Learning, Culture and Social Interaction 21 (2019) 378–389

Contents lists available at ScienceDirect

Learning, Culture and Social Interaction

journal homepage: www.elsevier.com/locate/lcsi

Full length article

Role of teachers in students' mathematics learning processes based on robotics integration

Sanna Erika Forsström

Østfold University College, Halden, Norway

1. Introduction

Many countries, such as the Nordic countries Finland and Sweden, integrate programming into their mathematics curriculum. Norway is in the planning phase of a similar curriculum redesign.

The educational potential of programming in mathematics education is still unclear. In Nordic countries, the rationale for introducing programming into the mathematics curriculum is to foster students' logical thinking, problem-solving skills, and motivation to learn mathematics (Bocconi, Chioccariello, & Earp, 2018). According to the report produced by European Schoolnet, "a network of 31 European Ministries of Education," there is a need for studies to be conducted on ways in which teachers can effectively integrate programming into their teaching (Balanskat & Engelhardt, 2015; Bocconi et al., 2018). On the basis of the literature review about the educational potential of programming in mathematics education, programming integration has the potential to foster students' learning in mathematics and motivation to study mathematics (Forsström & Kaufmann, 2018). However, Forsström and Kaufmann (2018) argued that the results cannot be generalized. In addition, there is a need for studies that discuss the effect of "the role of the teacher" and "collaboration among students" in students' learning processes regarding mathematics. Collaboration among students and the changed role of the teacher are usual in programming activities. Previous studies discussed that the teacher acts more like a guide, supporter, and conflict solver in students' collective learning processes than a traditional lecturer. Moreover, the effect of the roles of the teacher in students' learning is still unclear. This study contributes to the discussion regarding the roles of the teacher in students' learning processes in mathematics based on programming integration.

In general, programming tools fall within the general area of digital technology, which, according to previous studies, can influence mathematics education positively. The curricular integration of digital technologies into mathematics can provide innovative learning environments in mathematics classrooms, such as a creative task design and a new kind of division of labor between students and teachers in the classroom. It has the ability to change a traditional, teacher-led mathematics classroom to be more student-centered (Bray & Tangney, 2017; Olive et al., 2010). Moreover, the way in which technology is used in the classroom completely depends on the choices made by the teacher (McCulloch, Hollebrands, Lee, Harrison, & Mutlu, 2018).

The propensity of any of these potential benefits of programming integration to be achieved depends on the teacher's computing background. When programming is integrated into the mathematics curriculum, the teaching of programming becomes the responsibility of the mathematics teacher.

One way to make programming integration easier for teachers who do not possess any programming background is to use visual programming environments, wherein programming is made possible by the application of different graphical blocks. In visual programming environments, different figures represent different programming structures, such as loops and if-statements. One can then program by changing the values of variables in the figures (Bocconi et al., 2018). The EV3-programming environment for Lego Mindstorms robots is one example of a visual programming environment that is currently used in schools. Lego Mindstorm robots are the most studied educational robots (Benitti & Spolaôr, 2017).

In the educational application, there are various types of robots and toolkits (Karim, Lemaignan, & Mondada, 2015). According to the literature on educational robotics, it is still unclear as to how teachers can fruitfully integrate robotics into curriculum activities

E-mail address: sanna.forsstrom@hiof.no.

https://doi.org/10.1016/j.lcsi.2019.04.005
Received 8 December 2018; Received in revised form 18 April 2019; Accepted 21 April 2019
Available online 04 May 2019

(Benitti & Spolaôr, 2017; Karim et al., 2015; Mubin, Stevens, Shahid, Mahmud, & Dong, 2013). The studies focusing particularly on robotics in mathematics education brought out the need for discussion of how the role played by the teacher in robot-based activities influences students' learning of mathematics (Lindh & Holgersson, 2007; Savard & Freiman, 2016). Earlier studies discuss how robot integration affects students' performance in mathematics and their motivation to learn mathematics (Ardito, Mosley, & Scollins, 2014; Barak & Assal, 2018; La Paglia, la cascia, Francomano, & La Barbera, 2017; Leonard et al., 2016; Lindh & Holgersson, 2007). Changing the role of the teacher from that played in a traditional classroom is mentioned in some of the studies (Lindh & Holgersson, 2007); however, such changes are not widely discussed as components of students' learning processes with robots.

To integrate programming into mathematics education, Lego Mindstorm robots have the means to accomplish such smooth programming integration. This study focuses on the integration of Lego Mindstorm robots into the learning processes of mathematics. In addition, as the role of the teacher in successful robot integration into mathematics education is unclear, the study aims to specifically discuss what roles teachers can play in students' learning processes regarding mathematics in robot-based activities by answering the following question:

How does the role of the teacher in robot-based activities influence students' learning processes in mathematics?

This question is investigated by comparing two different sessions from data gathered in one secondary school in Norway in which a mathematics teacher without any previous knowledge of programming introduced Lego Mindstorms robots to his students. We will concentrate on what changes occur to the everyday practice of the classroom when programming and robots are introduced. When the teacher does not have any previous knowledge of programming, such an introduction is not always an ideal one. The focus of this study is not what a teacher should do in the classroom but what the teacher actually does and what kind of choices they make in the process of introducing learning with robots. We will concentrate on the role played by the teacher in the collective learning processes of one group of three students, aged 12–13. During the first session, the students were unable to complete the assigned task with the robots. During the second session, they were more successful. Furthermore, during the second session, their use of mathematical tools increased.

We analyze the role of the teacher in the collective learning processes of students using Engeström's (1987) activity system analysis in cultural–historical activity theory (CHAT). CHAT enables the analysis of the effect of various components, such as the role of the teacher in collective learning processes. CHAT considers teaching to be one part of students' learning processes and enables researchers to analyze learning and the teacher's role in collective learning processes where the teacher is a participant (Engeström & Sannino, 2012). In this model, knowledge is distributed among participants and tools. Learning is thus viewed and analyzed as a development of the collective knowledge of a group rather than as knowledge transferred from the teacher to the students (Engeström, 2005). In the sessions analyzed as part of this research, teaching and learning were affected through innovative, collective group processes, as well as through interactions between students and the teacher. Our analysis concentrates on student–teacher relationships as measured through interactions and negotiations between the teacher and the students during the open learning processes with robots.

The rest of the paper is organized as follows. First, existing literature on the role of the teacher in robot-based activities is discussed. A discussion of the theoretical framework of this study comes next. Then, we present our research strategy and methods, detailing how the two different sessions are analyzed and compared using concepts from activity system analysis. In the final section, we review the findings and discuss ways in which the findings can be generalized.

2. Literature review

2.1. Robots in mathematics education

The various studies on the application of robotics in mathematics education mentioned the changed role of the teacher in classroom activities (Barak & Assal, 2018; Lindh & Holgersson, 2007). The studies reported that even if the role of the teacher differs from the teacher's traditional role as a lecturer, the teacher still has an important role to play. Students need the teacher as a guide and support while learning the technology. At times, students also need help to solve technical problems before they can continue programming and working with robots. Teachers with previous knowledge of technology, physics, or natural science are able to link their knowledge to Lego technology (Lindh & Holgersson, 2007). Barak and Assal (2018) reported that students sought the teacher's advice in the beginning. Once they got control over the robot, collaboration between students took a more central role than that of the teacher. Students received feedback from each other, rather than the teacher, when successfully completing a task. However, the teacher was still needed to help in ways other than answering questions. For example, according to Lindh and Holgersson (2007), the teacher is needed to help in resolving conflicts among students and to effectively improve their collaborations.

Moreover, even if the changed role of the teacher is mentioned in previous studies, the deeper discussion on ways in which the role of the teacher influences students' learning processes is missing in mathematics (Forsström & Kaufmann, 2018; Savard & Freiman, 2016). Thus, in this study, we extend this literature review to include programming and more generally, integrate technology into mathematics education.

2.2. Technology in mathematics education

The idea of integrating programming into the mathematics curriculum was introduced in 1980. Papert (1980) suggested that programming should be a part of the curriculum. The author remarked that programming integration can provide a different kind of learning environment in a mathematics classroom, where also the role of the teacher differs from that of a traditional lecturer. In fact, he stated that "the role of the teacher is to create the conditions for invention rather than provide readymade knowledge" (Papert, 1996). In addition, he stated that "I am convinced that the best learning takes place when the learner takes charge…" (Papert, 1993, p. 25). Different studies have been conducted on programming and technology integration into mathematics education on the basis of Papert's suggestions. From this perspective, we discuss how the role of the teacher can help in mathematics education.

According to the systematic literature review by Bray and Tangney (2017), technology integration in general and programming integration in particular have the potential to change classroom culture in mathematics education. Previous studies dealing with technology integration into mathematics education discussed learning environments that were self-directed (Bray & Tangney, 2017; Martinovic, Freiman, & Karadag, 2013; Olive et al., 2010) or student-centered (Bray & Tangney, 2017; Olive et al., 2010), and collaborative (Martinovic et al., 2013). Some studies refer to various challenges in the traditional, teacher-led mathematics classroom (Bray & Tangney, 2017; Martinovic et al., 2013; Olive et al., 2010).

One significant issue in mathematics education is that in many schools, mathematics is still presented as an isolated, formal, and abstract subject, in which the absolute authority is the teacher, whose role is to be the arbiter of knowledge (Bray & Tangney, 2017). The problem with this kind of learning environment is that it hinders students' abilities to make out-of-school connections with what they are learning (Olive et al., 2010). Digital technologies have the potential to address this issue by providing students with more practical connections to the course material, as well as by offering a pedagogical approach that puts the student at the center of their learning environment. In a student-centered learning environment, students are given the opportunity to design their own technologies and to lead tasks with out-of-school connections. Furthermore, the teacher is able to act more like a guide and less like an inveterate lecturer who gives students contrived tasks to solve (Bray & Tangney, 2017; Martinovic et al., 2013; Olive et al., 2010). Although a great deal of innovative research has been conducted in this area, when it comes to everyday classroom practices, technology still tends to be used as a convenient tool for solving traditional problems rather than as a central object of inquiry in a student-centered learning environment (Bray & Tangney, 2017; McCulloch et al., 2018). Earlier studies suggested that our general unwillingness to integrate technology into the mathematics classroom might well be due to teachers who are themselves unfamiliar and uncomfortable with technology in the context of pedagogy (McCulloch et al., 2018). McCulloch et al. (2018) argued that teachers primarily use technology to support pedagogical models and goals with which they are already familiar. Teachers who integrate more "non-mathematics-specific" technology in their pedagogy tend to possess a broader understanding of technology integration (McCulloch et al., 2018).

The role of the teacher in integrating technology into education has been discussed in earlier studies with the help of the technological, pedagogical, and content knowledge (TPACK) model (Ruthven, 2014). The TPACK model enables researchers to analyze how the teacher's technological, pedagogical, and content knowledge influences technology integration (Koehler & Mishra, 2009). Student-centered integration of technology ultimately depends on the teacher's technological knowledge (Guerrero, 2010). Furthermore, reality differs from the ideal situations that research seeks to present. Researchers can dream up new ideas and new models; they can provide devices and assistance to teachers. However, when teachers are left to do their jobs, they themselves will decide what the changes should be (Bray & Tangney, 2017). A further consideration is that teachers may be afraid of losing control of the classroom (Drijvers, Doorman, Boon, Reed, & Gravemeijer, 2010; Olive et al., 2010). In the traditional mathematics classroom, the teacher has the control and the power to make decisions. They can decide how technology is used. If students are given more control and responsibility in the classroom through technological integration, they will be forced to engage in a new set of difficulties: pedagogical and otherwise. (Olive et al., 2010)

In summary, technology has the potential to change classroom practices in mathematics education. How the classroom changes depends on the manner in which teachers integrate technology into their classrooms (Bray & Tangney, 2017; Olive et al., 2010), which itself depends on the teacher's technological knowledge (e.g., Guerrero, 2010). It remains unclear as to how a teacher who does not have previous knowledge about programming or robots manages to integrate robots into their classroom successfully.

3. Theoretical framework

Teachers with strong technological knowledge are able to integrate technology into their teaching in a student-centered way (Guerrero, 2010). In such cases, the integration of technology has the potential to change the classroom culture in mathematics education. It is very likely, however, that a teacher integrating programming in their classroom lacks the technological knowledge of someone with a programming background (Bocconi et al., 2018). As we focus on the choices of a teacher without technical expertise, we apply a different theoretical perspective than the TPACK model. Rather than focusing on the teacher's knowledge or intentions toward integration, we aim to understand what actually happens in the classroom by using a wider relational perspective. We discuss the influence of the role of the teacher on students' learning processes by addressing all the components of collaboration among students, student-centered classroom environments, and teachers' technological knowledge. This is possible with CHAT.

Engeström's (1987) activity system (Fig. 1) is the prime unit of analysis in CHAT. Engeström's (1987) activity system analysis considers the role of the teacher in relation to the collective learning processes of the students. The activity system analysis in CHAT considers tool-mediated activities in light of all the components of the activity system (Fig. 1). The seven components considered in relation to one another are subject, object, tool, rules, community, division of labor, and outcome (Table 1).

Activity is always led by an object, which motivates and determines it. Subjects work collectively through the division of labor toward their collective object (Engeström, 1987). The collective object of an activity can be collaboratively constructed by subjects and can be the synthesis of individual perspectives (Engeström, 2008; Holland & Reeves, 1996). The object can be shaped and changed in the course of the development of the activity by the subjects (Engeström, 1987, 2008).

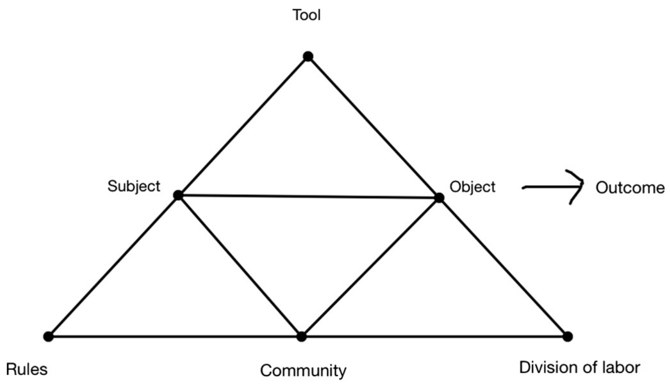

Fig. 1. The activity system model (Engeström, 1987, p.78).

Table 1
Definitions of the components of the activity system analysis.

Component	Definition/meaning	Examples from this study
Subject	The individual or group of people who are engaging in the activity (Yamagata-Lynch, 2010)	The students and the teacher
Object	The driving force of the activity (motive and goal) (Engeström, 1987)	Fulfill a task with the robot.
Tool	The instrument that mediates the activity (Engeström, 1987)	The robot, computer, and mathematical tools
Rules	The regulations that are relevant to the activity (Yamagata-Lynch, 2010)	Task assignment, rules of the mathematics classroom
Community	The social group to which the subject belongs during the activity (Yamagata-Lynch, 2010)	The whole class of students and the teacher (or teachers)
Division of labor	How the tasks are shared during the activity (Yamagata-Lynch, 2010)	Collaboration between students, the mediation of the teacher
Outcome	The result of the activity (Yamagata-Lynch, 2010)	The robot drives a track as it is programmed.

Activities are mediated by tools as subjects are connected to objects through the use of the tools that they possess. There cannot be any activity without tools. Moreover, the tools are not the main objective or the goal of an activity even if the focus is temporarily on the tools (Engeström, 2005). The tools required for robot-based activities can be working tools (Engeström, 2005), such as computers and robots, or nonmaterial tools (Engeström, 2005), such as knowledge of a programming language-specific mathematics.

Engeström's (1987) activity system model is well suited to analyzing the role of the teacher on the basis of activities transforming over time, and the history of the participating subjects should be a part of the analysis of programming and robot integration because CHAT is used for collaborative activities. Each subject has its own history, which shapes the activity through the division of labor. Thus, the role of the teacher in collective learning processes can be analyzed using the relationship between the role of the teacher as a part of the division of labor and other components in the activity system, such as various tools and the object of the activity. Programming tasks can be solved in various ways because collective activities are not predictable (Engeström, 2005). Consequently, even if the teacher designs the tasks, they may not know beforehand the type of problem-solving activities that will be set in motion. Therefore, this may change the division of labor in the classroom.

In this regard, Engeström and Sannino (2012, p. 46) stated the following:

> But the very assumption of complete instructional control over learning is a fallacy. In practice, such control is not possible to reach. Learners will always proceed differently from what the instructor, researcher or interventionist had planned and tried to implement or impose.

Thus, learning processes using robots cannot be analyzed with standard learning theories wherein students are considered to acquire stable individual skills and knowledge that can be identified by the teacher beforehand. As aforementioned, learning in CHAT is a collective process. The subject of an activity collaboratively manipulates the object of the activity throughout activity development (Engeström, 2005).

To understand the role of the teacher in students' learning processes in detail, we discuss the relationships among “the role of the teacher,” “object of students activities,” “tools in use,” and “collaboration among students” in student activity system models. These relationships are the main focus of the analysis in this study.

3.1. The role of the teacher-object of the activity

As aforementioned in the introduction, technology integration has the ability to change classroom culture from being teacher-led to becoming more student-centered, depending on the role of the teacher. Engeström (2008) illustrated the traditional classroom model using activity theory (Fig. 2). In that model, the teacher and students have their own activity systems, where the teacher sets

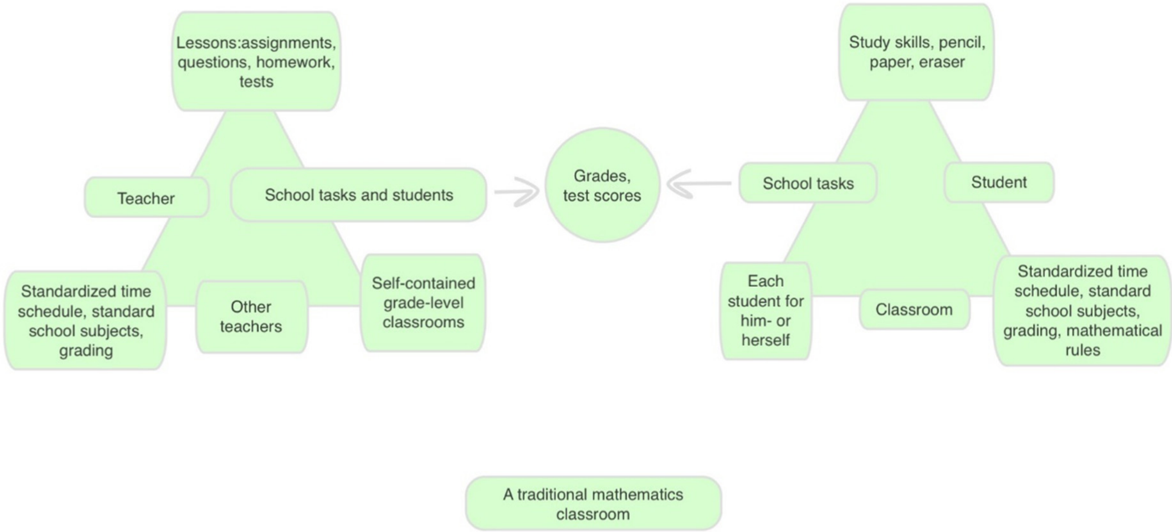

Fig. 2. Engeström's illustration regarding a traditional classroom model reconstructed from Engeström (2008, p. 89).

up tasks for the students to solve, i.e., the object of the students' activity is given (Engeström, 2008; Martinovic et al., 2013). In a more student-centered classroom, students have the opportunity to create their own tasks to be solved, i.e., students have their own objects. However, previous studies have shown that there may be a problem in integrating programming, particularly if the teacher does not have any programming background to enable the students to obtain their own objects. To understand this kind of activity in the classroom, we address the problem of the relationship between the role of the teacher and the object of the activity in students' activity systems. Thus, the relationship between the role of the teacher and the object of students' activity system is one main focus of analysis in this study.

3.2. The role of the teacher- tools

According to the previous studies that applied the TPACK model, technology integration into mathematics education depends on the teacher's technological knowledge (Guerrero, 2010). In CHAT, teacher and student technological knowledge, as well as teacher pedagogical knowledge, can be discussed by utilizing the concept of tools. Activities transform over time, and the history of the participating subjects should be a part of the analysis. Activity development depends on the history of the different tools that mediate and shape the activity (Engeström, 2005). The students and the teacher can have different histories regarding programming tools. If programming is integrated into mathematics education and the mathematics teacher does not have any previous knowledge of it, some of the students may have more control over the knowledge tools than the teacher (Olive et al., 2010). The influence of the teacher's role in student activity systems can be discussed in such a situation by addressing the relationship between the teacher's role and the tools in use, which is our second unit of analysis in this study.

3.3. The role of the teacher-collaboration among students

Previous research proved that technology, programming, and robot integration support collaborative learning in mathematics classrooms (Forsström & Kaufmann, 2018; Bray & Tangney, 2017; Martinovic et al., 2013). CHAT can be used for collaborative activities. Each subject has its own history, which can shape the activity through the division of labor. The subjects participating in the activity can always have multiple perspectives, opinions, traditions, and interests, which can cause tension (Engeström, 2005). Previous studies proved that the teacher needed robot integration as a conflict solver (Lindh & Holgersson, 2007). However, the influence of the teacher as a conflict solver on students' learning is not widely discussed. Activity system analysis in CHAT enables us to discuss the influence of the teacher's role as a conflict solver on students' learning processes in mathematics, through the relationship between the teacher's role and collaboration among the students. This constitutes our third unit of analysis in this study.

In the following chapter, we introduce the design applied to our study. We use CHAT to analyze the teacher's role in robot-based activities and how it can influence the students' learning processes in mathematics.

4. Research methods

4.1. Research context and design

We explore data gathered in one secondary school in Norway to better understand the role of the teacher in student learning when technology is being implemented in the classroom.

Norway is planning to integrate programming in the mathematics curriculum, and technology is already an important part of the curriculum in Norway, which makes a Norwegian school an interesting target for this study. Mathematics plays a central role in the national curriculum in the 10-year compulsory elementary school in Norway, and logical thinking, problem-solving, and the use of technology are the central focus of the mathematics curriculum in Norway. It is recommended that teachers use technology in most mathematical activities (Kunnskapsdepartementet, 2007; Utdanningsdirektoratet, 2013).

Although the design of this study is not completely that of an intervention study, it has features of an intervention study in terms of our role as researchers. We played an active role in the beginning when we introduced Lego Mindstorms robots to the teacher shortly before the data was collected through the basic programming figures. After the introduction, he gained basic programming skills with robots by himself. The teacher planned and conducted an introduction to robots. We had a more passive role during the data collection sessions; however, we negotiated with the teachers in between the sessions, which reactivated our role.

4.2. Data collection

The videotaped data with ethnographic features were gathered to understand everyday activity in the classroom in which robots were integrated. The mathematics teacher who participated in this study did not have any previous knowledge of programming or robots. This made it possible for us to get a natural picture of the situation of programming integration. The data were collected as part of an elective subject, “technology in practice.” There were 31 students aged 12–15 in the classroom.

We started by introducing Lego Mindstorms robots to the teacher shortly before the data were collected through the basic programming figures. After the introduction, he gained basic programming skills with robots by himself. The teacher planned and conducted an introduction to robots, first introducing the basic programming figures to the students so that they could steer the robot motors. Other programming skills were self-taught as needed. The students worked in groups of 2–4 that were assigned by the teacher. The task that was most frequently selected for groups was to drive a certain path with the robot. Students were also able to plan the path that the robots would drive by themselves. The teacher, with his peers, guided students when needed.

We observed the activities in the classroom during eight 75-min sessions; the last five of the sessions were videotaped. By observing the first eight sessions incorporating robots, we got a sense of the students' first learning experience with robots. During the sessions, the teacher's involvement with students' learning processes varied.

The focus in our observation was on one group of three students, “Oscar,” “Lucas,” and “Jacob,” aged 12–13. Oscar, Lucas, and Jacob worked enthusiastically with the robots, and they were natural in front of the video camera. Observing only one group of students made it possible to gain a detailed understanding of the collective learning processes of that one group.

Permission for gathering the sensitive videotaped data material was obtained from the Norwegian Centre for Research Data. Permission for the videotaping was also granted by the teacher and the parents of the students. The data has been processed confidentially, and the participants are anonymous. During the sessions, the author concentrated on videotaping and writing field notes. The role of the author in the classroom was that of a moderate participant, which is between an active participant and a totally passive one (Spradley, 1980). The author briefly introduced the robots to the teacher but did not participate in teaching or guiding students, instead concentrating on observing the activity development and the effects of different components such as the role of the teacher, collaboration between students, and different tools in use. Furthermore, the author observed students' and the teacher's gestures and expressions to understand interactions between students and the teacher.

4.3. The data analysis

The first step in data analysis was to select for transcription the most interesting part of the most interesting sessions, with respect to the role of the teacher. Two different sequential sessions were the most interesting for this article because the teacher had a different role during these sessions.

To get a broader picture of the impact of the role of the teacher on students' collective learning processes, we used Engeström's (1987) activity system analysis, which made it possible for us to analyze the influence of the role of the teacher on the different components in students' learning processes. We also compared the two different sessions regarding the role of the teacher, and on the basis of this comparison, we analyzed certain relationships between the role of the teacher and other components in the activity systems in which the role of the teacher had an influence on both of the sessions, which could be seen in the collaboration between students, the tools that the students were using, and the objects of students' activities.

5. Findings

In this section, we briefly present Sessions 1 and 2, and then, we provide a comparative analysis of the roles played by the teacher during these sessions, using activity system analysis.

During Session 1, the task assigned was to program the robot to drive a given path as quickly as possible. Students Jacob, Lucas, and Oscar got the idea to use touch sensors to control the robot in such a way that the robot turned left when the touch sensor connected to the left-hand side of the robot was pressed down. The right-hand side would work similarly. When no sensors were pressed, the robot would drive straight forward. This idea was generalizable and innovative; they were not able to implement it because they lacked the necessary programming skills. The teacher was not able to help them either.

During the other session, 1 week after Session 1, the assigned task was still the same as that in the previous time because none of

Table 2
Comparison between Sessions 1 and 2.

	Session 1	Session 2
Object	The teacher was not present when the students negotiated the object.	The teacher negotiated the object together with the students.
Mathematical tools	Students did not use mathematical tools.	Mathematical tools were in use.
Programming tools	Students had problems with programming. They could not solve these problems.	Students did not have any problems with programming.
Collaboration	The students had difficulties with collaboration.	The students had difficulties with collaboration; with the help of the teacher, the difficulties were resolved.
Outcome	Students did not complete the task.	Students completed the task.

the groups had yet succeeded. Students had the option of designing a path on which they programmed the robot to drive. During Session 2, Oscar was absent, and Jacob and Lucas had difficulties in getting started and collaborating. They had to wait for a long time before the teacher came to help them; however, when he did, he negotiated a new task assignment with the students. The new task was to program the robot to drive a circle of 1-m radius. This negotiation with the teacher helped the students to successfully collaborate again, and they were able to solve the problem using mathematical tools and collaboration.

The roles of the teacher during these two sessions were different in many ways, and so were the sessions themselves. These differences are listed in Table 2.

Using the relationship in the activity system analysis, we discuss the differences between Sessions 1 and 2. For this analysis, the role played by the teacher is considered to be a part of the division of labor. In the following sections, we use Table 2 as the basis for discussing the relationship between the teacher's role and the object of the activity, between the teacher's role and the tools, and between the teacher's role and collaboration between students.

5.1. The role of the teacher - object of the activity

During Session 1, the teacher was not present when the students negotiated their object:

Citation 1 from our field notes (Session 1)

Students found some sensors and became curious about their purpose. After the students learned the purpose of the touch sensor, Oscar got an idea about using it to control the robot. He described how the touch sensor could be used. Jacob got excited about Oscar's idea.

Lucas was not excited about Oscar's suggestion: *We are not going to do that.*

The students connected two touch sensors to the robot with long cables so that the sensor could be pressed while the robot was driving.

At this point, Lucas also got excited: *Let's make a program.*

Oscar started programming while he negotiated with Jacob and Lucas. Thus, the students found a common object to work on without any input from or negotiation with the teacher.

Citation 2 from our field notes (Session 1)

The teacher came to see the students after they had tried to solve their problem for some time.

Teacher: *Do you know what to do?*
Oscar: *We are just testing things out…*
Jacob laughed: *We are trying to make a controller*.
The teacher was a bit confused: *Okay.*
Oscar: *We are having problems in getting this to work somehow. We are having problems in getting these things to work somehow. I mean the buttons…*
The teacher: *What did you say?*

The teacher pointed to the computer screen and took a quick look at the computer, smiled, and left. He did not answer the students' question and did not return to the students during that session. The students did not mind that the teacher left; they just continued working.

Analysis based on Citations 1 and 2

The teacher did not understand the students' object. This is evident because he did not comment on the students' idea in any detail; he just left and did not return. One reason for this is that he was not present during object negotiation. The other reason is that the teacher did not have the tools required to help the students. We discuss more about the required tools in the tools section.

As opposed to Session 1, during Session 2, the students' object was a result of the negotiation with the teacher:

Citation 3 from our field notes (Session 2)

The teacher came to see the students 30 min after the beginning of Session 2. He noticed that one student was absent:

Teacher: *Are you without Oscar today?*
Lucas: *Yes.*
The teacher remembered the students' project from the last time: *Was it he who planned the controller, or?*
Lucas: *We gave up on the controller.*
The teacher laughed relieved: *Okay, what are you doing now instead?*
The students gave almost the same answer at the same time.
Jacob: *I don't know what he is doing.*
Lucas connected the robot to the computer and smiled: *We made it (the robot) turn*.
Jacob continued, a bit frustrated: *I just continued with this thing here (programming the robot), which he started. He was sitting here like this, more than half the time he just built it (Lego bricks). And now I do not know what he is doing with it (the robot).*
Lucas gave an answer while he started the robot on the floor, and he pointed out a route on the floor with his hands: *Now I'll make the robot drive from here (start point), and then, it will drive around there (end point), past the bag, and in like that.*
Jacob: *Yes. How many times?*
Lucas: *One. Until now*.

Both of the students and the teacher observed the robot while it was driving. The robot almost drove in a circle by ending almost at the starting place. Everybody got excited that the robot almost drove a circle. The teacher sat next to the students facing the computer and pointed to the screen:

Can you make a circle with only one such (program) so that it (the robot) drives around one circle.
Lucas: *I think so.*
Jacob: *Make your circle a bit more specific. It might be like turning that way.*
Lucas laughed enthusiastically and drew a circle with his hands: *Should it drive like that? Did you mean the pi-circle?*
The teacher raised his shoulders and suggested: *Radius of 1 m, for example*.

Analysis based on Citation 3

The start of Session 2 was not smooth. The students had difficulties in collaborating, and it took quite a long time before the teacher came to see them. When the teacher came to see the students and realized that they were not working with the touch sensors anymore, he seemed relieved. After realizing that the students did not successfully complete the previous project, he took on a different kind of role and negotiated a new object with the students by suggesting one that was related to the situation they were engaged in. Students' questions and enthusiastic laughter indicated that they were interested in the teachers' suggestion.

Analysis based on Citations 1, 2, and 3

The comparison of Sessions 1 and 2 confirms the indication that the teacher had difficulties with the students' object during Session 1. This is manifested in a few different ways. First, the teacher did not come to see the students at the end of Session 1 after leaving. This is confirmed by the fact that it was a long time before the teacher came to see the students in the beginning because he thought that the students were still working on the previous project. Second, when the teacher came to see the students during Session 2, he immediately mentioned the object from the last time, and he laughed, relieved, on realizing that the students were not working on that object anymore. Third, he assumed a different role during Session 2 by discussing the assignment with the students in a different way. He used time for the students in a different way by sitting down and planning with them. He participated in the students' discussion, unlike during Session 1.

5.2. The role of the teacher – tools

The tools applied are based on the objects of the activity (Engeström, 1987):

Analysis based on Citations 1 and 2

During Session 1, programming tools were needed to mediate activity toward the object, which, in this case was the use of touch sensors to control the robot (Engeström, 1987). However, without sufficient tools, the students were not able to achieve their object and would have needed help and advice in programming. Their plan could not be implemented as such; however, the idea could have been developed with the help of the teacher. As also in Lindh and Holgersson (2007), the teacher was needed as technological support during students' learning processes with robots. However, the students did not get technological support from the teacher. As mentioned earlier, the teacher did not have the tools required to support the students. The students did not ask or even expect to get help from the teacher. They explained their plan and problems to the teacher when the teacher asked what they were doing. When they did not get any answer, they just continued working and did not mind that the teacher left.

Analysis based on Citation 3 and other field notes from Session 2

Session 2 had a view contrary to what Session 1 had regarding the use of tools. Apart from the programming tools, the students used mathematical tools that were appropriate for the object of the activity during Session 2. The teacher managed to mathematize the object by suggesting that the students could program the robot to drive a circle with a 1-m radius. The mathematized object needed mathematical tools to mediate the activity (Engeström, 1987). The students needed the circle perimeter formula to define the length of the route that the robot needed to drive. They also needed proportions to define how much the robot had to turn. The teacher did not intervene in the selection or use of these tools; however, the use of the tools was dependent upon the object, which, in turn, was the result of negotiation with the teacher.

The students did not have any difficulties with the use of programming tools during Session 2. The teacher saw that the students were able to program the robot to almost drive a circle. Thus, the teacher knew that the students had the programming tools required to achieve their object. The teacher's suggestion to have the robot drive in a circle was not challenging to their programming skills. It was rather challenging in its mathematical aspect, where the teacher had the tools required to guide the students.

During Session 1, the focus was on technological tools, and during Session 2, it was on mathematical tools, and the role of the teacher varied accordingly. The teacher was much more involved during Session 2 when the focus was on mathematical tools. He was able to understand and guide students during their entire learning process.

5.3. The role of the teacher – collaboration among students

At the beginning of Session 1, the students collaborated well and did not mind that they did not get any help from the teacher. However, the collaboration between the students collapsed after some time:

Citation 4 from our field notes (Session 1):

Oscar worked relentlessly with programming and reasoning: *So, we must have this, at least. And then we should not use it, because when you press it then it stops just what it's connected to. The exclamation point… Of course, we have to connect something from here to them…I can do that. No. Yes… Listen. Come. Yes. We've got something, at least. So that we have to use… And then we have one, and then it's when the buttons are held in, something happens.*

The other students were no longer excited about the project. They did not listen to Oscar's reasoning. Oscar tried to get them to listen and got Lucas' attention.

Oscar continued: *Yes, or it does not work. But, then we have to take up something, but what is the same?*

Lucas listened, but then, he continued building the Lego blocks. Jacob looked at what the other groups were doing and was worried about the time.

Jacob: *How long have we got? Oh, ***, we have too little time. We have 17 min on us.*

Oscar continued his reasoning, and Lucas continued to build the Lego blocks; Jacob tried to listen to Oscar; however, he could not follow what Oscar was doing. He also reminded Oscar of the time.

Analysis based on Citation 4

The students became frustrated when the activity did not develop as desired, and the students' difficulties with collaboration escalated into a contradiction between subject and object in the activity system (Engeström, 2005). Because the activity did not develop in the desired way, the students developed different objects. Lucas and Jacob were no longer listening to Oscar. Oscar's reasoning was not consistent and became difficult to follow. Lucas started to build using Lego blocks, and Jacob was stressed with the time.

Analysis based on Citations 2 and 3

The students struggled to find a common object at the beginning of Session 2. Jacob had difficulties in following what Lucas was doing; however, the teacher's question regarding what students were doing got them to interact with each other. Jacob got a clue about what Lucas was doing, and both of them concentrated on the robot again. The students' new collective object, to program the robot to drive a circle with a 1-m radius, got students to collaborate again, and the activity got a new direction.

From this interaction, we can see that the role of the teacher can impact collaboration between students. The teacher's guiding questions were key to bridging the gap in understanding between the students. The situation in which Lucas and Jacob ended up with different objects because they had difficulty in following Oscar's reasoning might have been avoided with the help of the teacher's guiding questions. The example of this study supports the argument of Lindh and Holgersson (2007) that the teacher is needed to resolve conflicts among students during problem-solving activities with robots.

5.4. Summary of the analysis

The analysis above indicates that the role of the teacher differed during Sessions 1 and 2. The role of the teacher influenced object development, the tools in use, and collaboration among students during Sessions 1 and 2. These findings are summarized in Table 3.

As shown in Table 3, the development of the activity was based on object negotiation at the beginning of the sessions. It can be deduced from the teacher's role during Sessions 1 and 2 that the key to the development of the whole activity was the teacher's role during object negotiation. Barak and Assal (2018) argued that the teacher is needed at the beginning of the sessions, which is a claim supported by the comparison between Sessions 1 and 2. On the basis of our study, it could be said that the role of teachers at the

Table 3
Summary of the findings regarding the relationships between the role of the teacher and object development, the tools in use, and collaboration among students.

	The role of the teacher- object	The role of the teacher- tools	The role of the teacher- collaboration
Session1	The teacher was not present in the design phase of this session when students negotiated their object. This had an influence on activity development, such as tools in use and collaboration among students.	Students did not have the tools required to obtain their object. This could have been avoided if the teacher was involved earlier in object negotiation. The teacher did not have the tools required to guide the students in this phase.	At the end of the session, students' collaboration was not successful. This was a consequence of activity development that was based on the object of the activity and tools in use. This could have been avoided had the teacher been involved in the previous phases with some of his questions as a guide.
Session2	By making suggestions on the basis of students' original activity, the teacher and the students negotiated a common object together. This had an influence on the development of activity, such as tools in use and collaboration among the students.	Students had the programming tools required to obtain their object. In addition, mathematical tools were in use. The tools applied were based on the object negotiated with the teacher. Moreover, the teacher had the tools needed to guide the students, such as his mathematical and pedagogical knowledge.	Students had difficulties with collaborating among themselves in the beginning. This situation was solved by the teacher's guiding questions and negotiation at the beginning of the session. After the collective object was negotiated, collaboration among the students was successful during the development of the whole activity. This was based on the object of the activity and tools in use.

beginning of the activity is key to the development of the whole activity. First, this is because teachers are able to help the students during their learning processes by utilizing their (teachers') acquired mathematical and pedagogical knowledge. On the basis of studies conducted using the TPACK model, the manner in which programming can be integrated into mathematics education depends on teachers' technological knowledge (Guerrero, 2010). We argue that teachers can compensate for their lack of programming skills with their pedagogical knowledge and by using object negotiation with the students.

Second, teachers are capable of indirectly influencing the use of different tools during the learning process through the object. The reason is that students had mathematical tools in use, and they managed with their programming tools in use.

Third, the role of teachers affects students' collaboration. According to previously conducted studies, technology, programming, and robot integration support collaborative learning in mathematics classrooms (Forsström & Kaufmann, 2018; Bray & Tangney, 2017; Martinovic et al., 2013). We proved that collaboration among students depends on the teacher's role, particularly in the object negotiation phase.

6. Discussion

Even though the sessions observed and analyzed for this article were not part of a mathematics class, the observations are transferable to the mathematics classroom because the activities support the mathematics curriculum with the development of problem-solving skills and the use of mathematical tools. We observed a circumstance under which it was possible to integrate programming into mathematics even when the mathematics teacher did not have a technological background.

The key difference between the data from the two sessions that we observed was the role of the teacher. The task during Session 1 was highly student-centered, and the teacher did not participate in the activity. The students were the only subjects in the activity, and activity development was dependent on the tools that they were using. The availability of tools to the subjects depended on their knowledge and histories (Engeström, 2005). However, they did not have the required knowledge; hence, they were not able to make progress.

During Session 2, the teacher renegotiated the object of the activity together with the students. Thus, the teacher was one of the subjects, together with the students. The teacher influenced object development with his knowledge and tools. The object eventually agreed upon by the students and the teacher kept the students and the teacher motivated throughout the activity.

These sessions show that the key to the successful use of robots appears to be fruitful teacher intervention for the negotiation of objects that are obtainable by the students and pedagogically useful. In this case, the teacher and the students worked together as subjects of the activity toward the same object, and thus, they have the knowledge and tools of both the teacher and the students. When they worked together, their knowledge was stronger and they had more tools to use, which enabled fruitful activity development.

The model that we used could also be used to analyze the integration of technology into a mathematics classroom where the teacher is not an expert in technology. According to earlier studies, although the integration of technology has the potential to change the culture of traditional mathematics classrooms to be more student-centered (Bray & Tangney, 2017), teachers without strong technological knowledge still tend to integrate technology using a teacher-led approach (e.g., Guerrero, 2010; McCulloch et al., 2018). In a traditional, teacher-led classroom, the students and the teacher have separate activity systems, and each uses their own tools to achieve their individual objects. Traditionally, students are objects in the teacher's activity system, which we typically call "teaching." The learning activities of students have a different object, which is frequently the completion of a given task (Engeström, 2008; Martinovic et al., 2013). In a totally student-centered approach, the students have their own separate activity system, and they use their own tools to achieve the objects that they themselves created. In such a system, they are on their own if the teacher is not able to help them. Even if they have good technological knowledge, the teacher's guidance is needed if technology is to be successfully integrated into the classroom. The mathematics teacher often has strong pedagogical and mathematical knowledge on the basis of their history as a teacher even if they lack technological knowledge. Neither the students nor the teacher knows everything, and one key is that students and the teacher know different things. The use of technology in the classroom is most effective when the teacher and students pursue a common object together rather than pursuing two disparate objects. Through the common object, the teacher brings their knowledge and tools in addition to the students' knowledge and tools to the activity that the students are engaged in.

This article addressed the very beginning of programming integration. This paper might not have a report on what happened over time when the students and the teacher were more familiar with the programming tools; however, it gave valuable information from the beginning of programming integration on situations with the potential to further development. However, it was obvious at the beginning of the sessions that the development of the whole activity depended on the teacher's role as object negotiator, which provided a good basis for future activities.

Another question of interest is the following: what happens when students want to develop their innovative ideas and need technological advice? We proved that the teacher's role as an object negotiator provides a good basis for this because it creates a conducive, facilitative environment for the teacher and the students to work together and use their knowledge to solve emerging problems. Moreover, there is a need for many more studies to be conducted on the questions raised in this paper and others. The observations made during this study support the idea that there is a need for further education and peer support for teachers who do not have previous knowledge regarding programming but wish to or must integrate programming into their classrooms (e.g., Balanskat & Engelhardt, 2015; Bocconi et al., 2018).

7. Conclusions

This article has explored the impact of the role of the teacher in the integration of robots into the mathematics curriculum on students' mathematics learning processes. Our findings suggest that the choices of the teacher in the activity design phase are the most essential element supporting students' whole learning process with robots. It enables fruitful mathematics when the teacher is an active and engaging object negotiator at the beginning of the sessions in technology integration. These learning processes depend on the interactions between the teacher and students, and therefore, these cannot be predicted or controlled in advance (Engeström & Sannino, 2012).

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Acknowledgements

I thank Geir Afdal, Odd Tore Kaufmann, Grete Netteland and two anonymous reviewers for their valuable comments. I also thank all participants in this study.

References

Ardito, G., Mosley, P., & Scollins, L. (2014). We, robot: Using robotics to promote collaborative and mathematics learning in a middle school classroom. Report *Middle Grades Research Journal, 9*(3), 73.

Balanskat, A., & Engelhardt, K. (2015). *Computing our future: Computer programming and coding - priorities, school curricula and initiatives across Europe.* Brussel European Schoolnet.

Barak, M., & Assal, M. (2018). Robotics and STEM learning: students' achievements in assignments according to the P3 task taxonomy—Practice, problem solving, and projects. *International Journal of Technology and Design Education, 28*(1), 121–144. https://doi.org/10.1007/s10798-016-9385-9.

Benitti, F. B. V., & Spolaôr, N. (2017). How have robots supported STEM teaching? In M. S. Khine (Ed.). *Robotics in STEM education: Redesigning the learning experience* (pp. 103–129). Cham: Springer International Publishing AG.

Bocconi, S., Chioccariello, A., & Earp, J. (2018). *The Nordic approach to introducing computational thinking and programming in compulsory education. Report prepared for the Nordic@BETT2018 steering group.* https://doi.org/10.17471/54007.

Bray, A., & Tangney, B. (2017). Technology usage in mathematics education research – A systematic review of recent trends. *Computers & Education, 114*, 255–273. https://doi.org/10.1016/j.compedu.2017.07.004.

Drijvers, P., Doorman, M., Boon, P., Reed, H., & Gravemeijer, K. (2010). The teacher and the tool: Instrumental orchestrations in the technology-rich mathematics classroom. *Educational Studies in Mathematics, 75*(2), 213–234. https://doi.org/10.1007/s10649-010-9254-5.

Engeström, Y. (1987). *Learning by expanding: An activity-theoretical approach to developmental research.* Helsinki: Orienta-Konsultit.

Engeström, Y. (2005). In G. Rückriem (Vol. Ed.), *Developmental work research: Expanding activity theory in practice. Vol. 12*. Berlin: Lehmanns Media.

Engeström, Y. (2008). *From teams to knots: Activity-theoretical studies of collaboration and learning at work.* Cambridge: Cambridge University Press.

Engeström, Y., & Sannino, A. (2012). Whatever happened to process theories of learning? *Learning. Culture and Social Interaction, 1*(1), 45–56. https://doi.org/10.1016/j.lcsi.2012.03.002.

Forsström, S. E., & Kaufmann, O. (2018). A Literature Review Exploring the use of Programming in Mathematics Education. *International Journal of Learning, Teaching and Educational Research, 17*(12), 18–32. https://doi.org/10.26803/ijlter.17.12.2.

Guerrero, S. (2010). Technological pedagogical content knowledge in the mathematics classroom. *Journal of Computing in Teacher Education, 26*(4), 132–139. https://doi.org/10.1080/10402454.2010.10784646.

Holland, D., & Reeves, J. S. (1996). Activity theory and the view from somewhere: Team perspectives on the intellectual work of programming. In B. A. Nardi (Ed.). *Context and consciousness: Activity theory and human-computer interaction* (pp. 257–281). Cambridge, Massachusetts: MIT Press.

Karim, M. E., Lemaignan, S., & Mondada, F. (2015). Review: Can robots reshape K-12 STEM education? *Paper presented at the proceedings of the 2015 IEEE international workshop on advanced robotics and its social impacts, Lyon, France*.

Koehler, M. J., & Mishra, P. (2009). What is technological pedagogical content knowledge? *Contemporary Issues in Technology and Teacher Education, 9*(1)https://www.

citejournal.org/volume-9/issue-1-09/general/what-is-technological-pedagogicalcontent-knowledge.
Kunnskapsdepartementet (2007). *Utdanning-fra barnehage til voksenopplæring*.
La Paglia, F., la cascia, C., Francomano, M., & La Barbera, D. (2017). Educational robotics to improve mathematical and metacognitive skills. *Annual Review of Cypertherapy and Telemedicine, 15*, 70–75.
Leonard, J., Buss, A., Gamboa, R., Mitchell, M., Fashola, O., Hubert, T., & Almughyirah, S. (2016). Using robotics and game design to enhance children's self-efficacy, STEM attitudes, and computational thinking skills. *Journal of Science Education and Technology, 25*(6), 860–876. https://doi.org/10.1007/s10956-016-9628-2.
Lindh, J., & Holgersson, T. (2007). Does lego training stimulate pupils' ability to solve logical problems? *Computers & Education, 49*(4), 1097–1111. https://doi.org/10.1016/j.compedu.2005.12.008.
Martinovic, D., Freiman, V., & Karadag, Z. (2013). Visual mathematics and cyberlearning in view of affordance and activity theories. In D. Martinovic, V. Freiman, & Z. Karadag (Eds.). *Visual mathematics and Cyberlearning* (pp. 209–238). Dordrecht: Springer Netherlands.
McCulloch, A. W., Hollebrands, K., Lee, H., Harrison, T., & Mutlu, A. (2018). Factors that influence secondary mathematics teachers' integration of technology in mathematics lessons. *Computers & Education, 123*, 26–40. https://doi.org/10.1016/j.compedu.2018.04.008.
Mubin, O., Stevens, C., Shahid, S., Mahmud, A., & Dong, J.-J. (2013). A review of the applicability of robots in education. *Technology for Education and Learning, 1*, 2–7. https://doi.org/10.2316/Journal.209.2013.1.209-0015.
Olive, J., Makar, K., Hoyos, V., Kor, L. K., Kosheleva, O., & Sträßer, R. (2010). Mathematical knowledge and practices resulting from access to digital technologies. In C. Hoyles, & J.-B. Lagrange (Eds.). *Mathematics education and technology-rethinking the terrain: The 17th ICMI study* (pp. 133–177). Boston, MA: Springer US.
Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas.* New York: Badic Books, Inc.
Papert, S. (1993). *The Children's machine: Rethinking School in the age of the computer.* New York: Basic Books.
Papert, S. (1996). *The connected family: Bridging the digital generation gap.* Atlanta, Georgia: Longstreet Press.
Ruthven, K. (2014). Frameworks for Analysing the expertise that underpins successful integration of digital technologies into everyday teaching practice. In R. O. Clark-Wilson A, & N. Sinclair (Vol. Eds.), *The mathematics teacher in the digital era. Mathematics education in the digital era. Vol. 2. The mathematics teacher in the digital era. Mathematics education in the digital era* (pp. 373–394). Dordrecht: Springer.
Savard, A., & Freiman, V. (2016). Investigating complexity to assess student learning from a robotics-based task. *Digital Experiences in Mathematics Education, 2*, 93–114.
Spradley, J. P. (1980). *Participant observation.* New York: Holt, Rinehart and Winston.
Utdanningsdirektoratet (2013). Læreplan i matematikk fellesfag. Retrieved from http://data.udir.no/kl06/MAT1-04.pdf?lang=http://data.udir.no/kl06/nob.
Yamagata-Lynch, L. C. (2010). *Activity systems analysis methods.* Dordrecht: Springer.