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Digital technology in mathematics education – more than a tool

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Digital technology in the mathematics classroom is often seen only as a tool. The purpose of this paper is to expand the discussion about the kind of roles digital technology can play by using programming activities as examples. We apply components from Engeström's Cultural Historical Activity Theory to discuss programming as the object of the activity; the tool in use; part of the division of labor; and as a part of a classroom community. Digital technology as a part of division labor and classroom community has the potential to provide rich classroom communications and learning processes in which the students, the teacher, and digital technology interact with each other.

Keywords: Digital technology, programming, roles, CHAT, mathematics education

Introduction

Digital technology has become an increasingly more important part of education in the last decades. In mathematics education, we see a development of concepts like ICT literacy (e.g. Dede, 2010) and digital competence, and research titles like Clark-Wilson et al.'s (2014) *The mathematics teacher in the digital era*. During the last decade, programming has been introduced as an important 21st-century skill. It is included in mathematics curriculums (and other subjects) in many countries (Balanskat & Engelhardt, 2015) and national policy documents (Bocconi et al., 2018).

Hoyles (2018) stated that the dominating view on mathematics is that “mathematics is simply a set of disparate rules for calculation and students attempt to master this ‘mathematical machinery’ without seeing its purpose” (p. 209). Teaching based on this view is dominated by students being given premade tasks to be solved with predefined mathematical tools and students have difficulties seeing the purpose of doing the tasks. Hoyles argued that the digital technology in such classrooms is used to speed up procedures, and calculations are largely only replicating doing mathematics with paper and pencil.

According to reviews by Batiibwe (2019) and Bray and Tangney (2017), digital technologies are often integrated into non-transformative ways in mathematics classrooms, and they are often regarded as tools only. Batiibwe (2019) reviewed articles on the mediating role of digital technology in mathematics education from a Cultural Historical Activity Theory (CHAT) perspective. All of the reviewed articles discussed the role of digital technology in classroom activities only as a mediating tool. Other roles, such as digital technology as an object, as the driving force in the activity, were not discussed. Bray and Tangney (2017) found that digital technology is primarily used traditionally in mathematics classrooms. Task assignments are not adapted to the integration of digital technology, and digital technology is used as a substitute for the teacher or to save time in calculations (e.g. Åberg-Bengtsson, 2006). Digital technology is often used because it simplifies things and releases students from tiresome calculations. Such use of technology generates to a little extent changes for the teaching and learning of mathematics.

However, digital technology can be used to explore mathematics in diverse ways. The integration of digital technology has the potential to transform activities in mathematics classrooms by engaging students and providing them possibilities to take ownership of their learning (Hoyles, 2018). According to Bray and Tangney (2017), programming activities were more transformative than the activities with other digital technologies used in mathematics classrooms. In most of the studies that discussed programming integration, the task assignments in programming activities were often collective, freer, and more student-centric. The teacher was often acting as a guide instead of just being a lecturer, and the students were able to use their ideas in the task design by negotiating with each other and the teacher and by interacting with digital technology.

To investigate the transformative possibilities of including programming in mathematics education, *the focus in this paper is on programming's potential to play roles that go beyond the role of being a tool.* We use examples from two earlier studies on mathematics and programming presented in Forsström and Afdal (2020) and Herheim and Johnsen-Høines (2020). In both studies, the students worked collectively with their programming activities. By taking a CHAT perspective, we exemplify and discuss programming's potential to be an object, to become part of the division of labor and community, as well as being a tool in the students' collective activities. The analysis is based on a micro-level approach of the activity system analysis in Engeström's (1987) version of CHAT, where social, multi-voiced interactions are part of the knowledge creation processes. Focusing on collective classroom activities instead of individual actions gives the possibility to get information about relational processes in the classroom. An activity system analysis enables a discussion of the potential roles of programming as a part of mathematics classroom activities in addition to being a tool. The different roles can be discussed in relation to other components in the activity system during the activity development. Taking a CHAT perspective makes it possible to see teaching and learning as dialectically intertwined processes (Engeström & Sannino, 2012).

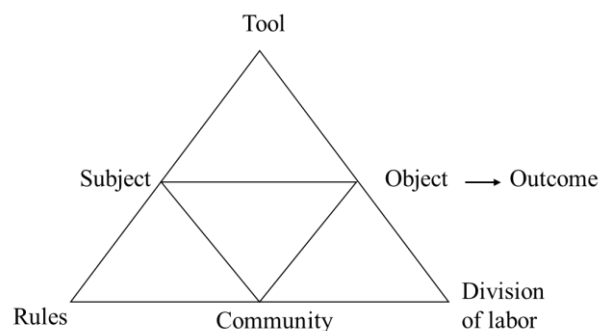


Figure 1: The activity system model from CHAT (Engeström, 1987, p. 78)

Cultural-Historical Activity Theory

The analytical approach is based on an activity system analysis, where the seven components: subject, object, tool, rules, community, division of labor, and outcome (see Figure 1 and Table 1) include the potential roles we argue that programming can play. According to Engeström (2005), the components are interrelated. For instance, in the uppermost sub-triangle, the tool mediates the subject's activity towards the object. With the help of tools, subjects interact with the object of the activity, which is the driving force in the activity. The activity is framed by collective components of rules, community, and division of labor, and the relationships between the components influence the activity development. Due to the interactions between subjects and dynamic relationships between the components, the collective activities are constantly transforming and developing. Knowledge is distributed between the different participants and components in the activity system, and learning is seen as a change in the components of collective activities; as an expansion of a collective object.

Table 1: Components in the activity systems analysis

Component	Definition/meaning	Examples from these studies
Subject	The individual/group of people who engage in the activity (Yamagata-Lynch, 2010)	The students and the teacher
Object	The driving force of the activity (motive and goal) (Engeström, 1987)	Fulfil a task by using programming
Tool	Instrument that mediates the activity (Engeström, 1987)	A robot, app, computer, and mathematical tools
Rules	The regulations that are relevant to the activity (Yamagata-Lynch, 2010)	Task assignment, the rules of the mathematics classroom
Community	The group the subject belongs to 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 role of the teacher and the programming
Outcome	The result of the activity (Yamagata-Lynch, 2010)	A robot drives a track, a shape is drawn etc. as they are programmed

When applying this theoretical perspective, we understand mathematics and digital technology such as programming, as components in an activity system. They can play different kinds of roles depending on the activity, the other components and the relationships between them, and how the activity develops. To understand the role of programming in relation to the role of mathematics, the activities described in Forsström and Afdal (2020) and Herheim and Johnsen-Høines (2020) were analyzed from a CHAT perspective, with a particular emphasis on the components object and tool, and on community and division of labor. To identify the object of the activities, we focused on the collective aim of the subjects (the students). We identified, for instance, what the students and the teacher were aiming to do, what the driving force in the activities was, such as to make a robot drive a track. The tools in the activity were determined by identifying what kind of tools the subjects used to achieve their object. The tools were distinguished from the objects by identifying the focus of the subjects. According to Engeström (2005), the focus can only temporarily be on tools. The activity components are dynamical and multilayered and the activities constantly transforming. The role of programming and mathematics developed in relation to other components in the activity system.

Expanding the discussion about the roles programming can play

In the following, we discuss how programming can play the role of an object and tool, be part of the division of labor and community, and how programming, when being more than a tool, can act as a resource in students' collective learning processes in mathematics.

Programming as an object and tool

In the programming activities discussed in this paper, the students are challenged to program a robot to drive a certain path (Forsström & Afdal, 2020) and to draw a particular geometrical shape with programming in Scratch (Herheim & Johnsen-Høines, 2020).

In Forsström and Afdal (2020), students aged 12–13 years old programmed Lego Mindstorm robots. The students were challenged to make the robot drive a circle, and the programming elements became their main object at the beginning. The students then used a trial-and-error strategy to achieve their object, but the mathematical tools were not used systematically (see Figure 2). The teacher negotiated with the students and suggested that they could program the robot to drive a circle with a radius of one meter. In that way, the teacher helped the students to mathematize their programming object and it developed a need for mathematical tools in the activity. The students focused on mathematics when they did the calculations. They used, for instance, the circle perimeter formula to find out the length of the route the robot had to drive, as well as proportions to uncover how much the robot had to turn. After the students obtained the needed results from their calculations, they used them in their programming to reach their object (see a more detailed discussion about the activity development in Forsström and Afdal (2020)). From a mathematics education perspective, such transformation of an object, from a programming object to a mathematical object, is often the intended purpose of including digital technologies in the teaching and learning of mathematics.

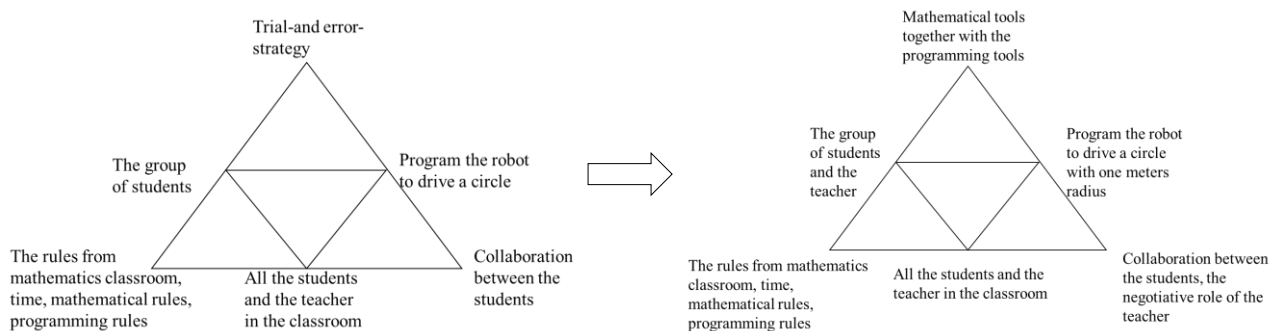


Figure 2: The activity development in Forsström and Afdal (2020)

Programming tools were in use together with mathematical tools. The students revised their codes according to their mathematical calculations to improve the programming of the robot. The programming tools provided an opportunity and a need to test mathematical tools. When the students did not remember the circle perimeter formula and used radius instead of diameter, they got immediate feedback because the robot only drove one half of a circle. Because of the visual feedback of an error, the students were able to return to their code and do corrections. Based on the feedback, the students successfully concluded that to get the robot to drive a whole circle, they needed to double their answer. The teacher encouraged, with his questions, the students to find out why they needed to double their answer. The students accepted the challenge and mathematics became the object of the activity.

Herheim and Johnsen-Høines (2020) investigated screen-based programming with Scratch where two 12–13 years old students collaborated to program a pentagon. This programming required both mathematical and programming considerations from the students. The students were unfamiliar with

the geometrical properties of a pentagon, about the number of sides and the size of the interior angles. They also faced programming challenges such as how the turn block does not give the anticipated interior angle but the turning angle. The students struggled with both mathematical and programming aspects, but they used a systematic trial-and-error strategy to get closer and closer to programming a pentagon. The properties of the programming software allowed them to find out more about pentagons. They could test different angle sizes in their code and after each attempt, they received immediate feedback through the shapes drawn by the program: a hexagon shape that lacked one side; a pentagon where the first and last side intersected; and a pentagon with a tiny gap between the first and last side. This Scratch programming activity can be regarded as an example of how programming and mathematics can become an intertwined object of the activity – not only as of the overall object but for sub-objects during the process as well.

Being able to successfully program something can be the main driving force for students, and that makes programming an overarching object. However, during such work processes, students need not only to figure out what mathematics is needed and how to use it. They also need to figure out how a path or a shape can be programmed, what code blocks to include in the code and how to include them, and then they often need to try out different versions of a code. In several phases of their work, there are programming aspects that play the role of intermediate aims in the students' activities. This gives ground for saying that students can have several programming sub-objects as well.

Based on our discussion of the examples from Forsström and Afdal (2020) and Herheim and Johnsen-Høines (2020), we argue that programming can be an object as well as a tool. This can take place through a transformation between being a tool and an object, or as an intertwined object together with mathematics. Programming as an object in activities can enable the use of mathematics as a tool in students' activities. The programming tools enabled the testing of mathematical tools and by that, the programming tools brought a new dimension to the use of mathematical tools. As the activities unfolded, the programming provided feedback to the students about the mathematical tools they were using. When the students tested the codes, the robot and the visualizations on the computer screen gave them immediate feedback on the mathematical tools in use. The robot and the Scratch program acted as a part of the division of labor in students' activities. That will be discussed in more detail in the following.

Programming and robots as a part of the division of labor and as a part of the community

In some studies on digital technologies in mathematics education (e.g. Monaghan, 2005; Lavy & Leron, 2004), the technology is considered by students as a participant or quasi-human agent. The classroom activities can be seen as networks, which constitutes both human and non-human actors, such as the students, the teacher, and the robot. Students use screen images to express themselves and the other students use the same images to interpret the utterances – the technology provides language. Digital technologies can prompt, respond, and frame communication, but they have, unlike teachers and peers, infinite patience and do not have expectations and are not judgmental (Monaghan, 2005). Technologies can appear to act like subjects when they respond to inputs so that students get the feeling they must justify their responses, without feelings or expectations. Wegerif (2004) pointed out that this dual role of digital technologies can make them able to play a part in students' activities.

In the studies presented by Forsström and Afdal (2020) and Herheim and Johnsen-Høines (2020), knowledge was embedded in processes between robots and students and between computer screens and students. Students got information about their mathematical tools by getting feedback from nonhuman actors – the robots and the computer screens. With this feedback, the students got the opportunity to interact and negotiate with their mathematical object. The nonhuman actors worked as resources for students' understanding of their mathematical object and mathematical tools in use. The students interacted with their mathematical object through the mediation of tools but also through the mediation of division of labor. The programming, together with the students and the teacher, took part in the division of labor and mediated by that the relationship between the community and the object of the activity. In that way, programming did not act as a substitute for the teacher, but it acted to some extent as a participant together with the students and the teacher.

In Forsström and Afdal (2020), the development of the activity was constituted by the negotiations between the students and the teacher. The teacher encouraged the students to use mathematical tools with his questions. However, the teacher's questions would have been of little value without the participatory role of the robot. He referred to the robot's movements when discussing with the students, for instance when the robot drove only a half of a circle and he challenged them to find out why they needed to double their answer.

In Herheim and Johnsen-Høines (2020), the students discussed the geometrical properties of a pentagon. They based their discussions and revisions for the next attempt on the feedback from the Scratch program, on how the mathematics was represented by the code and in particular the drawings of the shapes. Through the collaboration with each other and with the programming, the students found out more about pentagons and programming. During this process, the programming played a role in the division of labor (see Figure 3).

When programming becomes a part of the division of labor and interacts with the students and the teacher by giving feedback, it also becomes part of the collective activities. The programming can be seen as a part of the social classroom group, as a part of the community in students' activity systems. Such communities can be regarded as

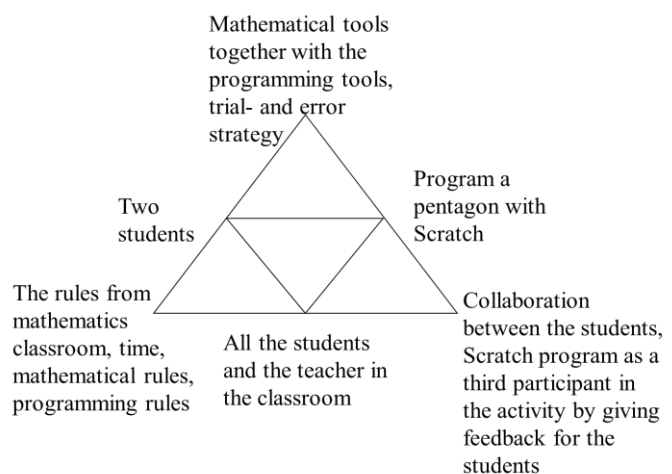


Figure 3: The activity system in Herheim and Johnsen-Høines (2020)

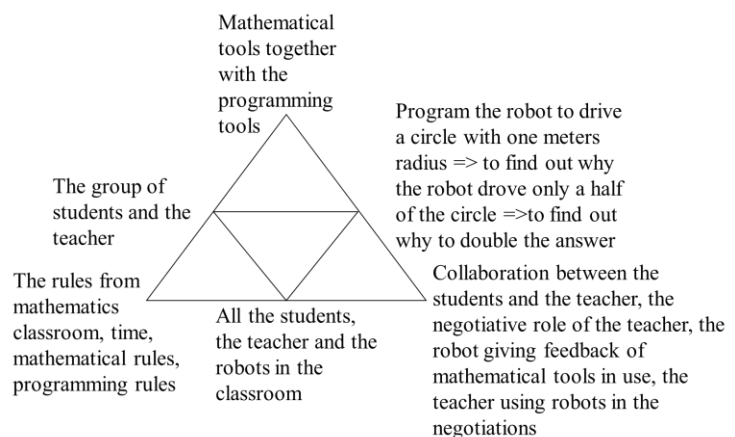


Figure 4: Robot as a part of the division of labor and community in Forsström and Afdal (2020)

digitalized classroom communities. In digitalized classroom communities, students and teachers interact with digital technology, and digital technology can be seen as a kind of a digital participant in the collective classroom activities (see Figure 4).

Concluding comments

As discussed in the introduction, digital technology is often regarded as a tool. Based on Bray and Tangney (2017), digital technology is mostly integrated into mathematics classrooms in non-transformative ways, used as a tool to save time in calculations, and as a substitute for the teacher or paper and pencil. We have discussed how digital technology can play more than the role of being a tool, how it can take different kinds of roles in classroom activities by introducing programming activities from earlier studies. The different roles discussed are programming as a tool, an object of the activity, a part of a division of labor in students' classroom activities, and as part of the community.

From a mathematics education perspective, the students' use of mathematics in programming activities is a priority, and the different roles of programming are discussed in connection to the role of mathematics in students' collective activities. We have argued that programming acted as part of the division of labor and as a part of the digital classroom communities in both the robot and the Scratch example and contributed to fruitful learning processes in mathematics. We called the classroom communities, where digital technology acts as a part of the community as digitalized classroom communities.

In the digitalized classroom community, digital technology can take different kinds of roles in students' collective learning processes in mathematics. The students, the teacher, and the digital technology can interact with each other, and programming and mathematics can have an active and transformative role. Digital technology can act as a resource for students' understanding of their mathematical object by giving students feedback and in that way play a participative role. In the examples described in this paper, it might appear as if the programming acted just like a paper and pencil by drawing a circle or a pentagon, but the programming acted more diverse than paper and pencil. The programming brought an extra dimension to the students' activities by acting together with them, the teacher, and mathematics. It gave confirmations of the use of mathematical tools by correcting students' mistakes and providing visualizations of key properties in mathematics and showed by that a potential to trigger and facilitate students' mathematical activity.

Furthermore, the teacher can use digital technology as a teaching partner. As in the examples discussed in this paper, the programming gave information to the teacher about students' understanding as well as their struggles and mistakes. The teacher and the students can base their comments, suggestions, and revisions on the movements of a robot or drawing of shapes on a screen. Digital technology as a part of the classroom community can play a valuable role in the collective activity with students and the teacher. In the digitalized classroom community, the students can work towards their object, together with the teacher, the digital technology, and the mathematics.

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