Programming in preschool—with a focus on learning mathematics

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Abstract

This article presents a teaching intervention where programming was used to facilitate preschoolers' learning of mathematics, especially in their development of spatial thinking. In the intervention, the programming was made with a small programmable robot especially designed for young students. The results indicate that the children developed their ability to mentally compare and connect movements in reality with maps and symbols. Further, the children showed ability to mentally envision, hold in mind, and conceptualize actions and relationships between paper maps, gridded maps, and symbols. Thus, the intervention indicates potential in teaching mathematics through programming in preschool.

Keywords

Programming; preschool; early mathematics; computational thinking; intervention; spatial thinking

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Introduction

This article reports on a mathematics teaching intervention carried out over 4 months in two Swedish preschools. Preschool children's ability to engage in mathematical activities and their interest in doing so is no longer a question of whether, but how to organize preschool mathematics (Ginsburg, 2009; Perry & Docket, 2008). The teaching intervention presented here explored the potential in teaching mathematics in preschool through programming. In Sweden, the use of digital technology and programming have been strengthened in the curricula for all grades. This is not only a national Swedish phenomenon but an ongoing trend in several European countries. This trend is based on digital competence being one of the key competencies stressed by the European Community as important in a society of lifelong learning ("Key competences for lifelong learning", 2007). The trend is also visible in the US (National Research Council, 2012), and in many countries around the world, digital technology and programming are implemented formally in curriculums for different grades. The programming in this teaching intervention, however, was not conducted using coding software, but with a small programmable robot specially designed for young children. Though coding software and other digital tools can be used, the development of computational thinking does not depend on the tool used to program, but instead on the content within the programming activity (National Research Council, 2012).

A research overview by Lye and Koh (2014) of studies conducted with children aged 5–14 years shows that it is possible to foster computational thinking through programming. However, the overview also shows a need for further research on programming in naturalistic classrooms settings. Especially there is a lack of studies on programming conducted in everyday preschool practices (Fessakis, Gouli & Mavroudi, 2013). The study presented here is an example of a teaching intervention conducted in a naturalistic classroom setting during everyday preschool practice. There are opinions that research in mathematics education should focus more on *what ought to be* (e,g., interventions of teaching known as successful) than *what already is* (e,g., observations of current practice). In relation to those extremes, this teaching intervention is somewhere in the middle, exploring *what might be* (i.e., an intervention of what might be successful teaching). (Gadanidis, Hughes, Minniti & White, 2017). The children involved are younger than the children in any of the studies reviewed by Lye and Koh (2014). There are however, studies indicating that children as young as 4 years of age can program (Bers, Flannery, Kazakoff, & Sullivan, 2014) and that programming can have a crucial influence on young children's development of cognitive functions (Papadakis, Kalogiannakis, & Zaranis, 2016). A significant challenge though, is to reassess what can be learned by programming at this young age. Not only knowledge about programming for its own sake but also other knowledge that can be learned with programming (Benton, Hoyles, Kalas, & Noss, 2017). In the teaching intervention presented here, the children's development of spatial thinking was a particular focus. Even though children start to develop spatial thinking at a very young age, such development is heavily dependent on relevant experiences, where communication and spatial activities have proven to be influential (Cross, Woods & Schweingruber, 2009; Kersh, Casey, & Mercer Young, 2008). The overall purpose with the study presented here was to investigate *what might be,* when programming is implemented in naturalistic preschool activities with children 3–5 years old. The following research question will be addressed: How does young children's spatial thinking develop through systematic involvement in programming activities?

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Programming and computational thinking

Despite what might be inferred from ongoing reforms in national curriculums throughout Europe and the US, programming is not new in educational settings. In the 1960s, *Logo* programming language was introduced internationally into mathematics teaching and it was still used in primary and secondary school in the 1980s and 1990s. However, during the late 1990s the use of *Logo* faded and was eventually replaced by the *use of* technology rather than its *creation* (Benton et al., 2017). Higginson (2017) divides this history of programming in school into five distinct phases; preparation, development, implementation, retreat, and renaissance. A significant difference between the first implementations in the 1960s and today's renaissance is that the early initiatives were made by small groups of enthusiasts, while today's renaissance is part of a widespread political agenda. However, programming is more than coding, and a similarity between the first implementations and today's renaissance is the relative paucity of research into what other knowledge, for example mathematics, can be learned with programming.

During programming, children are exposed to computational thinking which is not a univocal notion but refers to a broad range of competencies (Bers et al., 2014). Lye and Koh (2014) divide computational thinking into three dimensions: concepts (e.g., testing and debugging), practices (e.g., problem solving), and perspectives (e.g., the relation between the child and a digital world). Similarly Bers et al. (2014) refer to abstraction, decomposition, debugging, remixing, and productive attitudes against failure as included in computational thinking. Further, they mention competencies such as creativity, critical thinking, and problem solving; competencies that are emphasized in a society of lifelong learning ("Key competences for lifelong learning", 2007). Thus, computational thinking includes general competencies that are useful beyond programming, competencies needed by all people in a modern world (Bers et al., 2014; "Key competences for lifelong learning", 2007; Papadakis et al., 2016). According to Papadakis et al. (2016), there is recognition in the academic and scientific society of "coding [being] the new literacy for preschool education" (p. 190). Often, however, computational thinking tends to be viewed as its own objective and not integrated with (and therefore not enriching) other subjects (Gadanidis et al., 2017).

The introduction of programming in the Swedish school system is part of this ongoing emphasis on digital competence and computational thinking with the aim to foster better and future technology producers and to promote lifelong learning. Furthermore, programing is considered to promote creativity and logical thinking since it calls for decomposing tasks into subtasks to be solved separately (National Agency for Education, 2017).

The programmable robot

Research has indicated that it is better to use visual programming with young children as this enables them to focus on the logic and structure rather than on the learning of a programming language (Kelleher & Pausch, 2005). Also, visual programming often makes testing and debugging more manageable (Lye & Koh, 2014; Papadakis et al., 2016). Programmable robots offer interactive representations of mathematical concepts and when using them, children can explore mathematical concepts and relationships in a playful way (Gadanidis et al., 2017). The programming in the teaching intervention was made with a small programmable robot named Bee-Bot.

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Programming with Bee-Bot is done through command buttons on the back of the robot, where up to 40 instructions can be set for a single sequence. The commands available are: moving forward (arrow pointing in the forward direction of the robot), moving backward (arrow pointing in the backward direction of the robot), turning 90 degrees right or left (curved arrows), *GO* (green button activating the sequence of instructions), *PAUSE* (says 'pause' on the button—makes the robot temporarily stop), and *CLEAR* (says 'clear' on the button—erases the memory). When moving forward or backward, the robot crosses a 15 cm distance; when turning, the robot turns on the spot. Each command is followed by a blink of the eyes on the robot, and when a sequence is finished a beep sounds. Together with the robot, it is possible to use different carpets which look like gridded maps with 15 cm squares. In the intervention, two such grid maps were used: one picturing a farm and the other picturing a treasure map. When the robot is to be programmed to move on these gridded maps, counting (the commands), measuring (the distance), and space (where and how to go) become natural elements of the activity; these notions will be further described in the next section. In the intervention, spatial thinking, counting, and symbols were explored verbally and mentally, as well as through gestures and different kinds of maps and programming schemes.

Programming and learning mathematics

Young children develop mathematical knowledge before entering school, and early mathematics has been shown to be important for later mathematical achievement (Cross et al., 2009; Duncan et al., 2007). Besides focusing on programming for its own sake, the widespread inclusion of programming in curricula around the world highlights the question of what is learnable in other subjects through programming (Benton et al., 2017). According to Benton et al. (2017), studies on the impact of programming on children's learning have been inconclusive. This diversity, however, may be based on the simultaneous development of programming milieus as well as on the diversity of research paradigms used in the studies. As mentioned there are no studies with children under the age of 5 years but a study with children aged 5–6 years showed that programming offered learning potential regarding counting, orientation skills, concepts, communication, and collaboration. Furthermore, while programming children develop both problem-solving skills and metacognitive skills (Fessakis et al., 2013).

As mentioned, the present intervention focused on children's development of spatial thinking: where and how the robot was to move on grid maps. Spatial thinking is about mentally comparing, rotating, holding in mind, and conceptualizing relationships and transforming objects (Cross et al., 2009; Kersh, Casey, & Mercer Young, 2008; Sarama & Clements, 2009). These abilities have been shown to be a predictor for further mathematical achievement, not only in specific mathematical domains such as geometry and measurement but also in problem solving (Cross et al., 2009). Programming a robot also requires counting and an understanding of the symbols (arrows) on the robot. In particular, one-to-one correspondence together with the number sequence (Gelman & Gallistel, 1978) are explored when coordinating the number of presses on the commands with the number of grids the robot is to move on the grid map. Not being able to coordinate verbal number words with actions, such as pointing at objects where one and only one number word is assigned to each object, is common among young children (Sarama & Clements, 2009). In a long-term perspective, children can develop their algorithmic problem-solving skills by programming (Fessakis et al., 2013).

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Theoretical foundations

There "has been a turn to social theories in the field of mathematics education" (Lerman, 2000, p. 20), which implies that learning is seen as situated in social activities and visible as changes in an individual's participation in different social activities. In line with this turn, the intervention has a sociocultural approach (Vygotsky, 2012; Wertsch, 1998) that implies that the children in the intervention learn (mathematics) through participating in the joint programming activities. The learning that was the main focus in the study was the development of children's spatial thinking through their systematic involvement in programming activities. In line with the sociocultural approach, such learning can be investigated by observing changes in the children's participation in the joint programming activities. These activities are not conducted in isolation but in a context that (based on the sociocultural approach) is to be understood as what the children are interacting with. In the study, the children interacted with the robot, the researcher, the preschool teachers, and the other preschool children. The robot can be considered as a "manipulative" (an object designed to represent abstract mathematical ideas) or a tool (Nührenbörger & Steinbring, 2008; Lye & Koh, 2014). As no manipulative or tool can do the work on its own, the action of the teacher becomes important in the intervention. In the activities, *guided interaction* was used, meaning teachers taking both a reactive and proactive role (Stephen & Plowman, 2008). The teachers used open questions and tried to get a balance between adult direction and child initiatives in the dialogues, as this has been shown to increase the quality of communication between preschool teachers and children (National Agency for Education, 2010b).

The teaching intervention

The intervention was carried out over 4 months in two Swedish preschools; in this section, the selection of these preschools, the pre- and posttest, as well the design of the intervention, is presented.

Selection of preschools and 'focus children'

The researcher has, for several years, participated in a local network on *mathematics in preschool through digital tools*. The intervention was presented by the researcher during a network meeting in spring 2016, and all participants were invited to take part. The first two preschools that responded positively were selected for the intervention. These two preschools were located in two different Swedish towns. In Swedish preschool care, socialization and learning are to form a coherent whole. Exploration and curiosity are important foundations in the preschool activities, which should promote play, creativity, and enjoyment of learning. Focusing on mathematics, the Swedish preschool should strive to ensure that each child develops their ability to use mathematics to investigate, reflect on, and test different solutions to problems raised by themselves and others; to distinguish, express, examine, and use mathematical concepts and their interrelationships, putting forward and following reasoning; as well as to develop their understanding of, among other things, space, location and direction, and measurement as well as basic number concepts (National Agency for Education, 2010a).

At one of the selected preschools, two preschool teachers became involved in the intervention; at the other preschool, one preschool teacher became involved. At these

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preschools, the participating preschool teachers selected four children from each preschool that became the "focus children" of the intervention. This signifies that even though all children at the two preschools were involved in the activities within the intervention, these eight children were those that met the researcher and that participated in the pre- and posttest. The criterion for the selection of focus children was children who probably not would feel uneasy by working with the researcher (Alderson & Morrow, 2011). The focus children were between 3 and 4.5 years old, five girls and three boys. The children's guardians were given written information about the study and approved their children's participation in line with the ethical guidelines provided by the Swedish Research Council (2011).

Pretest

Before the intervention began, a pretest was conducted with the eight focus children. The aim was to provide a baseline for evaluating the efficacy of the intervention and also, partly, to allow planning of the intervention. First, the children were asked to move in the room in accordance with instructions. For example: "can you move two steps forward and then turn to the left?". Then they were asked to describe similar movements made by the researcher. After this, they were asked to describe the actions of three plastic toy bears and to move these toy bears on a gridded map accordingly to instructions. Thus, the understanding of directional notions (forward, backward, turn, left, right), the ability to coordinate verbal number words with actions, as well as spatial thinking, were elaborated in the pretest.

The intervention

The intervention was divided into four steps, where each step was introduced to the children by the researcher. During these introductions, the preschool teachers were participating, interacting with the researcher and the focus children and taking notes. Between the introductions of each step, the preschool teachers carried out the activities with all children at the two preschools for 3 to 4 weeks. As activities in Swedish preschools are based on free will and curiosity rather than being scheduled, the amount of the focus children's participation in the activities differed. However, all of the children thought of the activities as fun and so, according to the teachers, most often participated in the programming activities several times a week.

In line with the curriculum for Swedish preschool, the programming activities were planned to make it possible for the children to explore and use mathematics to investigate, reflect on, and test different solutions to problems raised by themselves and others. To enable this, the programming activities included both implementation of preplanned programming as well as the children creating and editing their own initiatives. This is also in line with research showing the importance of children being both producers and consumers of technology (Gadanidis et al., 2017). The previously described guided interaction (Stephen & Plowman, 2008) enabled children's agency and promoted both thinking *and* doing, not just *doing*, which has been the tendency in earlier studies on programming. For example, the teachers could initiate debugging by helping the children to recognize when something in the programming was not working according to the plan. However, the children had the agency, either to try to solve the problem or to switch the goal (Bers et al., 2014).

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Each step in the intervention consisted of two or three activities, which did not have to be conducted sequentially, and neither did all activities have to be conducted each time. The activities in Step 1 did not have to end when Step 2 was introduced. Instead, the teachers and children could continue with the previous activities in parallel with new activities being introduced. The call for the teachers was to integrate the activities into the ordinary preschool activities. Common in all intervention activities was the children investigating mathematical ideas by trying them out themselves. To be able to do this, the children had one robot each during all intervention activities. Throughout the activities, the children were to predict the outcome before realizing their programming and to reflect on the outcome. Such predictions are important to later be able to reevaluate the programming.

The first activity in **Step 1** was the teacher programming a robot and the children describing how it moved on a gridded map. Gradually the teachers included more movements and more notions (e,g., forward, right, left, counting steps, backward, outside, inside, at first, after, rotate). The second activity was for the children to program their robots, making them move the same way as the teacher's robot. In this activity, similarities and differences were discussed (e,g., "How many grids did your robot move before rotating" or "My robot rotated in front of the house, where did yours rotate?"). The third activity was for each child to draw the movement of his or her robot on a preprepared paper map that was identical, except in scale, to the big gridded map.

In **Step 2**, the first activity was the teacher "programming" the children by using notes with arrows similar to those on the robot (Figure 1). After this, the children were to program the teacher and each other with the same notes. The intention was to let the children interpret and connect symbols (arrows) with movements in the room. The third activity was the children programming their robot in any way they liked and, before pressing go, predict how it would move on the map.

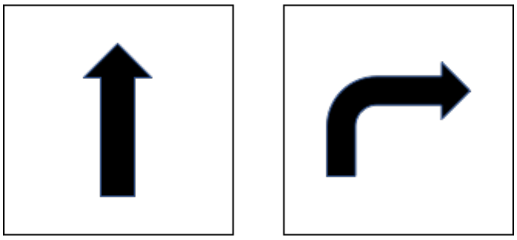

Figure 1. Example of notes with arrows used to "guide" the children.

In **Step 3**, the children got another prepared paper map representing the big grid map. On the paper map, there was an image of how their robot was to move on the big grid map, and the children were to program the robot in line with the instructions (Figure 2). As before, similarities and differences between the instructions on the paper map and the movements of the robot were discussed. After this, the children were to draw arrows describing the movement of the robot and thus connecting the movement of the robot with maps and with arrows (Figure 2).

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Figure 2. Example of preprepared paper map and a child's drawing of arrows.

Finally, in **Step 4**, the children got a paper with arrows describing how to program the robot. The children were to program the robot and, before pressing go, they were to predict where the robot would end up on the grid map. As mentioned, such predictions are important to later be able to reevaluate the programming. As a second activity, the children were tasked to program the robot to move from one predecided point to another and to make a drawing of the arrows they were to use before they programmed the robot.

Posttest

After the four steps, a posttest was conducted with the focus children. During all activities in the posttest, the children were encouraged to talk and describe their actions, to investigate their conceptual thinking. The intention with the posttest was to investigate their understanding and use of notions such as forward, backward, turn, left, and right as well as their spatial thinking and their ability to coordinate symbols, maps, and number words with actions. In line with the theoretical framework, the aim was not to investigate *if* or *how* the children had developed computational concepts in their heads, but to investigate how they had learned to *use* computational concepts in problem-solving (computational practice) activities. First, the children were shown notes with arrows (Figure 1) and asked to describe what they meant. After that, they were given a prepared paper map with an image of how their robot was to move on the big grid map. The instruction was to program: "two steps forward, rotate to the left, two steps forward, rotate to the right, one step forward". After programming their robot in line with the paper map, they were to draw symbols (arrows) describing the programming they just had made. Finally, the children were given a paper with arrows describing how to program the robot and, after programming their robot in line with these instructions, predict the outcome, and afterwards they were to draw its movements on a paper map.

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Results

As mentioned, the overall purpose with the study was to investigate *what might be,* when programming was implemented in naturalistic preschool activities with children 3–5 years. This will briefly be addressed in the beginning of this section. After that, the development of the young children's spatial thinking through the systematic involvement in programming activities will be highlighted. In line with the sociocultural approach, these results will be based on observations of the children's participation in the programming activities. Finally, some additional results focused on the children's learning of symbols will be presented. As teaching is a system of interacting features, it is impossible to isolate the effects of an intervention like this. Instead, the results presented here focus on regularities (Cobb & Gravemeijer, 2008) between the activities in the intervention and children's participation in the posttest.

The children participated enthusiastically in the programming activities showing pleasure and joy. As mentioned, the call for the preschool teachers during the intervention was to integrate the programming into the ordinary preschool activities. In previous studies on computer programming, one major difficulty has been young children's familiarization with the software where it has taken time and effort for the children to make sense of the symbols and commands to be used (Fessakis et al., 2013). This was not the case when implementing the robot at these preschools. Quite the opposite: the children intuitively explored and figured out the meaning of the command buttons on the robot. In the activities the PAUSE button was never introduced by the researcher or the teachers. However, the children themselves explored the meaning of this command and used it in their own programming.

Differences among the focus children were expected due to several reasons: they were of different ages, they showed different preunderstandings in the pretest, and they had been involved to varying degrees in the activities during the intervention. However, despite these expected differences, there were some regularities found in the posttest. All focus children could program the robot based on the prepared paper map, thus they had an understanding of the relationship between the drawing on the paper map and the big grid map as well as of how to program the robot for it to move in line with the paper map. The children were talking at the same time as they programmed their robot. Looking at the paper map they said, for example, "two forward" and then they pressed the arrow for forward on the robot twice. After that, they looked at the paper map, saying "rotate" and then pressed the arrow for rotate on the robot. One child put the paper map on the grid map and then moved the robot with her hand on the grid map at the same time as she said and pressed the commands; thus, she moved her hand one grid forward, said "forward", and then pressed the forward button on the robot. Another child did something similar, but instead of moving his hand one step at a time, he moved all steps in the same direction at the same time saying, "one, two forward", and then pressed two times on the forward button of the robot. Thus, several modalities were used by the children simultaneously. Some of the children programmed the robot in several stages. That is, first they programmed "two forward and rotate to the left", then pressed go and let the robot move two forward and rotate. Then they added the continuation of the programming, moved the robot to the initial starting place, and again pressed go. Thus, there were many different ways by which the children decomposed the task into subtasks. The children showed an ability to sequence, which includes, planning and putting objects (commands) in the correct order, which is important in both literacy and mathematics.

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When asked to draw arrows describing the programming they just had made, the children showed (with words and gestures) that they knew what the arrows represented. When given a paper with six arrows describing how to program the robot, four of the eight children could predict exactly where the robot would end, and the other four were very close in their predictions. Again, some of the children moved their hand along the grid map at the same time as they said, for example, "forward" or "rotate", showing knowledge of what each arrow would make the robot do. Finally, when they were to draw the movements of the robot on a paper map, all of the children could do this. Some of them let the robot drive the distance several times, drawing a bit at a time (decomposing), while others drew the whole distance at once.

Besides spatial thinking, there were observed changes in the children's understanding of the arrows as symbols. They used the notions "forward", "backward", "rotate" and "turn" when explaining the meanings of the arrows. At the same time as they used these words, they also used gestures (hands) and movements (body) to show how the robot would move if using the different symbols. Thus, several modalities were most often used by the children simultaneously. Some of them used the notions "right" and "left" connected to rotations, but not always correctly.

To summarize, there were many observed changes in the children's spatial participation in the joint programming activities and in their understanding of the arrows as symbols.

Discussion and implication

The overall purpose with the study presented here was to investigate *what might be,* when programming is implemented in naturalistic preschool activities with children 3–5 years old. The research question addressed is how young children's spatial thinking develop through a systematic involvement in programming activities. As mentioned, in line with the sociocultural approach, such learning can be investigated by observing changes in the children's participation in the programming activities.

In the intervention, spatial thinking, counting, and symbols were explored verbally, mentally, as well as by using gestures and different kinds of maps and programming schemes. The call for the preschool teachers was to integrate the activities into ordinary preschool activities, which is why the participation rates for the focus children in the activities differed. Thus, differences between the focus children were expected, and this is why regularities between the activities in the intervention and children's participation in the posttest were highlighted instead in the results.

The results show that, in addition to spatial thinking, the intervention also made it possible for the children to explore counting and symbols (arrows). In the posttest, all children used such words as "forward", "backward", "rotate", and "turn", and they also used gestures (hands) and movements (body) to show how the robot would move based on the different arrows. With regard to spatial thinking, the children showed the ability to mentally compare the paper map and grid map as well as symbols and movement. Further, they showed the ability to mentally envision, hold in their minds, and conceptualise actions and relationships between paper maps, gridded maps, and symbols. Such abilities have been shown to be a predictor for further mathematical achievement in geometry, measurement, and problem solving (Cross et al., 2009). Several times they decomposed the tasks into subtasks, which is in line with the process of problem-solving.

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In the pretest, the children also showed the ability to use one-to-one correspondence together with the number sequence (Gelman & Gallistel, 1978) when coordinating the number of presses on the commands with the number of grids the robot is to move on the grid map. However, the numbers used were quite low which is why nothing can be said about this ability in relation to other objects or an increased number sequence.

In summary, the presented intervention indicates potential for teaching mathematics through programming in preschool showing. This does not, however, imply that it is the best way or the only way to teach mathematics in preschool—only that it is one possible way of *what might be*.

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