) Robotic activities enable preschool children to use spatial skills while solving problems in the programming phase; (d) Unplugged robotic activities that focus on different spatial concepts prepare preschool children for plugged-in activities more; (e) Providing a context, robotic activities facilitate preschool children's frequent use of specific spatial vocabulary. These themes are presented under the relevant research questions in this chapter.

4.1 How do 5-year-old pre-school children demonstrate their spatial skills during the pre-programming stage of the robotic tasks?

The first research question of this study explores preschool children's spatial skills during the pre-programming stage of the robotic tasks. In the pre-programming stage, participants planned their robot's route or path and designed grids for the robot's path. During this early stage, participants were observed as actively engaging in spatial skills as they prepared for programming and often using manipulative gestures to support their planning process. These gestures included using their hands to measure the relative size of the robot, estimate distances on the grid, and simulate the directional flow of movement. In addition to using manipulative gestures, participants also demonstrated spatial skills during the design of tangible materials for plugged-in robotics activities–such as building Lego mazes or mapping out robot routes on craft papers. In these collaborative tasks, participants often relied on communicative gestures and verbal dialogue enriched with spatial language to express and refine their ideas. These communicative gestures included pointing to specific locations, illustrating shape and size with their hands, and using sweeping motions to indicate paths or turns.

4.1.1 Robotic activities encourage preschool children's use of spatial skills while planning their robotic programming

In this study, participants seemed to engage in spatial skills primarily during the planning their programming phase. Preschool children usually use manipulative gestures to think about the robot's path or route before programming. They used more manipulative gestures when they tried to make the robot move in the targeted destination such as using hands to indicate relative size and distance. Participants' used their planning strategies use their planning strategies to simulate the robot's movement before the programming. For example, participants tried to calculate how many steps the robot needed to reach the finish line in the Meeting with Bee-Bot (plugged-in activity in week 6) as shown in Figure 2.

Figure 2. Participants counted each robot's movement by implementing different strategies in the Meeting with Bee-Bot activity.

They produced different planning strategies for the size of each robot move in the Meeting with Bee-Bot (plugged-in activity in week 6). Olivia first measured the robot's size with her hands. Then, she calculated length of the steps with her hands while simultaneously pressing the forward button on the robot to code it. On the other hand, Uriel measured the robot's size with his hands, similar to Olivia's technique, and began calculating the steps. After finishing his calculations, Uriel pressed the forward button for the number of times he had counted. However, Uriel realized he had pressed the forward button too many times and said, "My robot went forward too much." Changing his calculation method, Uriel took the robot between his hands and counted the steps while moving the robot to the finish line without programming it. After finishing the counting process, he returned to the starting point and pressed the forward button for the number of times he had counted. These examples demonstrated that participants produced different planning strategies which were observed through their direct physical interaction with programmable toys to check the robot's size and movements to reach the finish line.

Participants also used different planning strategies to navigate the robot's movement in the Travelling Campus with Robot (plugged-in activity in week 8). For example, Uriel first explained how to navigate the robot. Then, he held the robot and counted its steps to reach the forest on the campus. Then, he pressed the forward button to get there. At the same time, Yuma planned the route that he wanted his robot to go by placing his finger on the mat and counting how many steps the robot should go in the swimming pool. Participants engaged in spatial skills and used their manipulative gestures to plan the robot's movements before they began programming.

During the activity, participants played with the drawing robot for the first time. They initially explored its features, particularly the designated pen area for drawing. The robot operated in two modes: free mode and drawing mode. After experimenting in free mode, participants expressed readiness to use the drawing mode. Prior to drawing, participants were presented with a shape card, indicating that they would be drawing specific shapes using the robot. Participants demonstrated their planning strategies before the programming process in the drawing activity with the robot. For instance, Uriel traced his finger on the robot's screen with a colorful button to understand how to draw a star. In the example below, Uriel decomposed the shapes into simpler components to plan the coding sequence on the robot's screen with colorful buttons. It seems that Uriel could transfer his mental plan into physical actions, pressing the correct buttons to control the robot. The robot's screen enabled him to trace the drawing with his finger. He tried to trace a star shape for a while before starting coding. When the robot's drawing was incomplete, Uriel could identify the missing part and devise a solution to complete it:

> Ms. Hill (Teacher): Children, if you wanted to draw a star on a piece of paper, how would you do it?
> Uriel: I know, I know. [He took the robot and planned and executed how to draw a star by moving his fingers over the button's surface of the robot.]
> Uriel: Yay, we're going to draw a star!
> Ms. Hill (Teacher): Uriel, you were very close.
> Uriel: It just needed to be like this. [Even though a part of the star was missing, the robot drew almost all of it. He took the pencil and completed the missing part.]

In this study, it was saliently observed that participants engaged in spatial skills during robotic activities, while planning in the pre-programming phase. Participants employed different approaches to planning the robot's movement, such as using their hands to measure distances, tracing routes, and moving the robot manually to estimate the number of steps needed. When participants used their manipulative and communicative gestures to indicate the relative size and distance for the robot's path or route, they were also engaged in sensorimotor exploration which is a key mechanism of embodied learning. As a result, participants interacted physically with programmable toys to understand abstract spatial concepts such as direction, distance, and position.

4.1.2 Designing tangible materials before plugged-in robotics activities help preschool children to enhance their spatial skills

Another noteworthy observation from the study is that participants used their spatial skills while designing tangible materials before plugged-in robotics activities. For example, in the Lego Maze (plugged-in activity in week 9) activity, participants planned their ideal maze in their groups before implementing their ideas. Each group presented their ideas by selecting a spokesperson. Sophie presented her group's ideas, "It will be a semi-circle with a bridge next to it. Then we will go around the semi-circle and turn and there will be obstacles." She stepped forward and used her hands to explain what the maze would look like. She used her hand to show the circle, the bridge, the turns, and the obstacles." Uriel also presented his group ideas, "We are like this too. They chose me. Well, we wanted to make our obstacles a bit challenging. Our maze will be large. We will either make our obstacles full lines or half lines. There will be curved paths, straight paths and then squared paths." He explained his group imagined maze by referring paths and obstacles. The mention of full lines, half lines, curved paths, straight paths, and square paths indicates the complexity of his decision-making process. He explained what he wanted to do in the maze using his hands as shown in Figure 3. He tried to show each step using his hands and body.

Figure 3. Uriel explained his group maze design using hand gestures in the Lego Maze activity

From these examples, it may be concluded that participants used their body as a communication tool to convey their ideas more effectively. Participants used their gestures to be more expressive when dealing with a spatial task such as the maze design as it required participants to use spatial concepts, including directions, size, and distance. Children actively visualized the maze in their minds, using spatial features of the maze such as *half-circle*, *bridge*, and *obstacles*. They considered challenges and solutions, such as making the maze more complex by adding more obstacles. That is, participants seemed to create the mental model of the maze, helping them to plan the layout and anticipate challenges. In this case, participants' use of gestures such as using their hands to represent maze features such as a *half-circle* or *bridge* demonstrated iconic and communicative gestures that visually represent abstract spatial concepts.

Participants looked at the campus map in the Travelling Campus with Robot (plugged-in activity in week 8). They pointed to the places indicated by the teacher (Ms. Hill) during the activity. Participants located the places that they knew on the campus. They used pointing gestures to explain where the places were and indicated directions. After their observations, they identified specific locations on the craft paper, establishing a spatial reference frame. They used their observation to design a grid for their robot. For instance, Uriel used the edges of the paper as a reference point to determine where the sea and ships were nearby the campus. He also put the campus square at the center of the craft paper. Uriel and his groupmates outlined the boundaries of the drawing area, visually defining the space. They also combined verbal communication and physical gestures to discuss their ideas and plan the composition of the drawing. Participants discussed the placement of the buildings and materials that they saw on the actual map. For instance, Ms. Hill asked Uriel and Yuma what they were drawing. They responded, "We drew a ship and a helicopter." Olivia said, "I drew a helicopter," prompting Uriel to inquire, "Where?" Pointing to the craft paper where they had drawn the campus map, Olivia confidently replied, "Of course, this blue thing." However, Uriel disagreed, stating, "No, the helicopter is on the seaside." In this dialogue, particularly Uriel's inquiry about the helicopter's location and Olivia's subsequent spatial reference provides an example of developing spatial skills. In this example, they discussed their design by indicating directions to the places based on their campus map observations.

In conclusion, participants used their spatial skills through communicative gestures, their verbal dialogue with enriched with spatial language, and visual references to design tangible materials in the pre-programming phase. These examples from the data demonstrate that participants used their bodies, gestures, and verbal dialogue as tools to externalize and refine spatial concepts, illustrating an early ability to plan, visualize, and communicate spatial information in the preparation for robotics tasks.

4.1.3 How do 5-year-old pre-school children use their spatial skills during unplugged and plugged robotic activities?

In this qualitative research study, unplugged activities were intentionally designed to immerse participants in key spatial skills as shown in Table 9, such as spatial awareness, spatial visualization, spatial language, and mental rotation. Through these experiential learning opportunities, it was expected that participants gain the foundational knowledge to approach and tackle spatial problems in subsequent plugged-in robotic activities. That is, these embodied, hands-on experiences form the concrete foundation that participants later draw upon when interacting with programmable toys. For instance, giving instructions for coding their friends to put blocks in the Coding My Friend (unplugged activity in week 1) enables participants to internalize the meaning of instruction, making these commands more intuitive during plugged-in programming.

In the Create Your Dance Steps (unplugged activity in week 3), participants were asked to craft a sequence of dance moves, directly linking it to the sequential commands necessary for robotic coding. For example, Emily created a visual representation of her dance by placing pictures of herself jumping on one foot and snapping her fingers in a specific order on the floor. With 12 images, she built a unique sequence. After she finished the sequence, she performed her dance by following each card. She used a unique pattern to perform her dance. Emily's actions demonstrated a strong understanding of spatial awareness concepts in this activity. By creating a visual representation of her dance using pictures, she effectively translated her internalized sequence of movements into a concrete and tangible spatial arrangement. By arranging the pictures on the floor, Emily visually represented the dance sequence. That is, she was able to translate internalized spatial information (the order of dance moves) into an external, two-dimensional representation. As Emily danced, she needed to be aware of her body position, the pace around her, and the placement of the pictures. She expressed the dance movements with her body, demonstrating her body awareness, as well.

Table 6. Spatial Concepts/Skills During the Unplugged Activities

Concepts and Skills	Description	Sample Indicators (Participants' demonstration of concepts and skills)	Non-Verbal Indicators
Spatial Awareness	Being aware of her/his body position, the pace around her/him, and the placement of the objects.	In the "Create Your Dance Steps" activity, young children visually represent their dance figures using picture cards. They translated their internalized sequence of movements into a concrete and tangible spatial arrangement.	They used their bodies to demonstrate dance movements.
Mental Rotation	Mentally rotate the objects around them.	In the " Floor is Lava" activity, children observe their grid designs and realize their mirror placement.	They used their hands and feet to point to grid representations.
Spatial Language: Directional/ Shape Words	Using directional and shape-related language to describe spatial relationships and objects.	My Coding Friend: Children built structures or created designs using blocks. They used directional language (e.g., "left," "right") and shape-related terms (e.g., "triangle," "square") to guide their partners in placing blocks correctly.	They used nonverbal cues to demonstrate the features of blocks, such as pointing and indicating to supplement their verbal instructions.
Distance/ Relative Positions of Objects/ Symmetry	Understanding distance, relative positions, and symmetry to plan and execute tasks.	In the "Origami Plane" activity, they followed step-by-step instructions, and the children folded paper to create an origami plane. They considered symmetry, distance, and relative positions of folds to achieve the desired shape.	They used their hands to indicate direction. For instance, they pointed to where the wind was coming from to fly their planes.

The "Floor is Lava" activity involved a 3x3 grid where participants placed red papers (representing lava) on various squares. Emily placed two lavas on the left side of the grid and one in the center of the bottom row. As illustrative example is presented in the Table 10. Yuma saw a similarity between his grid and Emily's grid designs. He said, "I did like this." He continued to point about the arrangement of red papers on the grid as shown Table 10. However, Emily disagreed, stating, "No, you did not put there; you put here." She pointed out a different location on the grid. Emily recognized a difference in their lava placements. She demonstrated her friends' placement by pointing the other side of the grid as shown in Table 7. This observation suggests that participants mentally rotated the placement of the grid.

Table 7. Participant's Use of Spatial Skills During the Lego Maze Activity

Dialogue	Embodied Interaction	Transduction	Spatial Skills Observed
Emily: "Now, I will make a simple one because I love Olivia. Olivia: But you're coming forward. How will the robot pass? Ms. Hill: "I think we should watch from a little further back. Emily: and dee dit.	 [She placed the last paper]	She places the lavas for her friend, and she makes it very easy. She begins by placing two lavas on the left side of the grid. Subsequently, she positions the final lava in the center of the bottom row.	Spatial orientation. She demonstrated an understanding of how objects are positioned in space on a grid.
Yuma: I did it like that too.	 [Sat up from where he was sitting and pointed to the grid with his hand.]	Yuma realizes the similarity between his lava placement and her friend placement. Yuma. mentally rotates the image of the initial placement, imagining it from a different perspective.	Mental Rotation. He mentally reoriented visual information to compare layouts from different perspectives.
Emily: Nooo. You didn't put it here. You put it here.	 [She thinks about her designated way and responds her friend with pointing the other side of the grid]	 She remembered her friend arrangement of the red papers. She referred his previous lava placement by demonstrating with her hands.	Mental Rotation. She also mentally reoriented visual information to compare layouts from different perspectives.

Participants produced alternative ways to solve "lava" problems in the activity. For instance, Uriel placed the red cards diagonally. Participants tried to walk without touching red cards that represented lavas. They thought about alternative ways to walk because the placement did not allow to walk without touching red cards. Yuma pointed the crosswise way to reach the finish line. As illustrative example is presented in Table 8. He thought of different paths to the finish line, considering the obstacles.

Table 8. Yuma’s Problem-Solving Process for Navigating Obstacles in the Lego Maze Activity

Dialogue	Embodied Interaction	Transduction	Spatial Skills Observed
Ms. Hill (Teacher): Do you think a robot can pass through here without jumping? Yuma: diagonally Ms. Hill: can he pass diagonally. Olivia: we turn diagonally.	 [He stops because there is a lava in front of the grid. He shows crosswise way to reach finish line.]	He shows the crosswise way to reach finish line. He thinks different paths to the finish line, considering the obstacle. He selects the most efficient strategy, which involves moving around the obstacle. He uses the ability to visualize the grid, the obstacle, and the alternative path is crucial.	Spatial visualization. They mentally imagined their movements, including diagonal orientation and rerouting.

Uriel then explained his idea for an alternative approach, stating, “If I had done it like Yuma, it would have been easier. But this is difficult.” He was considering a different way to place the lava papers. An illustrative example is presented in the Table 9. He realized that if he had not placed the lava diagonally, his friend could have easily walked through the grid and reach the finish line. This demonstrates Uriel's manipulation of the spatial arrangement of the red cards. It can be concluded from these examples that participants could manipulate spatial information to solve the challenges presented in the Floor is Lava activity. Participants dealt with these spatial problems by using their ability to mentally rotate lava pieces and altered the spatial arrangement of the red cards.

Table 9. Uriel's Visualization of Alternative Path for Navigating Problems in the Lego Maze Activity

Dialogue	Embodied Interaction	Transduction	Spatial Skills Observed
Uriel: If he were here. This one would immediately come like this, pass like this, and do the same as me. But it's difficult. Ms. Hill: Yes. I think you can also go diagonally; we can also turn the robot diagonally and go. Let's see.	 [He shows the alternative way to places lavas for his friend by pointing with his leg.]	He visualizes the alternative way to putting lava papers. If he does not place the lava diagonally, his friend can easily walk into grid and reach finish line. He demonstrates the alternative way to putting lava papers.	Spatial visualization. He imagined changes to object placement and foresee its effect on his movement.

The activity My Coding Friend involved instructing a partner to build a structure or create a design using blocks, requiring identifying and manipulating different shapes. Participants needed to describe each geometric shape in the building process for their friend as shown in Figure 4. For example, Emily said, "Now, you put a red triangle on the left side," and she continued, "Now, you put a green triangle on the right side." Here, she conveyed a specific direction with her finger, providing additional spatial information. She made pointing gestures that visually indicated the target location. These nonverbal cues, such as pointing and gesturing, enhanced the meaning of her verbal instructions. By incorporating these visual cues, she was able to construct a shared mental model of the desired spatial configuration with her partner. In this activity, participants’ use of gestures for expressing spatial information such as pointing and indicating target direction helped them to build their structure more effectively.

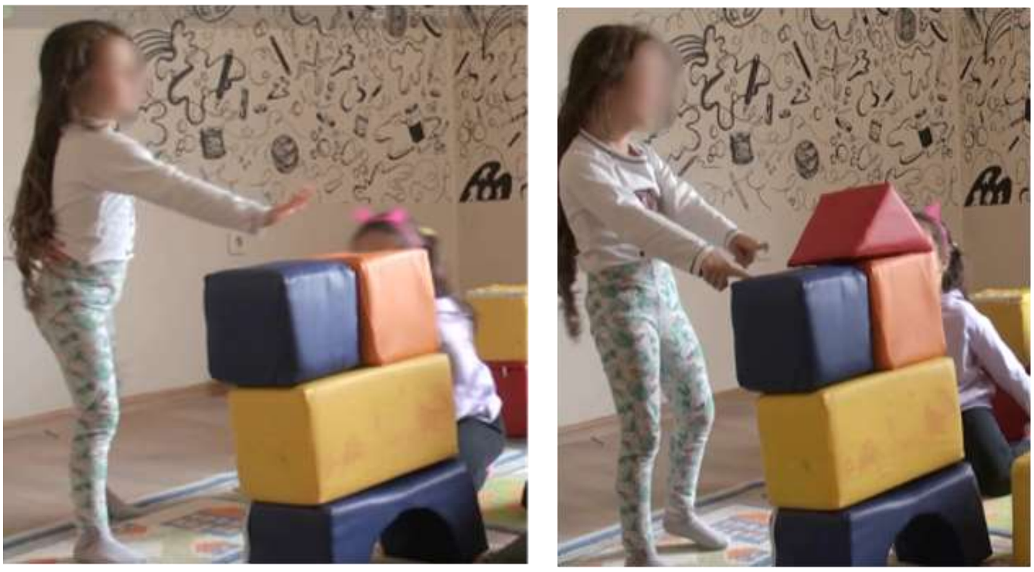

Figure 4. Pointing and indicating direction gestures in the Coding My Friend activity.

In the Origami Plane (unplugged activity in week 4), participants folded a paper introducing basic spatial concepts such as symmetry and halves, and they relied on trial and error, unfolding and re-folding the paper to achieve the desired result. Participants followed the instructions paper, and Ms. Hill guided them through each step as shown in Figure 5. For instance, Uriel showed an understanding of his progress and asked his friends, "Which step am I on now?" for clarification. Besides, participants looked at each other’s folding and were informed by each other to fold paper. Participants tried to understand each step and asked what they did in the next step.

Figure 5. Participants following the origami instruction paper

In the Origami Plane (unplugged activity in week 4), participants seemed to interpret spatial concepts such as distance and the relative positions of objects by using visual information. For instance, Uriel tried to explain why Olivia's plane failed to fly by pointing at where the wind comes from as shown in Figure 6. Uriel demonstrated how he held the origami plane and in which direction to fly it. He made gestures to show where the wind was coming from, clearly grasping the concept of spatial direction. He pictured how the plane would navigate through the air, considering how the wind would influence its path. He clearly understood the relationship between the plane's movement and the wind's direction. Furthermore, the activity encouraged spatial reasoning as participants analyzed the plane's flight path and considered the impact of wind direction, showcasing their ability to understand and predict spatial outcomes.

Figure 6. Uriel supported his friend to how she holds and flies the origami plane

As seen, by following step-by-step instructions, observing others, and actively seeking clarification, participants demonstrated an increasing understanding of spatial concepts such as symmetry, halves, and the relative positions of objects during the unplugged activities.

4.2 How do 5-year-old pre-school children demonstrate their spatial skills during programming stage of the robotic tasks?

The second research question explores how preschool children used spatial skills during the programming phase of robotics activities, particularly while identifying and solving problems related to robot's path or route. As children programmed the robot to follow specific paths or draw shapes, they frequently encountered challenges such as incorrect direction, distance miscalculations, or shape formation errors. To address these, participants applied a variety of strategies, such as using gestures, recalculating step counts, and reprogramming commands to revise their plans.

These problem-solving moments revealed key spatial skills, including spatial visualization, spatial orientation, and spatial transformation. Children used physical interactions, such as tracing shapes with their fingers, rotating the robot, pointing to directions and verbal dialogue to collaboratively analyze the problem and propose corrections. In doing so, they demonstrated not only spatial skills but also the ability to deconstruct complex tasks, sequence actions, and collaborate with peers to refine their coding. The following examples illustrate how children's spatial skills supported their problem-solving efforts in both path-planning and shape-drawing tasks by using the programmable toys.

4.2.1 Robotic activities enable preschool children to use spatial skills while solving problems in the programming phase

Participants used spatial skills to deal with problems that emerged during the robotic activities. They recognized coding errors by using their spatial knowledge about distance, size, direction in the robotic activities. Below is an example of a dialogue between participants while solving the problem of how their robot reached the planned location in the map activity. In this example, participants identified errors in their initial plan which robot going too far or in the wrong direction) and proposed solutions to correct the mistakes. They worked together to discuss the problem, share ideas, and solve it using their spatial skills. As illustrative example of this interaction is presented in Table 10.

Table 10. Children's Problem-Solving Process by Using Spatial Skills in the Travelling Campus with BeeBot Activity

Verbal Dialogue	Embodied Interaction	Transduction	Spatial Skill Observed
Emily: Because she pressed too much. One, two, three. Look, it needs to do it like this. One, two, three, four, five, six, seven, eight. Like this. Sophie: No	 [She demonstrated diagonal way by her hand to reach the indented location.]	She attempted to correct Sophie's error by demonstrating the correct sequence of button presses, emphasizing the importance of accurate counting. She observed and interpreted the robot's movement in relation to the grid.	Spatial visualization. She mentally rotated the robot to know which rotation code to add her program and demonstrate with her hand movement.
Uriel: It went diagonally. Emily: How? Uriel: You went diagonally like this, like this.	 [He explained that robot already gone diagonally by his hand]	He explained that the robot already gone diagonal way by using his hand.	Spatial transformation. He described position of the robot relative to the locations on the grid.
Olivia: But if she keeps the robot like this, it will really go diagonally.	 [She demonstrated how to put robot for diagnol way by rotating the robot with her hand]	She demonstrated how to hold the robot to make it move diagonally. She emphasized the physical manipulation in achieving the desired outcome.	Spatial visualization. She also mentally rotated the robot to know which rotation code to add her program and demonstrate with her hand movement.

Participants also demonstrated an ability to break a spatial problem into smaller steps to successfully complete a robotic activity, including calculating robot movements and drawing a geometrical shape with the robot. For example, Hazel tried to draw a square, and her friends helped her to explain how to draw a square. In this part, the teacher (Ms. Hill) encouraged participants to explain how they helped Hazel draw a square with the robot. Participants stuck a pen on their robot to draw a shape in the drawing activity. There is an example of dialogue between children to solve the problem of drawing a square with the robot as shown in Table 11.

Table 11. Breaking Down How to Draw a Square by Using Spatial Skills in the Drawing with Bee-Bot Activity

Dialogue	Embodied Interaction	Transduction	Spatial Skills Observed
Yuma: First, you need to press this.	 [He showed which buttons needed to be pressed by indicating to them with his fingers.]	He gave a specific instruction to draw a square by the robot.	Spatial orientation. He traced the path to draw a square with the robot.
Uriel: Then, one more.. No. Look, a square is like this. First, it needs to go backwards. Uriel: Look, it needs to be done like this. Uriel: One, two. Press it twice. Then press this.	 [He showed how to draw a square with robot by tracing his fingers He insisted with his mimics and gestures.]	Uriel corrected his friend, and he used his gestures and finger tracing to visually represent square.	Spatial orientation. He traced the path to draw a square with the robot.
Yuma: One time.	 [He showed “one” by raising one finger.]	He reinforced the Uriel instructions to code the robot for drawing a square.	Spatial visualization. He adjusted his body when thinking of path.
Uriel: Then press this again twice. Then hmm this time press this again twice. Then go back. Uh, press exactly two times backward. Wait, that’s too much. Press this. Then this. Then press this twice.	 [He explained how to draw a square by coding the robot. His friends watched his actions at this point.]	Uriel continued to refine the sequence, adding more detailed instructions and corrections. He used a lot of hand motions and gestured to show the correct coding. His friends watching him shows that they are also trying to learn from his embodied interaction with the robot.	Spatial visualization. He described imagined path in a way to indicate he visualized the robot’s movement.

In this example, participants actively worked to solve how to draw a square with the robot, and they shared their ideas and built on each other’s suggestions. Yuma disagreed with his friend’s coding plan and explained the process clearly.

Yuma and Uriel explained which buttons their friends needed to press to create a square. They broke down the task of drawing a square into smaller, sequential steps. They identified the necessary commands, such as *forward*, *turn left*, *turn right* and their correct order. Uriel provided a step-by-step explanation, demonstrating a clear understanding of the task and the ability to articulate it. She listened to her friends explaining how to draw a square. They knew they needed to plan the sequence of commands to achieve the desired outcome. They identified the error and adjusted their strategy when the initial plan did not work. These examples suggest that participants engaged in robotics activities, applying different strategies to handle spatial problems which were usually about geometric shapes. Participants actively practiced how to solve spatial problems, drawing a square, by deconstructing complex tasks into smaller, more manageable components, recognizing and correcting mistakes in their initial plans, and working with their peers to exchange ideas and improve their methods.

4.3 How do 5-year-old pre-school children use spatial vocabulary while interacting with programmable robot toys over a semester?

The second main research question explores how preschool participants demonstrated spatial vocabulary through their engagement in both unplugged and plugged-in robotics activities. Spatial vocabulary is a critical component of spatial thinking and skills, and includes terms related to direction, shape, size, location, patterns, and spatial relationships (Cannon et al., 2017). As children interacted with programmable robots, they increasingly used spatial vocabulary to describe movement, give instructions, plan paths, and discuss shapes. Across activities, children frequently employed deictic terms; *this*, *that*, *here*, directional terms; *left*, *right*, *forward*, *backward*, shape words; *circle*, *square*, *zigzag*, and patter words; *first*, *second*, *third* as shown in Table 12. As the activities progressed, children's spatial vocabulary became more specific and sophisticated. The following examples illustrate the contexts in which spatial vocabulary emerged during unplugged and plugged-in activities.

4.3.1 Participants use a variety of spatial vocabulary during the robotic tasks

Within the scope of this study, spatial vocabulary of preschool children through their engagement in robotic activities (see Appendix D) was also observed to address the research question "Which categories of spatial vocabulary are predominantly used by preschool children during robotic activities?" Participants exhibited a distinctive spatial language during the robotic activities. As participants interacted with the robotic activities, they used a variety of spatial vocabulary identified by Canon et al. (2017), such as dimensions, shapes, locations/directions, deictic, spatial properties and spatial patterns in both unplugged and plugged-in activities. In both unplugged and plugged activities, participants mostly used location/direction, shape, deictic, and pattern words due to the nature of robotic activities. However, participants use of such spatial vocabularies increased during the plugged-in activities.

Table 12. Spatial Vocabulary Categories in the Robotic Activities

Spatial Word Category	Spatial Words	Frequency
Dimension	Most	5
Shape	Rectangle	3
	Triangle	11
	Square	42
	Circle	12
	Star	9
	Zigzag	3
Location/Direction	Right	42
	Left	17
	Backward	4
	Forward	6
	Back	4
	Next	26
	Diagonal	21
	Under	3
Continuous amount	Step	18
	Phase	6
Deictic	Here, there, this, that, from there	264
Feature/property	Horizontal	7
	Straight	13
	Sharp	3
Pattern	Before	27
	After	150
	Order words (first, second, third, fourth, fifth, last),	126

Participants used deictic words during the unplugged and plugged-in activities while explaining their path before the programming. For example, Uriel explained his friend how to draw a square “pressed this, then this, then press this twice, then this”. He used deictic words to demonstrate buttons on the robot. That is, he decomposed each step for drawing a square and explained it by using deictic words. He also used pointing gestures to show buttons for his friend.

Moreover, participants used direction words while programming the robot in the plugged-in activities. The arrow buttons on the top of the robot enabled participants to practice direction words such as forward, backward, left and right. For instance, in the Meeting with Bee-Bot and Drawing Robot activities, participants met two different types of robots that have unique button screens. There was a conversation among participants when they saw the robot’s button screen for the first time.

Ms. Hill (Teacher): So, what do you see on the Bee-Bot?
Uriel: I see dots.
Emily: Dots.
Ms. Hill (Teacher): Okay, what do you think these dots mean?
Uriel: They direct it [*He showed the buttons with his hands*.]
Ms. Hill (Teacher): Where do they direct it?
Sophie: Right, left, forward, backward.

It seems that participants understood basic directions: left, right, backward, and forward. They also expressed that the robot had buttons with different features like delete and stop. In the Race Activity (plugged-in activity in week 6), participants explored the robot's primary features and played with them during their free play. After that, they made a race with the robot using only the forward button as shown in Figure 7. In this introductory activity, participants just aimed to use basic codes to finish the race activity. And during the activity, participants began to refine their spatial language. They started to quantify their instructions, stating "Press forward three times" or "It needs five more steps." Additionally, participants started incorporating comparative language to express the robot's movements by providing accurate measure of distance and movements of the robot.

Figure 7. The race activity

Overall, as participants engaged in tasks such as the robot race, their language became increasingly sophisticated. Initially, their descriptions were simple, but over time, they began to integrate specific spatial terms that allowed them to articulate their actions and the movements of the robot more clearly. During the robot race, participants started to quantify their instructions, using comparative phrases to analyze and describe the robot's performance.

In addition to these, participants used pattern words especially in the activities with the drawing robot. Participants needed to produce pattern words by explaining each step to draw complex geometric shapes and figures. For instance, in the Adventures with Drawing Robot activity, participants explained each card in detail to help their friends code the robot. Firstly, they analyzed each card and coded the robot as a group. They worked as a pair; one gave instructions, and the other pressed the buttons. For instance, Olivia and Sophie tried to code the robot to draw an umbrella. Sophie outlined a specific series of button presses, showing her grasp of sequence and spatial arrangement. Labeling the buttons by using pattern words, such as *first*, *second*, *third*, and so on, she demonstrated an awareness of the relative locations of the objects.

Sophie: Let's start. Third yellow.
Sophie: Second green.
Sophie: Second blue.
Sophie: First red. Fifth orange.
Sophie: Fourth orange. Third blue. First red. Fifth orange. Fourth orange.
Sophie: Third yellow, fifth blue.
Sophie: Third green.
Sophie: Ms. Hill (Teacher), we drew something.
Olivia: We drew an umbrella.

Participant also explored shape words during the robotic activities. For instance, In the Meeting with Drawing Robot, participants explored its unique features, such as a screen with colorful buttons, a pen area that enables them to draw, and cards of geometric shapes. Participants were in the effort of understanding what the colors of the buttons on the drawing robot mean. Ms. Hill guided them to make an analogy, comparing the screen of colorful buttons to a piece of paper. This allowed participants to explore the buttons by tracing. Besides, Ms. Hill explained that while the robot could directly draw basic geometric shapes, it could also be used to create more complex figures, such as a ship by combining these shapes. When they saw the robot, they realized that they could draw different geometric shapes; Yuma said, "I want to draw a square," Uriel said, "I am going to draw a straight line," and Emily asked her friends, "Shall, we draw a circle, or perhaps a square?" After several trials, Uriel explained his coding process: "We pressed this, pressed this, pressed this, pressed this, and then pressed yes. Now it is doing it." He turned the robot towards Ms. Hill when he explained the coding process. Here, Uriel struggled to describe which buttons he pressed by using directional language. Instead of using terms like *left*, *right*, *top*, *bottom*, or even the colors of the buttons, he primarily used the phrase "we pressed this or that" while making pointing gestures to show the buttons. The activity required him to translate his physical actions (pressing buttons) into a verbal description, which may be challenging at that time.

During the Meeting with Drawing Robot activity, participants demonstrated limited but evolving spatial terms that involved geometric shapes and directions. Uriel wanted to draw a shape by saying, "I am going to draw a reverse triangle." He whispered by himself when he was coding the robot. He said, "one, two, turn around... turn left. Then go straight. Then turn left and go straight." This observation highlights the use of more sophisticated spatial language as participants engaged with the drawing robot. Initially, their descriptions revolved around simple shapes like *square* and *circle*, but over time, the children began to use more complex terms such as *straight line* and *reverse triangle*, which indicates an increasing understanding of geometric characteristics, as well.

In the further robotic activities with the drawing robot, participants described their drawings using geometric terminology. They created these drawings with a robotic device featuring a screen and colorful buttons to generate geometric shapes. For example, Emily showed their drawings and said “Ms. Hill, look, we pressed all the buttons in order and this is what happened.” She continued, “for example, it is like a trapezoid and looks like a caterpillar.” In the paper, there was a zigzag line, and she resembled it as a trapezoid caterpillar. Emily's description indicates the visual similarity between the zigzag line and a caterpillar. She successfully demonstrated understanding of how to use spatial language to express abstract concepts like zigzag and trapezoid. As shown in the example below, Emily was able to draw a complex geometric shape, which is a hexagon.

> Emily: Ms. Hill, look, I made a hexagon.
> Ms. Hill (Teacher): Let me see. You’re great! Can you count the sides? Are there six?
> Emily: One, two, three, four, five, six.
> Ms. Hill (Teacher): You’re awesome!
> Emily: Olivia, I made a hexagon, look.

Before demonstrating her hexagon drawing, Emily silently counted the sides of the completed robot drawing. Then, she excitedly showed her drawing to Ms. Hill, counting the sides of the hexagon aloud while pointing to each one. Emily's correct identification of the shape as a *hexagon* demonstrated her understanding of fundamental geometric shapes and their names. These instances illustrate how participants used geometric language during their code planning and activity discussions. This may suggest that participants internalized the geometric concepts introduced in the activities and used them in their own creative work.

Overall, the study findings highlighted the role of educational robotics on the use of spatial vocabulary among preschool children. Through their active engagement in both unplugged and plugged-in activities, participants demonstrated an extensive use of spatial vocabulary by using diverse terms especially, deictic words, shapes, directions and patterns.

4.4 Summary of the findings

The study explored young children's spatial skills in the context of educational robotics. Through 11-week robotics curriculum, five key themes emerged regarding the role of educational robotic activities on preschool children's spatial skills. Participants demonstrated spatial skills while planning during the pre-programming phase of the robotic activities. They used manipulative gestures and physical interactions to plan the robot movements, such as calculating steps and navigating routes. This finding indicated that participants used their spatial skills to plan their robot's path. Secondly, participants used spatial skills in the design of tangible materials for plugged-in activities. For instance, participants engaged in maze design, using their bodies and gestures to communicate spatial concepts, half-circle, semi-circle etc. This finding indicated that hands-on approach facilitated the visualization of spatial tasks during the robotic activities.

Furthermore, during the programming phase, participants applied their spatial skills to identify problems in the robotics tasks. They engaged in discussing problems and developing solutions with their ability to break down challenges into manageable steps. Moreover, the study observed participants used a variety of spatial terms related to dimensions, shapes, directions, and patterns, particularly in the plugged-in activities. This finding indicated that the use of distinctive spatial vocabulary reflected participant's understanding of spatial concepts in the context of educational robotics. Finally, unplugged robotic activities that focused on spatial concepts prepared participants for subsequent plugged-in activities. Unplugged activities fostered foundational spatial skills, such as spatial awareness, visualization, directional language, and problem-solving skills, enabling participants to deal with plugged-in robotic tasks with greater confidence and competence.

In summary, the findings of this study highlight how educational robotics can be used for spatial skill development of young children. From planning routes and designing materials to solving programming challenges and using a variety of spatial vocabulary, participants demonstrated their spatial skills through direct physical interactions with hands-on unplugged activities and programmable toys. The integration of unplugged and plugged-in activities played a crucial role for allowing participants to build foundational spatial skills through hands-on experiences and apply these skills in technology-enhanced tasks. Overall, the study illustrated that well-designed robotics curricula grounded in embodied learning can foster young children's early spatial skills, which is essential for later success in Science, Technology, Engineering, Arts, and Math (STEAM) learning.

CHAPTER 5

DISCUSSION

This qualitative study aimed to explore young children's spatial skills in the context of educational robotics in light of their physical interactions with programmable toys. The findings provide unique insights into the practical and pedagogical implications of integrating educational robotics along with spatial skills in early childhood robotics education. Through a structured and scaffolding approach, 11-week curriculum was designed to encourage preschool children to develop spatial skills by being involved in direct physical interactions with educational robots. This section aims to discuss the findings based on the research questions of the study, examine practical implications, make suggestions for further studies, and state the limitations.

5.1 How do 5-year-old pre-school children's spatial skills emerge when they engage with programmable robot toys?

The findings of the current study revealed that preschool children actively engaged in spatial skills while programming their plugged-in tasks. Within the scope of the study, preschool children's use of spatial skill was examined in two phases: Pre-programming and during programming stages. During the pre-programming phase, preschool children applied their spatial visualization abilities, a fundamental aspect of spatial skills, to complete various tasks, such as designing tangible materials for plugged-in activities and solving spatial problems in the pre-programming phase. In the programming phase, preschool children also used spatial skills to develop various strategies to cope with challenges of robot programming. In alignment with the research questions of the study, these spatial skills are discussed below.

Within the current study, preschool children used spatial skills while planning in the pre-programming phase during the plugged-in activities. Pea et al. (2007) suggested that planning should be considered a distinct cognitive subtask in programming, essential for practical problem-solving, especially for novice learners. In the present study, preschool children engaged in spatial skills, specifically units of measure and distance measurement to navigate their robots in the plugged-in activities. In this part, children simulated the robot's movements before they started programming. This finding aligns with the findings of Shumway et al.'s study (2023), which indicates that young children use gestures or verbal descriptions to indicate the additional distance a robot needs to go with regard to its current position.

In this study, preschool children used their hands and fingers to measure the robot's size to anticipate robot's movements for the target destination. Brainin et al. (2022) underline young children need to imagine the robot's action which is called mental imagination to plan the robot's route. Similarly, Di Lieto et al. (2017) concluded that preschool children use executive function skills such as mentally anticipating the robot's action, selecting appropriate commands, and continuously updating programming plan to reach the predetermined goal. Besides, previous research studies (e.g. Sandberg & Huttenlocher, 2001) show that kindergarteners can effectively use maps for navigation and demonstrate advanced planning skills by consistently selecting the most efficient routes. In the present study, preschool children were also in the search of most efficient routes for to complete the given robotic tasks successfully. For instance, children suggested to navigate robot diagonally to reach the predetermined destination in the activity of *Travelling Campus with Bee-Bot*. Eventually, they chose the most efficient and easiest way to navigate robot. This underscores the importance of using spatial skills in understanding programming tasks, given the spatial nature of programming toys and navigation-based activities (Shumway et al., 2023).

During 11-weeks robotic tasks, preschool children used manipulate gestures more often in the planning phase, prior to programming their robots. Austin and Sweller (2014) conducted a study on how gestures enhance cognitive processes, highlighting the importance of incorporating representational gestures of various types to improve spatial skills. Moreover, Austin and Sweller’s (2014) findings notably indicate that gestures support children's learning and retention of spatial information, particularly in navigating route directions. In the present study, preschool children’s use of gesture for measuring distances or tracing paths with their hands seemed to help them to program their robots successfully. Additionally, preschool children used different ways to program their robot during the pre-programming phase. One child simultaneously moved the robot with her hand while verbalizing and pressing the command buttons. Another child employed a similar approach but moved all the steps in one direction, saying "one, two forward," and pressing the forward button. This finding is consistent with Palmér’s (2017) study, which revealed that preschool children use gestures and movements alongside directional words to illustrate how the robot would navigate when using different direction symbols on the robot. Children often used both verbal and non-verbal methods simultaneously (Palmér, 2017).

According to Alibali et al. (2000), the use of gestures has a significant role in improving children’s ability to organize and structure their thoughts, cognitive processes, including thinking, memory, and problem-solving. The use of gestures also empowers learners to access vocabulary linked to physical actions or spatial concepts while encouraging the application of spatial strategies in problem-solving tasks like mental rotation and spatial reasoning (Alibali, 2005). Similarly, Goldin-Meadow (2015) emphasized that gestures reflect unique thought processes that may not be easily articulated in words. In the present study, children's pre-programming engagement with spatial skills, demonstrated through gestures to visualize and calculate distances, directions, and routes, underscores the importance of embodied learning in cognitive processes. According to Weisberg and Newcombe (2017), embodied cognitive tools offer a distinctive way to enhance STEM education by introducing methods that the cognitive system can easily adopt and internalize. By integrating diverse planning strategies and embodying spatial concepts through gestures, preschool children demonstrated an ability to navigate complex programming tasks in their planning step.

5.1.1 Designing tangible materials for plugged-in robotic activities supports preschool children’s use of spatial skills

In this study, children used spatial skills while designing tangible materials before the plugged-in activities. Zhu et al. (2024) highlighted that open-ended and divergent design tasks contribute to a deeper understanding of how children employ spatial thinking in design and open-ended problem-solving contexts. In the current study context, children visualized their maze with their groups before programming their robots in the Lego Maze (plugged-in activity in week 9). In the planning phase, preschool children discussed about their imagined maze designs based on their previous maze observations. According to Zhu et al. (2024), children have an ability to retrieve relevant visual information from their memory related to the desired form before they start their design tasks. Aligning with this finding, 5 or 6-year-old children employed gestures to enhance their expressiveness while engaging with spatial concepts related to their designs, which required the use of elements like direction, size, and distance in the current study. Shumway et al. (2023) further claim that students use language-gesture bundles to describe possible routes on a grid. This path planning leads to detailed discussions about artifact locations, with students using terms like *here*, *there*, and *that way* and gesturing to indicate their paths (Shumway et al., 2023). In the present study, pre-school children used their observations to design a grid for their robot in the *Travelling Campus with Robot* activity, as well. They identified specific locations and places on the craft paper, establishing a spatial reference frame.

These practices align closely with the findings of Mercan and Kandır (2024), who demonstrated that STEAM education programs, particularly those involving engineering design processes, significantly enhance preschool children's visual-spatial reasoning skills. In the current study, it was also observed that children's engagement in creating tangible materials such as Lego mazes and campus maps fostered their ability to visualize and manipulate spatial relationships. Similarly, Sisman et al. (2020) found that during the design phase, students encounter several challenges that require them to think critically and solve problems. They must visualize potential solutions and anticipate how their designs will function in real-world scenarios (Sisman et al., 2020). This finding aligns with the observations made during the maze and map tasks in the curriculum as preschool children needed to plan their design functions by taking their feasibility with robots into consideration. Freeman et al. (2017) also concluded that children can grasp complex urban concepts and spatial relationships and that mapping exercises effectively reveal their spatial awareness. In our context, pre-school children's ability to design grids and plan routes demonstrates a similar understanding of spatial relationships within a defined environment.

In the current study, children were actively engaged in planning mazes and creating grid layouts. They used hand gestures to express ideas about space, including direction and distance. This supports the idea that being involved in a design process naturally encourages spatial thinking, such as creating and changing mental images and representations (Zhu et al., 2024).

5.1.2 How do 5-year-old pre-school children use their spatial skills during unplugged and plugged robotic activities?

In this qualitative research study, participants engaged in unplugged activities during the first five weeks of the curriculum. Unplugged activities help children understand abstract concepts concretely, supporting their programming skills in plugged robotics activities (Battal et al., 2021; Lin et al., 2023; Saxena et al., 2020). These hands-on learning experiences were intended to equip participants with the essential spatial skills to analyze and solve problems during the following plugged-in robotic activities.

In this study, several spatial concepts during the unplugged activities, which include spatial awareness, spatial visualization, directional language, mental rotation, and geometric shapes were observed. Given the observed benefits of unplugged activities on spatial skills, curriculum developers can prioritize spatial skills through various methods, such as paper folding and maze design. This aligns with Burte et al.'s (2017) findings suggesting that paper folding and origami significantly promote spatial skills. Participants also engaged in unplugged activities that required solving grid problems, sequencing rhythmic movements to create a dance figure, and navigating their friends to accomplish tasks. As a result, it can be concluded that adopting hands-on and experiential learning strategies allow children to explore spatial concepts concretely.

In addition to being involved in programming concepts and skills, preschool children engaged in spatial concepts during both unplugged and plugged-in activities in the present study. The nature of the embodied design provided a context where spatial skills naturally emerged during the robotic tasks. Similarly, Palmér (2017) asserts that the spatial characteristics of robotic activities facilitate children's engagement in decomposition and sequencing while concurrently fostering their spatial cognition, numerical skills, and recognition of symbols, such as arrows. Fessakis et al. (2013) further found that programming activities allow children to learn counting, orientation skills, and angle turn concepts in addition programming skills such as command execution and debugging.

Overall, the current study demonstrate that early childhood curriculum developers need to prioritize the inclusion of both types of plugged and unplugged activities, with a particular emphasis on spatial skills to create developmentally appropriate and impactful learning experiences for young children in the robotics education.

5.1.3 How do 5-year-old pre-school children demonstrate their spatial skills during programming stage of the robotic tasks?

In the current study, children used spatial skills to deal with programming errors that occurred during the robotic activities, including calculating robot movements and drawing a geometrical shape with the robot. For instance, they were able to detect coding errors which were related to distance, size, and direction in the plugged-in robotic activities. It was saliently observed that preschool children used operations such as addition and subtraction of a code to solve programming mistakes. This aligns with findings from the study of Shumway et al. (2023), indicating that preschoolers utilized their spatial understanding to recognize mistakes in their programming tasks, often articulating their thought processes with phrases like "we need one more forward." That is, identifying, locating, and fixing errors largely relied on students' understanding of basic operations such as addition or subtraction and spatial skills because students needed to visualize the robot's movements to anticipate and identify errors, demonstrating the use of spatial reasoning in this process (Shumway et al., 2023).

In the present study, children also engaged in robotic activities that required them to decompose spatial problems into smaller, manageable steps. This decomposition process is crucial in programming, as it mirrors the cognitive strategies employed during problem-solving (Shumway et al., 2023). For instance, when tasked with drawing a square, pre-school children in our study identified and sequenced necessary commands, such as moving forwards and turning left or right. In alignment with this, Shumway et al. (2023) found that decomposition not only aids in understanding complex tasks but also reinforces foundational concepts of measurement and number (Shumway et al., 2023). Another study by Clements and Sarama (2009) further demonstrates that breaking down complex tasks enhances children's understanding of foundational concepts in measurement and number.

Overall, the current study highlights 5-year-old children's use of spatial skills with the engagement of programmable robot toys. Through exploration of both pre-programming and programming phases, young learners actively employ spatial skills in planning, designing tangible materials, and problem solving. This confirms the findings of Jessica et al.'s study (2021), suggesting that young learners made observations of the robots' movements and positions, planned and built programs, and debugged programs as they built. Moreover, their ability to debug or break down programs might have been influenced by their spatial reasoning, understanding of units of measurement, and knowledge of operations, which could either facilitate or obstruct their efforts (Shumway et al., 2023). This highlights the importance of fostering spatial skills in early childhood education, as they are critical for successful engagement in programming and robotics (Newcombe, 2010).

5.2 How do 5-year-old pre-school children use spatial vocabulary while interacting with programmable robot toys over a semester?

The study's second research question focused on exploring how 5 to 6-year-old children developed spatial language while interacting with robotic programming toys over a semester. The results indicated that engaging in robotic activities enhanced the spatial language of preschoolers, which is usually limited. This study also explored the use of spatial vocabulary by preschool children during their involvement in robotic tasks, revealing that they displayed distinctive spatial vocabulary throughout these activities. That is, children gradually refined their spatial language when they engaged in robotic activities. This progression aligns with the existing literature that emphasizes the malleability of spatial skills and the importance of targeted interventions in the early childhood education (Khine, 2016; Newcombe, 2017; Uttal et al., 2013).

Canon et al. (2007) identified eight categories of spatial vocabulary for examining the language used by children and caregivers when discussing space in both structured and unstructured settings. In this study, pre-school children's use of spatial vocabularies was analyzed based on these categories. The categories include spatial dimensions, shapes, location/direction, spatial orientations or transformations, continuous amounts, deictic terms, spatial features/properties, and patterns. Cassola et al. (2020) found that the experimenter's use of spatial language significantly influenced children's performance. This implies that a rich linguistic environment, which includes a variety of spatial words, enhances children's spatial vocabulary.

In this study, it was found that young children tended to use deictic words such as *here, there and that way* during both unplugged and plugged-in robotic activities. Similarly, Shumway et al. (2023) concluded that preschool children use language and gesture such as *here*, *there* and *that wa*y to indicate their intended path before the programming. Children often refer to the task objects using deictic terms such as "this one" and "that one" (Alibali, 2000). These expressions typically require an indicating gesture for the listener to understand, and consequently, the gestures accompanying these deictic terms serve a communicative function (Alibali, 2000). In the present study, children also used gestures to indicate a direction accompanying with their deictic words. According to Shimpi and Huttenlocher (2007), pointing or deictic gestures help children learn words by directing their attention to the object being named. Children use gestures more when they help clarify their understanding and express their desire to communicate (Alibali, 2005).

Moreover, pre-school children in the current study were exposed to a variety of spatial words related to direction such as *forward*, *backward*, *left*, and *right* especially in both unplugged and plugged-in activities. Palmér (2017) found that children's understanding of arrows as symbols improve when they use terms like *forward*, *backward*, *rotate*, and *turn* to explain the meanings of arrows. Misirli et al. (2019) also indicate that children engaged in the robotic intervention program demonstrated significant improvements in spatial representation test scores and gained knowledge regarding directional concepts such as left and right. In the current study, preschool children used direction words to provide suggestions for their friends in the problem-solving situation by saying “we need to go straight” and they used direction words to describe each step for programming the robot. Shumway et al. (2017) emphasized that kindergarteners exhibited decomposition skills through both language and gestures by simulating the robot's path and breaking down each unit of movement.

In addition to this spatial vocabulary, children in the present study also used most of the spatial pattern terms, such as *before*, *after*, *and order words (first*, *second*, *etc.)* when they engaged in the drawing robot. In this study, programming drawing robot required children to think critically about the order of commands to create sequences for drawing geometric shapes and figures. According to Kazakoff et al. (2012), the ability to sequence ordinal terms such as first, second, third, and etc., is essential for effectively organizing a narrative or a series of daily activities. Similarly, in the study of Palmér (2017), children showed an ability to sequence, which includes, planning and putting objects in the correct order, which is important in both literacy and mathematics.

Overall, Newcombe and Frick (2010) underlined that caregivers and educators should provide children with spatial language that may help them categorize and abstract relevant aspects of their spatial environment. The findings of the study showed that preschoolers developed their spatial vocabulary during robotic activities. The spatial nature of the robotic activities engaged preschoolers in spatial language. The spatial aspects of coding-toy and Logo programming language appear to be a promising point of connection between mathematics and programming (Clements & Barista, 1989; Sarama & Clements, 2009).

The children's initial struggles to articulate their coding processes, relying on phrases like "we pressed this or that," highlight the challenge of translating physical actions into verbal descriptions. However, as they became more familiar with the robots and the activities, their vocabulary became more precise and nuanced. In the study of Kısa et al. (2019), children's early spatial word comprehension was found to correlate with their parents' production of spatial words. That is, children who demonstrate a better understanding of spatial vocabulary may elicit more spatial language from their parents. Kısa et al. (2019) suggested that targeted interventions and repeated exposure to spatial language can effectively support vocabulary development. Similar to Kısa et al.'s study (2019), preschool children who were exposed to an 11-week robotic curriculum requiring the use of spatial vocabulary improved their spatial language skills in the current study.

Preschool children employed spatial language indicators such as *forward*, *straight*, and *turn*, occasionally specifying directions such as *left* and *right* during their program planning (Shumway et al., 2023). The ability to articulate spatial concepts is foundational for young learners as they engage in programming tasks (Shumway et al., 2021). For instance, children in our study used a comparative language to describe the robot's movement, providing an accurate measure of distance in the plugged-in activities. By counting each forward action between the start and finish lines before programming, they demonstrated an understanding of distance measurement which is essential for effective programming. This is consistent with Palmér (2017), who stated that counting, measuring distance and space are essential components of programming and spatial thinking, and these concepts can be examined verbally and mentally, as well as through gestures.

On the other hand, in the further plugged-in activities in the current study, children had a difficulty in using *left* and *right* arrows in their programming. They tended to rotate and turn the robot with their hands without pressing left and right arrows on the robot. Palmér (2017) observed significant changes in children's understanding of arrows as symbols during programming activities. As their use of *left* and *right* was limited, they employed terms like *forward*, *backward*, *rotate*, and *turn* to interpret the arrows' meanings (Palmér, 2017).

In the present study, the difficulties encountered by pre-school children in using left and right arrows during programming tasks may be attributed to the complexity of these directional terms for this age group. That is, children aged 5 to 10 years generally learn *left* and *right* as concepts later than other spatial words because left and right terms required a more complex understanding of how things related to each other in space (Scott & Sera, 2018). This is also consistent with the findings of Austin and Sweller's (2014) study which indicated that children with a strong vocabulary of nouns tend to remember object locations better than understanding movement terms (verbs), including concepts such as direction, speed, and the relationship between objects as they change positions.

The acquisition of language, including verbs and their meaning is a gradual process. Children may not yet have fully developed the vocabulary or comprehension skills needed to grasp the nuances of movement verbs. Moreover, Turan et al. (2021) found that children's performance in mental transformation tasks was positively associated with their knowledge of postpositions which are *left*, *right*, *on, in and above*. In the Turkish language, postpositions are used instead of prepositional ones.

That is, object name is presented first followed by the locative term. Turan et al. (2021) found that the postpositions *left,* and *right* were the least frequently produced and correctly comprehended vocabulary for preschoolers.

Preschoolers understand concrete action words more quickly than abstract directional terms, such as *left* and *right*. This means they are better at grasping specific movements rather than more complex ideas about direction. Additionally, when children use hand gestures and body movements to show how they want the robot to move, it highlights how their learning is connected to physical actions. Weisberg and Newcombe (2017) concluded that gestures are nonverbal representational movements, typically involving the hands and often accompanying with speech. The reliance on hand gestures and body movements to illustrate the robot's potential movements further emphasizes the embodied nature of their learning, as children physically enact the movements they are trying to program (Palmér, 2017). The findings that analyze embodied interactions, whether with or without technology, necessitates an approach that considers the complementary nature of different human interaction modes to fully grasp the meanings behind those interactions (Kopcha et al., 2020).

As highlighted by Papert (1980), educational robotics facilitates the exploration of shapes and allows students to externalize their ideas, making abstract mathematical concepts more tangible and accessible. In this study, pre-school children used shape words to explain their drawings during the robotic activities with the drawing robot. Their descriptions of shapes began to incorporate more complex terms, such as *straight*, *reverse*, *diagonal*, *trapezoid*, *and hexagon*.

Casasola et al. (2020) underlined that different spatial labels can enhance children's comprehension of spatial concepts, including geometric shapes, object arrangement, spatial properties, directions, and locations. McGee (1979) pointed out that spatial visualization is fundamental to success in various cognitive tasks, including mathematics, geometry, and algebra. As the children engaged with the drawing robot, they not only articulated their understanding of shapes but also began to consider these shapes in terms of their construction and the processes required to create them. For instance, preschool children who participated in the 11-week robotic coding program in the current study engaged with the concepts of sides, corners, and angles through the robot's movements, allowing them to recognize patterns necessary for drawing geometric shapes.

As preschool children interacted with the drawing robot, they utilized these spatial terms, demonstrating an increased familiarity with shape words. This aligns with research study by Clements and Battista (1989), which found that within the Logo-learning environment, kids gained a clearer comprehension of the components that constitute shapes (Clements & Battista, 1989). In the present study, young children used a variety of shape words, such as *square*, *rectangle*, *reverse triangle*, and *hexagon*, suggests that these activities can be a powerful tool for expanding spatial vocabulary related to shape words.

Overall, 11-week robotic curriculum enables young children to use spatial vocabulary illustrating the potential of robotic activities to enhance young children's spatial language skills. Meneghetti et al. (2020) found that preschoolers were able to effectively learn and recall environmental information in spatial recall tasks, suggesting that they can successfully form mental representations of the environments described to them. This aligns with the principles of embodied learning, which posits that knowledge is constructed through physical interactions with the environment (Gibbs, 2006; Wilson, 2002).

This qualitative study highlights the role of a well-designed robotic curriculum on the development of young children’s spatial skills through embodied interaction with programmable toys. The 11-week curriculum was intentionally structured to support hands-on exploration, spatial skills, and the use of spatial vocabulary by engaging children in both unplugged and plugged-in activities. Grounded in the principles of embodied learning, the curriculum allowed children to visualize, plan, and enact the robot’s movements using gestures, spatial vocabulary, and concrete problem-solving strategies. As research in embodied learning suggests, such physical engagement bridges abstract cognitive processes with real-world action (Goldin-Meadow, 2003; Kwon et al., 2022). Throughout the curriculum, children used gestures to measure distance, planned efficient routes, and debugged programs using spatial skills, demonstrating that educational robotics can guide the development of spatial skills in early childhood.

CHAPTER 6

CONCLUSION

This qualitative research study explores young children's spatial skills when they interact with programmable toys in the context educational robotics. The existing literature (e.g. Khine, 2017; Newcombe, 2017) shows spatial skill is not fixed; it can be enhanced through engaging and interactive experiences. Previous studies also emphasize the potential of educational robotics to foster cognitive development across domains, including visuospatial, computational, and mathematical skills (Diago et al., 2021; Misirli et al. 2019). Aligning with the existing literature, the current research study suggests that educational robotics in early childhood settings help children improve their spatial skills and spatial vocabulary.

Within the scope of the study, 5- and 6-year-old children were involved in 11-week robotic curriculum, which encourage them to use spatial skills in the robotic tasks. According to Shumway et al. (2023), combining programming with spatial concepts that were also related to mathematical concepts, such as a unit of measurement and geometry in early education, improved preschool children's spatial skills. Spatial skill is important for learning how to program robotic toys and impacts various aspects of the programming process (Francis et al., 2016; Palmér, 2017). Furthermore, participants showed an ability to engage in spatial skills in both the pre-programming and programming stages. They evolved their spatial skills during the planning phase of their programming tasks, designing tangible materials and employing various strategies and gestures to navigate challenging spatial problems.

The study also highlighted the use of spatial vocabulary development as children interacted with educational robots. Throughout the robotic activities, participants used a variety of spatial vocabulary, which was limited in the beginning, and they gradually use more sophisticated spatial vocabulary to communicate about spatial concepts in the robotic tasks. This aligns with previous studies showing that targeted interventions and repeated exposure to spatial language can enhance vocabulary development, and children with richer spatial language demonstrate better spatial reasoning (Casasola et al., 2020; Pruden et al., 2020; Turan et al., 2020). Moreover, gestures help children organize thoughts, solve problems, and communicate spatial information (Alibali et al., 2000; Ehrlich et al., 2006; Goldin-Meadow, 2015).

Furthermore, Brainin et al. (2022) revealed the need for a longitudinal study to understand the long-term effects of educational robots on the spatial skills of young children. Therefore, the current qualitative research contributes to educational robotics in early childhood education, offering new perspectives on how robotics can improve preschool children's spatial skills. Additionally, exploring two kinds of educational robots in the context of spatial skills suggests practical guidance for educators in selecting and implementing robotics tools in early childhood classrooms.

Overall, there is a growing need to design robotics curricula that align with the developmental stages of young children and to integrate programming activities into subjects like math, literacy, and science through project-based learning (Bers, 2019; Bers et al., 2019; Otterborn et al., 2019). Studies show that educational robotics and block-based programming languages can effectively teach programming skills to young children, enhancing problem-solving and spatial skills (Di Lieto et al., 2017; Kopcha et al., 2021; Sullivan & Bers, 2016).

6.1 Implications for designing robotic activities for preschool children to engage in spatial skills

The findings of this study have several implications for educators, curriculum designers, and researchers who want to integrate educational robotics into early childhood education. First of all, the current study demonstrates how educators can provide hands-on learning experiences with unplugged and plugged activities to encourage preschool children's spatial skills. It can also be concluded from the findings of the current study that young children were able to communicate about spatial concepts during the unplugged and plugged activities. Furthermore, the findings may provide a guideline to prepare robotic activities within the framework of embodied cognition for curriculum designers. Finally, the qualitative research design of this study may underline the need for multimodal, comparative, and longitudinal studies to understand young children's spatial skills.

According to Kafai and Fields (2018), designing a curriculum that incorporates constructionist principles involves creating an environment where personal projects are encouraged, students can support each other, teachers participate as members of the learning community, and failure is acknowledged as a natural part of the learning process. On the other hand, Bers (2023) concluded that there is a need for research-based robotics curricula that offer a structured scope and sequence while highlighting key concepts that are developmentally appropriate for young children (Bers, 2023). Therefore, a balanced approach combining both plugged (robotics) and unplugged (non-digital) activities is crucial for a more effective robotics instruction.

6.1.1 The role of embodied learning in the context of educational robotics to foster spatial skills

Educational robotics curricula should be designed to incorporate embodied learning principles, emphasizing the connection between physical actions and abstract thinking. By integrating hands-on, interactive activities with educational robots, educators can create a learning environment that fosters spatial skills through embodied experiences (Kwon et al., 2022). In the current study, children used gestures to communicate about spatial information in the robotic tasks. These embodied interactions enabled them to understand abstract concepts such as distance measurement and rotating the robot left and right. This approach aligns with the notion that physical interactions with technology can help children grasp complex spatial and mathematical concepts (Abrahamson & Lindgren, 2014; Meadow & Beilock, 2010). Therefore, activities should be structured to encourage preschoolers to use their bodies and surroundings to support their spatial skills. For instance, tasks that require children to physically navigate a space and then translate those movements into programming commands can enhance children's understanding of spatial relations and coding (Kwon et al., 2022; Papert, 1980). Similarly, preschool children utilized spatial visualization during the pre-programming phase of plugged-in activities, effectively planning robot movements by visualizing their paths in this study.

Furthermore, educators need to emphasize the importance of non-verbal interactions, such as gestures and body movements in the learning process. Various studies examining how individuals use gestures when communicating and tackling problems have shown that our thought processes are rooted in bodily experiences (Abrahamson & Lindgren, 2014). Research indicates that gestures are evidence of the body's involvement in thinking and reasoning (Alibali & Nathan, 2012). By physically moving on a mat and then translating those movements into codes for the robot, students could map their bodily experiences onto the symbolic representations used in programming (Kwon et al., 2022). In the current study, preschool children used their body movements to understand symbolic representations of directions on the robot.

Children use spatial language and gestures to describe robot movements, demonstrating their understanding of spatial concepts like direction, distance, and rotation (Jessica et al., 2021; Palmér, 2017). In this study, preschoolers' spatial vocabulary evolved over the semester as they started to use a variety of spatial terms related to direction, shapes, and patterns. It can be concluded from the current study findings that preschool children acquired various types of spatial vocabulary to explain spatial concepts more clearly due to the intensive use of spatial vocabulary during robotic tasks. Preschool children used more nuanced spatial language in explaining how to program the robot.

Moreover, teachers can create opportunities for children to simulate the robot's actions with their bodies. Research has shown that children who used their bodies to simulate the robot's actions were more successful in programming tasks (Sung et al., 2017). In light of these findings, we suggest that educational robotics activities should be designed to encourage preschoolers to use their bodies and surroundings to support their spatial thinking skills. Overall, educators can create opportunities for preschoolers to develop spatial skills by engaging them in tasks that require them to navigate, plan, and debug robot movements.

6.1.2 The role of multimodal analysis in understanding young children's spatial skills

In this study, Bezemer's (2014) social semiotic framework was used for multimodal analysis to examine children's interactions with technology. This framework provides a robust method for transcribing and analyzing embodied interactions, allowing for a comprehensive understanding of how cognition is expressed through various modalities, including gestures, gaze, and interaction with the unplugged materials and robotic tools (Goodwin, 2007; Streeck et al., 2011). By employing this approach, researchers can gain deeper insights into the cognitive processes underlying children's spatial skills during robotic activities.

The use of video data is crucial for capturing the richness of children's verbal and non-verbal interactions. This method allows researchers to analyze the dynamic interplay between different modes of representation, such as action, visuals, and symbols, as children engage with educational robots (Francis et al., 2015; Kopcha et al., 2020). In this study, multimodal analysis not only allows for a detailed observations of children's interactions with programmable toys but also facilitates a deeper understanding of how they constructed meaning through their embodied experiences.

Moreover, the multimodal analysis highlighted the ways in which children used gestures and non-verbal cues to communicate about their thoughts and intentions while interacting with programmable toys. Francis et al. (2015) highlights the interconnectedness of different modes of representation in the learning process such as action, visuals, and symbols. For instance, researchers can observe how children point to specific areas on the robot or use their bodies to demonstrate spatial concepts, providing valuable insights into their planning strategies and problem-solving approaches.

Meadow and Beilock (2010) concluded that actions representing ideas through gestures significantly affect thinking processes, as opposed to actions with direct physical consequences. Therefore, it is essential to study learners' interactions with technology and the significance of these interactions, highlighting the complementarity of various human interaction modes (Kopcha et al., 2020). The current study suggests that future studies should prioritize multimodal analysis to document and interpret the complexities of children's embodied interactions.

6.2 Transferability of the findings

The study involved a small, homogeneous group of six children from the same classroom, with similar socio-economic backgrounds and family education levels. This demographic similarity may enhance the transferability of the findings to other preschool settings with children with similar socio-economic and educational contexts. Educators in similar environments may find the insights relevant when implementing educational robotics. Furthermore, the study was conducted in a specialized early childhood education unit that integrated craft materials and educational robots. This context may be replicated in other early childhood settings that aim to incorporate hands-on learning and technology. The findings could be applicable to other classrooms that explore similar educational robotics curricula.

Additionally, the 11-week curriculum, which included both unplugged and plugged activities, provides a structured approach that can be adapted to other preschool programs. Educators in the search of a robotics curriculum can draw on the activities and methodologies used in this study, particularly the combination of different types of robots (Bee-bot and Bubble-bot) and the focus on spatial skills. That is, children engaged in both plugged and unplugged activities, using educational robots like Bee-Bot and Bubble-Bot to learn spatial concepts in this study. And, the findings emphasize the importance of hands-on and embodied learning experiences to foster spatial skills in young children, which might be a valuable insight for early childhood educators and researchers.

The involvement of a classroom teacher specialized in educational technology suggests that the effectiveness of the curriculum may be influenced by the teacher's experience. This is an important facet of the current study that may affect its transferability extensively. Other educators with similar expertise may find the results applicable, while those with less experience may need to consider additional training or support to achieve similar outcomes.

The use of multimodal analysis techniques to observe children's interactions and gestures provides a robust framework for understanding how children engage with educational robotics. This methodological approach can be adapted by other researchers or educators interested in studying children's interactions with technology in various contexts. On the other hand, participants of the current study had limited prior experience in educational robotics in the early childhood education unit. The findings could inform strategies for introducing educational robotics to children who are unfamiliar with such technologies.

6.3 Limitations of the study

The study primarily concentrated on young children’s verbal dialogues and physical interactions with programmable toys as indicators of spatial skills. While these aspects are important, they represent only a subset of the broader domain of spatial skills. Other critical components, such as spatial perception, mental rotation, and spatial visualization, are not directly observed through standardized measures. Future research should incorporate a wider range of spatial assessments to provide a more holistic understanding of how educational robotics influences various aspects of children's spatial skills. Furthermore, future research could benefit from a mixed-method approach that combines the quantitative assessments to triangulate findings and enhance the robustness of the conclusions drawn.

The study acknowledged the role of teachers in supporting the children's learning. However, it did not specifically examine the nature and extent of teacher interaction and its potential influence on the young children's spatial skills. Teacher facilitation strategies can impact the effectiveness of robotic activities in promoting spatial skills, including how teachers scaffold learning, provide feedback, and encourage children's engagement. Future research should explore the dynamics of teacher-student interactions in the context of educational robotics, exploring how different facilitation strategies impact children's spatial skill development and overall learning outcomes, too.

The study utilized two types of educational robots (e.g., Bee-Bot and Bubble-Bot). These robots' specific features and functionalities may have influenced the children's interactions and spatial skill development. For instance, the design, programming complexity, and interactivity of different robots can lead to varying levels of engagement and learning outcomes. Future research should explore the use of a broader range of robots with diverse functionalities to gain deeper insights into the relationship between robot characteristics and spatial skills.

APPENDIX A

ETHICS COMMITTEE APPROVAL

T.C.
BOĞAZİÇİ ÜNİVERSİTESİ REKTÖRLÜĞÜ
Sosyal ve Beşeri Bilimler İnsan Araştırmaları Etik Kurulu (Sbinarek)

Sayı : E-84391427-050.01.04-154601 21.11.2023
Konu : 2023-09T Kayıt Numaralı Başvurunuz Hakkında

Sayın Dr. Öğr. Üyesi Duygu UMUTLU

Tez danışmanlığını yürüttüğünüz öğrenciniz Simge Çiçek'in "The Role of Educational Robotics on Preschool Children's Spatial Skills" başlıklı projesi ile Boğaziçi Üniversitesi Sosyal ve Beşeri Bilimler İnsan Araştırmaları Etik Kurulu (SBİNAREK)'e yaptığınız 2023-09T kayıt numaralı başvurunuz 20.11.2023 tarih ve 2023/09 sayılı kurul toplantısında incelenmiş ve projenize etik onay verilmesi uygun bulunmuştur.

Bu karar tüm üyelerin toplantıya on-line olarak katılımıyla ve oybirliği ile alınmıştır. Onay mektubu tüm üyeler adına Komisyon Başkanı tarafından e-imzalanmıştır. Bilgilerinizi rica ederiz.

Saygılarımızla,

Dr. Öğr. Üyesi Işıl Erduyan
Kurul Başkanı

Bu belge, güvenli elektronik imza ile imzalanmıştır.

Belge Doğrulama Kodu : 0IGL-L5D8-0IO5 Belge Doğrulama Adresi : https://www.turkiye.gov.tr/bogazici-universitesi-ebys

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e-Posta: İnternet Adresi: https://www.bogazici.edu.tr/
Kep Adresi: bogaziciuniversitesi@hs01.kep.tr Telefon No:

APPENDIX B

FAMILY CONSENT FORM

KATILIMCI BİLGİ ve ONAM FORMU
Araştırmayı destekleyen kurum: Boğaziçi Üniversitesi
Araştırmanın adı: Eğitsel Robotik Kodlama Bağlamında Okul Öncesi Çocukların Uzamsal Becerilerinin İncelenmesi
Proje Yürütücüsü: Dr. Öğretim Üyesi Duygu Umutlu
E-mail adresi:
Telefonu:
Araştırmacının adı: Simge Çiçek
E-mail adresi:
Telefonu:

Sayın veli,
Boğaziçi Üniversitesi Eğitim Teknolojisi programından Dr. Öğr. Üyesi Duygu Umutlu, yüksek lisans öğrencisi Simge Çiçek'in tez çalışması kapsamında "Eğitsel Robotik Kodlama Bağlamında Okul Öncesi Çocukların Uzamsal Becerilerinin İncelenmesi" adı altında bilimsel bir araştırma projesi yürütmektedir. Bu çalışma okul öncesi dönemdeki çocukların kodlama eğitimi sırasında uzamsal becerilerini nasıl kullandıklarını incelemek
amacıyla yapılmaktadır. Bu araştırmada bize yardımcı olmanız için siz velilerden onay almak istiyoruz. Kararınızdan önce araştırma hakkında sizi bilgilendirmek istiyoruz. Aşağıdaki bilgileri okuduktan sonra araştırmaya katılmak isterseniz lütfen bu formu imzalayıp araştırmacıya ulaştırınız.

Bu araştırmayı onayladığınız takdirde araştırmaya katılan çocuğunuz 10 haftalık bir kodlama eğitimi alacaktır. Bu 10 haftalık eğitim esnasında araştırmaya katılan çocukların davranışlarını gözlemlenip (çocukların yüzleri görünmeyecek şekilde) video kaydı alınacaktır. Ortalama 30 dakika sürecek olan bu faaliyetler oyun niteliğinde olup B.Ü. yuvadaki sessiz bir odada yapılacaktır. Katılımcı çocuklara bu çalışmaya/eğitime katıldıklarını belgeleyen bir sertifika verilecektir. Bu araştırma bilimsel bir amaçla yapılmaktadır ve katılımcı bilgilerinin gizliliği esas tutulmaktadır. Video kayıtlarında çocukların ismi yerine bir numara kullanılacaktır. Video kayıtları araştırma projemiz süresince parola korumalı bilgisayar dosyalarında muhafaza edilip araştırma sona erdiğinde tamamen silineceklerdir. Bu araştırmaya katılmak tamamen isteğe bağlıdır. Katıldığınız takdirde çalışmanın herhangi bir aşamasında herhangi bir sebep göstermeden onayınızı çekme
hakkına da sahipsiniz. Bu araştırmada farklı yuvaları veya farklı sınıfları karşılaştırmadığımızı vurgulamak istiyoruz. Araştırma projesi hakkında ek bilgi almak istediğiniz takdirde lütfen Boğaziçi Üniversitesi Eğitim Teknolojileri Bölümü Öğretim Üyesi Duygu Umutlu ile temasa geçiniz. Araştırmayla ilgili haklarınız

konusunda Boğaziçi Üniversitesi Sosyal ve Beşeri Bilimler İnsan Araştırmaları Etik Kurulu'na (SBİNAREK) (sbinarek@boun.edu.tr) danışabilirsiniz.

Eğer çocuğunuzun bu araştırma projesine katılmasını kabul ediyorsanız, lütfen bu formu imzalayıp kapalı bir zarf içerisinde araştırmacıya teslim ediniz.

Ben, (Velinin adı) ...., yukarıdaki metni okudum ve çocuğumun katılması istenen çalışmanın kapsamını ve amacını, gönüllü olarak üzerime düşen sorumlulukları tamamen anladım. Çalışma hakkında soru sorma imkanı buldum. Bu çalışmayı çocuğumun istediği zaman ve herhangi bir neden belirtmek zorunda kalmadan bırakabileceğini ve bıraktığı takdirde herhangi bir ters tutum ile karşılaşmayacağını anladım. Bu koşullarda söz konusu araştırmaya çocuğum kendi isteği ile, hiçbir baskı ve zorlama olmaksızın katılmayı kabul etmektedir.

Formun bir örneğini aldım / almak istemiyorum (bu durumda araştırmacı bu kopyayı saklar).

VİDEO VEYA SES KAYDI ALINACAKSA:
☐ Ses kaydı alınmasını kabul ediyorum.
☐ Video kaydı alınmasını kabul ediyorum.

Katılımcının VELİSİNİN Adı-Soyadı:..
İmzası:..
Tarih (gün/ay/yıl):...../......./.............

Araştırmacının Adı-Soyadı: Simge Çiçek
İmzası:
Tarih (gün/ay/yıl):...../......./.............

APPENDIX C

CHILDREN CONSENT FORM

ÇOCUK ONAM FORMU

Merhaba çocuklar, bugün size okulda yapacağım bir etkinlikten bahsetmek istiyorum. Bir süreliğine sizinle eğlenceli oyunlar oynayacağız. Bu oyunlar, sizin daha önce kodlama derslerinde gördüğünüz oyunlara ve etkinliklere benzeyecek. Bazen robotları kullanarak bazen de herhangi bir teknolojik alet kullanmadan oyunlarımıza ve etkinliklerimize devam edeceğiz. Beraber yapacağımız bu etkinlikler 10 hafta sürecek. Her hafta bir kez hazırladığım bu oyunları oynayacağız. Etkinliklerimiz okulumuzun ana binasındaki teknoloji sınıfında olacaktır. Sınıfımızın belirli yerlerinde kameralar olacaktır. Buradaki amacımız yaptığımız etkinliklerin sizin öğrenmenize yardımcı olup olmadığını incelemektir. Oyunlarımızı oynarken yüzlerimiz videoya kaydedilmeyecek. En iyi kısmı şu ki, beraber hem çok güzel zaman geçireceğiz hem de yeni şeyler öğreneceğiz. Beraber bu oyunları oynamayı bitirdiğimizde sizlere bir sertifika vereceğiz. Ancak herhangi bir sebep olmadan herhangi bir zamanda bu oyunlara katılmayı bırakabilirsiniz. Eğer bu etkinliklere katılmak istersen aşağıdaki mutlu yüzü boyayabilirsin. Katılmak istemezsen de üzgün yüzü boyayarak ne hissettiğini bana söyleyebilirsin.

APPENDIX D

WEEKLY ROBOTIC CURRICULUM

Timeline	Type of the activity	Description
Week 1	Unplugged	My Robotic Friend: Children worked in pairs, taking turns being the "programmer" and the "friend." The programmer gave detailed, step-by-step instructions for a task, building a block tower while the friend acts as a robot and follows the instructions exactly.
Week 2	Unplugged	The Floor is Lava: Children worked in pairs, places red cards as lavas. One child placed red card for his or her friend. The other friend tried to walk without touching red cars.
Week 3	Unplugged	Create Your Dance Steps: Children used picture cards to represent different body percussion movements. They then cut and arranged these picture cards within a grid to design their own original three-beat rhythm. After creating their rhythms, each child got a chance to perform their unique body percussion sequence for the group during a "Showcase."
Week 4	Unplugged	Origami Plane: The main mission is to create a paper origami to follow steps in the origami plane sheet. After that, children flied it and test their origami planes in the class.
Week 5	Unplugged	Follow Leader: The activity began with a "Red Light, Green Light" warm-up to familiarize children with following instructions. Then, in "Follow the Leader," the teacher became the leader, giving "if...then..." instructions, such as "If I raise one hand, then you raise one hand."
Week 6	Plugged	Meeting with Bee-bot: The session began by discussing respect for tools, particularly the BeeBot robot. Next, they learned about traffic signs (stop and go) and practiced directional movements using their bodies and direction cards. Finally, children explored the BeeBot freely, discussed its controls, and then individually programed the BeeBot to follow a chosen path on the floor.

Week 7	Plugged	Drawing with Bee-Bot: Children stick a crayon on Bee-Bot and created drawings. They developed their creations with brushes, additional paint, markers, or crayons.
Week 8	Plugged	Travelling Campus with Bee-Bot: The activity started by exploring a child-friendly map of the South Campus, discussed its buildings and how to navigate within it. Children then planned their own Bee-Bot campus tour and draw it in the craft paper. Then, they chose a destination within the South Campus and planned the BeeBot's route to get there. Each child acted as a tour guide, showcasing their planning and navigation skills as they led their Bee-Bot on the chosen path.
Week 9	Plugged	Lego Maze: Children began by brainstorming how to build a maze with blocks and then planned their maze route by discussing with their friends. They worked in pairs, then built their mazes using blocks. Once the mazes were constructed, each group programed their Bee-Bot to navigate through the maze they created.
Week 10	Plugged	Meeting with Bubble-Bot: Children were introduced to Bubble-Bot, discussed its physical features and comparing it to BeeBot. They then explored shape cards using magnifying glasses. Finally, they experimented with Bubble-Bot, pressing buttons to create drawings and exploring its free-movement mode, activated by clapping or breathing, to familiarize themselves with its controls.
Week 11	Plugged	Bubble-Bot Adventures: Children participated in a coding challenge, worked in groups to use coding cards to create unique drawings with Bubble-Bot.

APPENDIX E

ROBOTIC ACTIVITIES

Unplugged Lesson 1: My Robotic Friend

Targeted Spatial Skills	• Spatial Visualization • Directional Language
Children will be able to…	• develop their spatial visualization skills by giving instructions in the correct sequence. • practice their spatial vocabulary especially by using direction words.
Teacher Preparation	• Read lesson plan.

Warm Up

- Simon Says Game *(Suggested Time: 10 minutes)*
    - Start by gathering the children in a circle and explaining the concept of the activity.
    - Let them know they will be programming a friend to complete specific tasks using clear and specific instructions.
    - Play the game of "Simon Says." This will reinforce the idea of following instructions accurately. You can say, "Simon says touch your nose," and observe how they respond.

Main Activity

- My Robotic Friend *(Suggested Time-15 minutes)*
    - Pair up the children, designating one as the "programmer" and the other as the "friend" who will follow instructions.
    - Provide a set of tasks or destinations within the classroom or play area, such as going to a specific corner, arranging objects, or building a structure with building blocks.
    - the programmer's task is to give step-by-step instructions to their friend, being as clear and specific as possible.
        - For example, if the task is to build a tower with blocks, the programmer will say, "Pick up a red block, place it on the blue block, and then add a yellow block on top."
    - the friend must follow the instructions exactly as they are given. If the instructions are not specific enough, they can ask for clarification.
        - For example, if the programmer says, "Put it there," the robotic friend can ask, "Where do you mean by 'there'?"

- o Change roles after each task so that both children get a chance to be the programmer and the robotic friend.

Notes: While they complete tasks, observe and provide feedback on the clarity and specificity of the instructions. Encourage the children to improve their communication skills as they progress.

Closing Tech Circle

- Share and Discuss *(Suggested Time: 5 minutes)*
    - Children sit in a circle, and one child whispers a simple instruction to the child next to them, who then whispers it to the next child, and so on. The last one is that the teacher must follow the instruction exactly as it was received and then share what they did. This mini game summarizes the importance of clear instructions for reaching the goal.

Unplugged Lesson 2: The Floor is Lava!

Targeted Spatial Skills	• Mental Transformation • Spatial Visualization
Children will be able to…	• identify errors if they cannot find the right path to reach the finish line without touching lava tiles. • use spatial visualization skills to find different ways to finish the task. • use mental transformation skills to find similarities among their lava placement in the 3x3 grid.
Teacher Preparation	• Read lesson plan. • Make a 3x3 grid on the floor. • Color a few squares red that represent lava. • Print direction cards (forward, backward, left, right, stop, and go).

Warm Up

- The Floor is Lava Game (Suggested Time: 10 minutes)
    - o Begin with playing the "The Floor is Lava" game at the beginning of the lesson.
    - o Discuss the ways of escaping lava on the floor with children.

Main Activity

- Do not Touch Lava! *(Suggested Time: 15 minutes)*
    - o Children need to program their route by using direction cards before playing.
        - How do you reach the finish line without touching lava tiles?
        - Can you plan your route?

- For example, “You need to go two steps forward and turn left. You can get help with direction cards. Can you show me which card shows forward or left?”
  - If children cannot reach the finish line without touching lava tiles, they restart to program their route. They demonstrate their debugging skills during this process.

Closing Tech Circle

- Share and Discuss
  - Encourage children to express the challenges they face and how they overcome them during the “The Floor is Lava” game.
  - Which strategies do they use when they cannot reach the finish line?

Unplugged Lesson 3: Create Your Dance Steps!

Targeted Spatial Skills	• Spatial awareness • Spatial visualization
Children will be able to…	• identify a spatial pattern (first, second, third, etc.) by arranging picture cards in a specific order to create rhythm patterns. • demonstrate awareness of directional concepts through body movements. • create simple rhytmic patterns using body movements and picture cards.
Teacher Preparation	• Read lesson plan. • Print Cards and Three Beats Frame worksheet.

Warm Up

- Rhythm Exercise *(Suggested Time: 10 minutes)*
  - o Create a rhythm exercise that includes different steps.
  - o Arrange various colored items on the table.
  - o Children count the number of colors on the table and tap their rhythm sticks accordingly to match the count.
  - o Encourage children to think about the pattern we repeat during rhythm exercise.

Main Activity

- Create Your Own Rhythm! *(Suggested Time: 15 minutes)*
  - o Using pictures and the grid cards, the children can create rhythms using body percussion.
  - o Children can decide on body percussion movements from picture cards.
  - o They create their own original rhythm movements by cutting picture cards and posting in three-beat frame worksheets.
- Showcase *(Suggested Time: 10 minutes)*
  - o After creating rhythm, each child demonstrates his or her body percussion movements.

Closing Tech Circle

- Share and Discuss *(Suggested Time: 5 minutes)*
  - o Encourage children to think about the patterns they repeated during the exercise.
    - "What did you discover about rhythm patterns?"
    - "How did you use the picture cards to create your rhythms?"

Unplugged Lesson 4: Origami Plane

Targeted Spatial Skills	• Spatial Visualization • Directional Understanding
Children will be able to…	• demonstrate directional understanding by folding specific orientations such as corner to corner. • plan a multi-step task by by breaking down the origami-making process into smaller, manageable steps.
Teacher Preparation	• Read lesson plan. • Print one set of origami instruction sheets.

Warm Up

- What is Origami? *(Suggested Time: 10 minutes)*
    - The teacher brings an example of origami and examines it together during circle time.
    - The teacher asks the children to share what they taught about origami.
    - The teacher brings a question for the whole class. How is origami done? All of them brainstormed the ways of origami with a paper.

Main Activity

- Planning *(Suggested Time: 20 minutes)*
    - The teacher supports with questions encouraging children to use cognitive strategies they will need to make the origami house.
    - Creating a good plan will help them tackle a challenging task. Children follow their steps in the origami plane sheet in Appendix A. Ask questions like;
        - What materials do we need to make the origami plane? Let's take a look together."
        - Begin by taking a square-colored origami paper.
        - "While making the origami plane, there are steps we need to follow. Let's review which paths we should take."
        - "We've examined the steps. Now, it's time to decide where to start. Which step should we begin with first?"

Closing Tech Circle

- Flying Our Paper Planes *(Suggested Time: 5 minutes)*
    - All the children bring their origami planes and review the steps they follow during construction.
    - Finally, all planes will fly in the classroom.

Unplugged Lesson 5: Follow the Leader!

Targeted Spatial Skills	• Spatial Orientation • Spatial Visualization
Children will be able to…	• use conditionals instructions using spatial language. • put actions or responses in an order or sequence.
Teacher Preparation	• Read lesson plan. • Organize music: *Red Light, Green Light*

Warm Up

- Red Light, Green Light *(Suggested Time: 15 minutes)*
  - Begin by letting children know you will play a game called *Red Light, Green Light*.
  - If there is enough space, have children line up at the start line and design a finish line in the room.
  - Explain that when you say "green light," they should start walking toward the "finish line," and when you say "red light," they should stop walking.
  - Repeat the instructions several times in a row.

Main Activity

- Follow the Leader! *(Suggested Time: 15 minutes)*
  - The teacher starts as the leader and gives various instructions to the children, using the "if... then..." structure.
  - The teacher delivers instructions slowly and clearly to help children understand and follow them. Instructions are as follows:
    - If I raise one hand, then you raise one hand.
    - If I ring the bell twice, then you jump twice.
    - If I sit on the ground, you clap your hands twice.
    - If I turn right, then you turn left.

Closing Tech Circle

- Share and Discuss *(Suggested Time: 5 minutes)*
  - Discuss the game "*Red Light Green Light.*"
  - In the game, children need to pay attention to what the teacher says. Depending on whether the teacher says, "red light" or "green light," we need to take different actions.

Plugged Lesson 1: Meeting the BeeBot!

Targeted Spatial Skills	• Spatial Visualization • Spatial Language
Children will be able to…	• plan paths for robots through spatial visualization. • use clear spatial vocabulary to describe movements and directions.
Teacher Preparation	• Read lesson plan. • Print traffic signs.

Warm Up

- Respecting Our Tools (Suggested Time: 10 minutes)
    - o Begin by discussing with the children the importance of following rules to show respect, not only to each other but also to the tools they use.
    - o Explain what respect means, and how taking care of their tools is a way to demonstrate respect.
    - o Let them know that the main tool for this class is a robot called BeeBot.
    - o Demonstrate specific behaviors and allow the children to give a "thumbs up" for good BeeBot behavior and a "thumbs down" for bad BeeBot behavior:
        - Thumbs Down: Holding BeeBot while jumping up and down or running.
        - Thumbs Up: Placing BeeBot down and then walking away.
        - Thumbs Down: Holding BeeBot with just one hand.
        - Thumbs Down: Balancing BeeBot on your head.
        - Thumbs Up: Working with BeeBot on your lap or on a table.

- Stop and Go *(Suggested Time: 5 minutes)*
    - o Show a Picture of Traffic Signs.
        - Ask children if they know what each sign means.
        - The first sign means STOP.
        - Second sign means GO.
- Direction Cards
    - o Show direction cards (forward, backward, right, left)
    - o Children practice directions by using their bodies at first.

Main Activity

- Programming the BeeBot *(Suggested Time: 15 minutes)*
    - o Children explore the BeeBot on the floor.
    - o The teacher should let them discuss directions on the BeeBot.
    - o Each child individually explores the BeeBot in their free time.
    - o After exploration, they decide on a path on the floor and program the BeeBot.

Closing Tech Circle

Clean-Up Song *(Suggested Time: 5 minutes)*

- o Introduce the BeeBot clean-up song and talk about where children will store their BeeBot's after class.
- o After finishing the activity, we need to store our robots so, we also need to also such a clean-up routine.

Plugged Lesson 2: Drawing with BeeBot

Targeted Spatial Skills	• Spatial Visualization • Visual Repsentation • Spatial Language
Children will be able to…	• use directional vocabulary to control Bee-Bots movements. • predict Bee-Bot's movements and adjusting paths accordingly. • create drawings with Bee-bot.
Teacher Preparation	• Read the lesson plan. • Prepare BeeBot • Arrange materials: crayons, craft paper, etc. • The teacher places the paints, brushes, and blank sheets of paper near the BeeBot mat. • Each child should have their own set of paints and brushes.

Warm Up

- *Hello for BeeBot (Suggested Time: 10 minutes)*
  - o The teacher explains to the children that they will be using Bee-Bot to create a painting.
  - o The teacher shows them how Bee-Bot works by demonstrating how to program it using the directional buttons (forward, backward, left, right).

Main Activity

- Programming Bee-Bot with direction cards *(Suggested Time:15 minutes)*
  - o Each child takes a turn programming Bee-Bot to follow the path or pattern.
  - o They can decide how far Bee-Bot should move and in which direction (forward, backward, left, or right).
  - o The teacher encourages them to experiment with different sequences to see how they affect their painting.

- Painting with Bee-Bot *(Suggested Time: 15 minutes)*
  - o Once Bee-Bot follows the programmed path, it will leave a trail of paint on the mat or paper.
  - o The children can use this trail as a starting point for their artwork.
  - o They can use brushes and additional paint to fill in the rest of the design.

· Creativity Time *(Suggested Time: 10 minutes)*
  - o The teacher allows the children to get creative with their paintings.
  - o They can add details, mix colors, and use markers or crayons to enhance their artwork further.

Closing Tech Circle

- Share and Discuss *(Suggested Time: 5 minutes)*

- After the paintings are complete, have a group discussion.
    - The teacher asks the children to describe their paintings, talk about the patterns they created with Bee-Bot, and share their favorite parts of the activity.

Plugged Lesson 3: Traveling Campus with the BeeBot!

Targeted Spatial Skills	• Spatial Visualization • Spatial Orientation
Children will be able to…	• develop step-by-step instructions for guiding their BeeBot along specific paths. • convert the real-world South Campus into a simplified map by focusing on the most relevant information. • show how places on the map and in physical space are connected through spatial orientation.
Teacher Preparation	• Read lesson plan. • Print the South Campus Map. • Prepare BeeBot (controlling their charge and technical problems etc.)

Warm Up

- Map of Our Campus! *(Suggested Time: 10 minutes)*
    - Bring a map of the South Campus that is designed specifically for children.
    - Talk about which buildings and places are on the South Campus.
    - Discuss how we can go somewhere in the South Campus.
    - Make a simple route with crayons on the map to see the path.

Main Activity

- Create Your Own Path with BeeBot! *(Suggested Time: 15 minutes)*
    - Take BeeBot for the Campus tour. So, we are tour guides that show each building and place on the South Campus.
    - Each child decides on a place that they want to take his or her BeeBot for the Campus Tour.
    - Each child plans for the path and displays his or her skills as a tour guide.

Closing Tech Circle

- Share and Discuss *(Suggested Time: 5 minutes)*
    - Encourage each child to describe the path they planned and the landmarks or places they visited with the BeeBot.
        - "Did you encounter any challenges or unexpected obstacles while guiding BeeBot on your chosen path?"

Plugged Lesson 4: Lego Maze

Targeted Spatial Skills	• Spatial Visualization • Spatial Orientation • Spatial Language
Children will be able to…	• create patterns with blocks. • translate the physical maze into a coded program that requires abstraction. • develop their spatial skills by planning and creating a maze with blocks.
Teacher Preparation	• Read lesson plan. • Prepare blocks, BeeBot, and instruction cards for the activity.

Warm Up

- Let's Plan the Route! *(Suggested Time: 15 minutes)*
    - The teacher brings every child into the opening circle and asks the question: "How to create a maze with blocks?"
    - Plan for the route on the big paper. Children need to create a route by drawing at first.
    - Children will be grouped as two persons.

Main Activity

- Let's Build the Maze for the BeeBot *(Suggested Time: 20 minutes)*
    - After planning the route, children start to create a maze with blocks as group work.
    - When they finish the route, they begin to code their BeeBot to finish the maze that they created.
    - Evert group creates their route and codes their BeeBot's to finish the maze.

Closing Tech Circle

- Share and Discuss *(Suggested Time: 5 minutes)*
    - Each group takes turns presenting their planned route to the class.
    - They can use the big paper where they drew their route to explain their design choices.

Plugged Lesson 5: Meeting the BubbleBot!

Targeted Spatial Skills	• Shape Recognition • Spatial Visualization • Spatial Language
Children will be able to…	• identify patterns in shapes and drawings created with BubbleBot. • develop sequential steps and basic algorithms to create drawings. • differentiate between basic shapes such as square, triangle, trapezoid, rectangle, star, and heart.
Teacher Preparation	• Read lesson plan. • Prepare BubbleBot (controlling their charge and technical problems, etc.)

Warm Up

- Hello for BubbleBot! *(Suggested Time: 5 minutes)*
  - o Gather the children in a circle and introduce BubbleBot to them.
  - o Prompt the children to observe and discuss the physical features of BubbleBot, including any buttons or unique characteristics.
  - o Facilitate a discussion about how BubbleBot differs from BeeBot, encouraging children to identify distinctive features.

Main Activity

- Create Shapes with Crayons! *(Suggested Time: 15 minutes)*
  - o Explain the purpose of using BubbleBot for drawing different shapes and patterns.
  - o Provide each child with shape cards featuring simple shapes like squares, triangles, trapezoids, rectangles, stars, and hearts.
  - o Let the children explore the shape cards using a redfish magnifying glass, encouraging them to observe details.
  - o After they explore shape cards with a redfish magnifying glass, they will try to draw these cards with crayons themselves without using BubbleBot.

- Drawing exercise with BubbleBot!
  - o Encourage children to explore BubbleBot features by pressing buttons and creating drawings.
  - o BubbleBot have also a free mode to move so, children can try to move the robot with their hands clapping and breathing.
  - o Encourage children to memorize buttons and numbers on the BubbleBot with free drawing and exploration.

Closing Tech Circle • Share and Discuss *(Suggested Time: 5 minutes)* o Encourage children to share their individual experiences with drawing shapes using crayons and the BubbleBot. Ask open-ended questions such as: • "What was your favorite shape to draw?" • "Did you discover any interesting buttons on BubbleBot?" • "How did you feel when you created your drawings?" • "What did you find exciting about using BubbleBot for drawing?" • "Did you try the free mode? How did it feel to move BubbleBot with clapping or breathing?"

Plugged Lesson 6: Bubble-Bot Adventures

Targeted Spatial Skills	• Shape Recognition • Spatial Visualization
Children will be able to…	• recognize geometric shapes through Bubble-Bot movements. • use spatial vocabulary to describe shapes, patterns, directions, and pathways. • give a sequence of commands to Bubble-Bot while drawing shapes.
Teacher Preparation	• Read lesson plan. • Check Bubble-Bot charge and other technical features.

Warm Up • *Let's Explore* o Allow the children to explore the colorful buttons on the Bubble-Bot keypad. o Ask children if you were to give instructions to Bubble-Bot using words, how would you tell it to draw a circle (or any specific shape)? This question encourages children to think about giving verbal instructions, introducing the idea that coding can involve both buttons and language.

- Let them press the buttons freely and observe how the robot responds.
- Encourage them to notice the different colors and shapes on the buttons.
- Demonstrate how to create a simple drawing using Bubble-Bot. Press a few buttons in a sequence and show the children how the robot replicates the drawing on paper.
- Give each child a chance to press the buttons and create their own basic drawings.

Main Activity

- *Coding Challenge*
    - Organize a coding challenge where children can pick coding cards and use them to create unique drawings with Bubble-Bot.
    - Group children before starting to code challenge.
    - Encourage collaboration and sharing of ideas among the preschoolers.

- *Decorate and Share*
    - Provide colored markers, stickers, and other decorating materials.
    - Allow the preschoolers to enhance their drawings and share their creations with each other.

Closing Tech Circle

- *Share and Discuss*
    - How did pressing different buttons on the keypad help Bubble-Bot create drawings? Encourage children to think about the cause-and-effect relationship between the buttons they pressed, and the drawings created by Bubble-Bot.
    - Can you explain how the coding cards guided Bubble-Bot to draw different pictures? Encourage them to think about how sequences of button presses can be considered as a form of coding.

APPENDIX F

TRANSLATED QUOTES

Türkçe (TR)	English (ENG)
Ms. Hill: Çocuklar eğer bir kağıda yıldız resmi çizmek isteseydiniz nasıl çizerdiniz. Uriel: "ben biliyorum ben biliyorum" [Uriel robotu eline aldı ve elini tuşların üzerinde gezdirerek nasıl çizeceğini planladı ve çalıştırdı.] Uriel: yeey yıldız çizcez. Ms. Hill: Uriel çok yaklaştın. Uriel: "sadece şöyle olması gerekiyordu" [Uriel eline kalemi alıp eksik olan kısmı tamamladı.]	Ms. Hill: Children, if you wanted to draw a star on a piece of paper, how would you do it? Uriel: I know, I know. [He took the robot and planned and executed how to draw it by moving his fingers over the button's surface of the robot.] Uriel: Yay, we're going to draw a star! Ms. Hill: Uriel, you were very close. Uriel: It just needed to be like this. [Even though a part of the star was missing, the robot drew almost all of it. He took the pencil and completed the missing part.]
Sophie: böyle yarım daire olacak yanında köprü olacak sonra yarım dairenin etrafında geçip döneceğiz sonra engeller olacak.	Sophie: ee it will be semi-circle with a bridge next to it. Then we will go around the semi-circle and turn and there will be obstacles.
Uriel: biz de böyle. Beni seçti. Ee böyle ee engellerimizi birazcık zorlu yapmak istiyoruz. Labirentimiz büyük olacak. Engellerimizi ya tam çizgi ya yarım çizgi yapıcaz. Böyle kıvrımlı yol, düz yol sonra kareli yollar.	Uriel: We are like this too. They chose me. Well, we want to make our obstacles a bit challenging. Our maze will be large. We will either make our obstacles full lines or half lines. There will be curved paths, and then square paths.
Sophie: sekiz, dokuz, on, on bir, on iki, on üç. Olivia: çapraz gidiyor.. Uriel: zaten döndü o Ms. Hill: acaba neden böyle oldu Sophie? Emily: çünkü fazla yaptı. Bir, iki, üç. Bak şöyle yapması gerek. Bir, iki, üç, dört, beş, altı, yedi, sekiz. Böyle. Sophie: hayır Uriel: çapraz gitti. Emily: nasıl? Uriel: sen çapraz gittin böyle böyle. Olivia: ama robotu böyle tutarsa gerçekten çapraz gider.	Sophie: eight, nine, ten, eleven, twelve, thirteen Olivia: it's going diagonally. Uriel: It already turned. Ms. Hill: I wonder why this happened, Sophie? Emily: Because it did too much. One, two, three. Look, it needs to do it like this. One, two, three, four, five, six, seven, eight. Like this. Sophie: No Uriel: It went diagonally. Emily: How? Uriel: You went diagonally like this, like this.

	Olivia: But if it keeps the robot like this, it will really go diagonally.
Yuma: önce buna basman gerek. [Hangi tuşlara basması gerektiğini robotun üzerinde arkadaşına gösterdi.] Uriel: sonra bir tane. Kare böyle bak. Önce geriden gitmesi lazım. [Hangi tuşlara basması gerektiğini gösterdi.] Uriel: bak önce bak önce şöyle yapması lazım. [Uriel mimikleri ile arkadaşına bu konuda ısrar etti.] Uriel: Bir iki. İki buna bassın. Sonra buna bassın. [Uriel kare yapabilmek için robotun tuşlarına basarak kodladı.] Yuma: bir kere. [Parmağı ile bir işareti yaptı.]	Yuma: First, you need to press this. [He showed which buttons needed to be pressed by indicating to them with his fingers.] Uriel: Then, one more.. No. Look, a square is like that. First, it needs to go backwards. w Uriel: Look, it needs to be done like this. [He insisted with his mimics and gestures.] Uriel: One, two. Press it twice. Then press this. [He coded a square by pressing buttons.] Yuma: One time. [He showed "one" by raising oone finger.]
Ms. Hill: peki şimdi Bee-Bot'un üzerinde neler görüyorsunuz? Uriel: noktalar görüyorum Emily: noktalar Ms. Hill: tamam ne anlama geliyor. Uriel: [eliyle tuşları göstererek] yönlendiriyor. Ms. Hill: nereye yönlendiriyor? Sophie: sağ, sol, düz, arka.	M. Hill: So, what do you see on the Bee-Bot? Uriel: I see dots. Emily: Dots. Ms. Hill: Okay, what do you think these dots mean? Uriel: They direct it. [He showed the buttons with his hands.] Ms. Hill: Where do they direct it? Sophie: Right, left, forward, backward.
Emily: Öğretmenim bak bütün tuşlara sırayla bastık ve böyle bir şey oldu. Mesela bir yamuk olmuş bir tırtıla benziyor.	Teacher, look; we pressed all the buttons in order and this is what happened." S/he continued, "for example, it looks like a trapezoid, like a caterpillar."
Emily: öğretmenim bak altıgen yaptım. Ms. Hill: bakayım. Süpersin. Say bakalım kenarlarını altı tane mi? Emily: bir, iki, üç, dört, beş, altı. Ms. Hill: süpersin ya! Emily: Olivia altıgen yaptım bak.	Emily: Ms. Hill, look, I made a hexagon. Ms. Hill: Let me see. You're great! Can you count the sides, are there six? Emily: One, two, three, four, five, six. Ms. Hill: You're awesome! Emily: Olivia, I made a hexagon, look.

Sophie: … başlayalım. Üçüncü sarı. Sophie: ikinci yeşil Sophie: ikinci mavi Sophie: birinci kırmızı. Beşinci turuncu Sophie: dördüncü turuncu. Üçüncü mavi. Birinci kırmızı. Beşinci turuncu. Dördüncü turuncu Sophie: üçüncü sarı beşinci mavi Sophie: üçüncü yeşil Sophie: öğretmenim çizdik. Olivia: şemsiye çizdik.	Sophie: ...let's start. Third yellow. Sophie: Second green. Sophie: Second blue. Sophie: First red. Fifth orange. Sophie: Fourth orange. Third blue. First red. Fifth orange. Fourth orange. Sophie: Third yellow, fifth blue. Sophie: Third green. Sophie: Teacher, we drew. Olivia: We drew an umbrella.

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