



The dual role of humanoid robots in education: As didactic tools and social actors

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Abstract

The idea of using social robots for teaching and learning has become increasingly prevalent and robots are assigned various roles in different educational settings. However, there are still few authentic studies conducted over time. Our study explores teachers' perceptions of a learning activity in which a child plays a digital mathematics game together with a humanoid robot. The activity is based on the idea of learning-by-teaching where the robot is designed to act as a tutee while the child is assigned the role of a tutor. The question is how teachers perceive and talk about the robot in this collaborative child-robot learning activity? The study is based on data produced during a 2-years long co-design process involving teachers and students. Initially, the teachers reflected on the general concept of the learning activity, later in the process they participated in authentic game-play sessions in a classroom. All teachers' statements were transcribed and thematically coded, then categorized into two different perspectives on the robot: as a social actor or didactic tool. Activity theory was used as an analytical lens to analyze these different views. Findings show that the teachers discussed the activity's purpose, relation to curriculum, child-robot collaboration, and social norms. The study shows that teachers had, and frequently switched between, both robot-perspectives during all topics, and their perception changed during the process. The dual perspectives contribute to the understanding of social robots for teaching and learning, and to future development of educational robot design.

Keywords Humanoid robots · Social robots · Education · Teachers · Activity theory

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1 Introduction

Robots were first introduced in educational contexts as tools for programming or explaining technology, but as robot technology advanced humanoid robots are nowadays also used as embodied social agents in education (Angel-Fernandez & Vincze, 2018; Belpaeme et al., 2018; Benitti, 2012; Mubin et al., 2013). The motive for using humanoid robots in educational environments is that they are supposed to increase students' motivation, engagement, and concentration (Keane et al., 2017; Pandey & Gelin, 2017). Hence, it has become interesting to explore the possibilities and limitations of using social robots for teaching and learning. When the robot is used as an embodied social agent, it can be designed to act in the role of a peer, learning companion, tutor, teaching assistant, or teacher (Belpaeme et al., 2018; Pandey & Gelin, 2017; Sharkey, 2016; Woo et al., 2021), with varying levels of involvement in the learning task (Mubin et al., 2013). Social robots have also been assigned the role of learning companion, as a peer or a tutee, often in combination with the theory of learning by teaching (Pandey & Gelin, 2017). For example, robots have been used in learning-by-teaching situations when a child teaches a robot tutee to play a digital math game (Pareto et al., 2019; Serholt et al., 2020), when a child teaches a robot tutee a foreign language (Jamet et al., 2018), or when a child demonstrate handwriting to a robot tutee (Lemaignan et al., 2016).

However, bringing in a social robot acting in a learning activity in the classroom also affects the role of the teacher (Mubin et al., 2013; Woo et al., 2021), and it is therefore important to understand the role of the teacher in a child-robot collaborative learning activity (Ahmad et al., 2016). When social robots are used for teaching and learning, the robot, as well as the student(s), are often assigned a predetermined role in which they are supposed to act. More rarely, is the teacher's role predetermined or even discussed as taking an active part in the role-play, and consequently, the role of the teacher or the teacher's experience of the role-play with a robot in the classroom is lacking in previous research (Ceha et al., 2021).

From the sociocultural perspective, learning is a constantly ongoing process that is closely integrated with the social context and where all actors involved do not necessarily learn the same thing (Vygotskiĭ, 2012). What a certain individual learns depends on the knowledge, experience, and expectations that the individual brings into the situation (Säljö, 2000), which gives a picture of the complexity that arises when the robot, the students, and the teacher interact in the classroom. Social interactions, including those between humans and robots, are important in the learning process and can lead to positive educational outcomes if the student succeeds in communicating and maintaining a relationship with the robot (Rosanda & Starcic, 2019). However, there is relatively little knowledge about learning activities with robots in a realistic context, with a group dynamic or complexity that resembles a real classroom environment (Rosanda & Starcic, 2019). Thus, it is more interesting to study the dynamics that arise in the learning activity than to examine the effectiveness of robotic activities (Rosanda & Starcic, 2019).

Nevertheless, actual behaviors emerge during activities and thus need to be negotiated within the social context in which the activity takes place. Therefore, we use

activity theory to study the learning activity, as it is based on a role-playing social environment with several interacting actors. Activity theory emphasizes the relationship between individuals and collectives, where each actor continuously contributes to a change in the activity system and vice versa (Roth, 2004). The participating actors' preconceived notions and ideas about what their role consists of, as well as their ideas and preconceived notions about how the other actors play their roles, affect both the interaction and the development of the activity.

However, the role-play setting with the social robot has an overarching purpose of stimulating learning, the peer robot is put into an educational setting for a didactic purpose, and therefore the teachers need to consider the learning activity from a didactic perspective and evaluate the potential of the proposed learning activity as such. It is important to include teachers in the design process of robots as they are the ones who decide both how and when students should use technology. It is the teachers who integrate the robots into teaching and consequently, they have to manage the changes that occur in their teaching practice (Ceha et al., 2021). Therefore, we have involved teachers early in the design phase, and the robot's behavior, as well as the learning activity, are co-designed with students and teachers in an authentic setting for a longer period (Barendregt et al., 2020). Involving teachers early in the design process is important because they are key stakeholders (Kory Westlund et al., 2016). A participatory approach is unusual in human–robot interaction and research in the field is usually done experimentally in a laboratory setting, two factors that may limit its contextual validity (Björling & Rose, 2019).

Therefore, we have tried to capture teachers' ideas of the child-robot gameplay as a learning activity in several ways during the early phases of the co-design process. In this study, we focus on their ideas, preconceptions, and intentions of the robot tutee role as an actor in the child-robot game playing activity, by examining how they talk about the robot in its role as a learning companion and how they imagine the robot to behave in this role. Thus, our research question is as follows: *How do teachers perceive and talk about a social educational robot designed as a tutee for a collaborative child-robot learning activity?* The study aims to provide an increased understanding of both opportunities and challenges associated with the use of social robots in education. The intention is also to start a discussion about whether the teachers' view of the robot may affect the learning situation.

2 Background

2.1 Related work

Social robots are designed to act in a number of different roles (Mubin et al., 2013; Woo et al., 2021), which are considered suitable for different educational contexts. When the robot acts in the role of a teacher or tutor, it is often supposed to be an assistant to the human teacher while it as a peer or co-learner is supposed to collaborate with the child. If the robot has less initial knowledge than the child and acts as a novice, the child can act as a tutor and teach the robot. Since the overall aim here is

for the child to learn, the robot learning is subordinate, the principles of learning-by-teaching apply (Ceha et al., 2021; Pandey & Gelin, 2017).

Social robots are primarily used to support the learning of subject-specific concepts or skills development (Benitti, 2012; Ceha et al., 2021) and are mainly used in language, science, or technology education (Mubin et al., 2013; Rosanda & Starcic, 2019). Most often it is about the robot being used to develop the students' theoretical abilities, more rarely about practical ones (Lemaignan et al., 2016). Robots are also used to support cognitive development in different ways (Jamet et al., 2018). Compared to other educational technology, social robots can add social interaction to the learning context through their embodiment (Mubin et al., 2013). Fully embodied robots can engage in social interaction with the child as they can both talk and show facial expressions, which can be an advantage if they are to be used in non-technical subjects such as language or music (Mubin et al., 2013). A proposal from teachers is to use social robots to teach children social skills such as taking turns, patience, and sharing (Kory Westlund et al., 2016).

The use of robots as an educational tool can have a motivating effect, especially in the beginning (Majgaard, 2015). Hence, social robots are used to achieve effective results such as attitudes to learning and perceived performance capability (Ceha et al., 2021). Moreover, the interaction with social robots seems to help children concentrate (Jamet et al., 2018). According to teachers, the use of robots can be a way to individualize teaching and adapt teaching to the students' different needs (Hrastinski et al., 2019). Besides, social robots encourage children to use their critical thinking skills and imagination, and to be sociable and independent (Causo et al., 2017). However, the empirical evidence supporting the effectiveness of social robots in education is limited, and more long-term studies are needed (Benitti, 2012; Konijn et al., 2020; Leite et al., 2008).

2.1.1 Robot as a tutee or peer

Social robots can be used in the role of tutee by combining the benefits of teachable qualities with social qualities, by making the robots adapt their learning style to the tutor and make the learning process clear while simultaneously enabling social interaction (Werfel, 2013). Using a robot in the role of tutee has been shown to help children develop in several different areas, such as reading, writing, language, and reasoning (Jamet et al., 2018). In addition, the approach of learning by teaching has shown an increased commitment and focus of the tutor (Jamet et al., 2018). A long-term goal may be for robots to learn from students through natural interactions, conversation, and gestures (Werfel, 2013). Since the way students teach can be used to interpret their level of knowledge and skills, it is beneficial if the robot tutee could use such information to highlight weaknesses as well as strengths, for example by asking questions or reflecting students' answers (Werfel, 2013).

There are some previous studies where the robot acts as a tutee. For example, Tanaka and Matsuzoe (2012) conducted a study with a care-receiving robot, i.e., a tutee. The goal was for the children to teach the robot English verbs through their spontaneous desire to take care of the robot, an activity that took place in the classroom with the teacher. However, the robot had a limited learning ability which

harmed the learning situation. In a study by Lemaignan et al. (2016), the children teach the robot handwriting by correcting what the robot wrote. The social interaction consisted of single phrases and the study showed that the children experienced that the robot wrote itself and that it learned over time. The experiment involved an adult who helped with taking turns and guidance. The teacher had an instrumental role during the interaction but was still important for the child's learning situation.

The aim of the study that Yadollahi et al. (2018) conducted was to explore whether a robot, acting as a reading buddy, can support children's reading practice. The child's task during the interaction was to continuously correct the robot's reading when mistakes occur, a task that was performed without the presence of a teacher. The robot was also able to point to what was read, but the pointing gesture turned out to be beneficial only for students with high reading ability, while for students with low reading ability it was rather a disturbance. Serholt et al. (2020) studied a learning activity where a robot and a child collaborated and played a digital math game together. The robot's task was to ask questions about the game and its mathematical content, questions that the child was expected to answer verbally. The study emphasized the complexity of the child-robot interaction and showed that there are problems related to the robot's social norm violations. Moreover, the study also showed that the children found strategies to solve the problems, and some strategies involved either the teacher or the present peers.

A clear description of the didactic contract between the tutee and the tutor is required, which also needs to be explicitly told to the tutor (Jamet et al., 2018). The child must know that they have the status of a tutor and must be clear about how he or she should teach the robot (Topping, 2000). In addition, the difference in level of knowledge between tutor and tutee needs to be clarified (Jamet et al., 2018). Although, it is usually more challenging and engaging for the tutor if he or she knows just a little bit more than the tutee (Topping, 2000). However, teachers seem to be more confident in the children's ability to use robots than their own (Chevalier et al., 2016), which indicates that it is also important to study the role of the teacher. Hrastinski et al. (2019) describe various research focuses regarding the implementation of new technology and the use of social robots in the classroom, including teachers' beliefs in teaching with social robots, their design of learning activities, and their digital competence. The role of the robot in learning activity consequently affects the role of the teacher in the same educational context, but research on the role of the teacher in child-robot interaction is still limited. Among other things, more research is needed on how teachers may act to supplement the limited social interactive capacities of social robots (Hrastinski et al., 2019). Social robots can in various ways assist the teacher or support its teaching, but the teacher's presence is difficult to replace (Pandey & Gelin, 2017).

2.1.2 Teachers' perspective on robots in teaching

Teachers find it difficult to imagine how or why robots could be used in teaching and exhibit a limited knowledge of what kind of technology robots actually are (Hrastinski et al., 2019). Nevertheless, teachers imagine that a robot can be an engaging tool and that robots can gather useful data for assessment (Serholt

et al., 2014). Teachers believe that robots need to be adaptable to the curriculum and develop over time to create a long-term engagement (Ahmad et al., 2016). Moreover, to create a long-term commitment, teachers must be able to implement new content around which the child and the robot can collaborate (Ahmad et al., 2016). However, the expected usefulness of robots seems to decrease after the actual use of social robots in teaching, which indicates that difficulties arise those teachers cannot anticipate (Chevalier et al., 2016). Teachers' motive to use social robots in teaching is not about the robot per se, rather teachers want to develop their knowledge and learn something new (Chevalier et al., 2016).

Using robots in the classroom requires structure and organized learning activities (Majgaard, 2015). Among other things, teachers are concerned about how the children will handle the robot and about disruptions during their teaching (Serholt et al., 2014). Teachers need to be confident that they can control the robot. Basic knowledge of robots is needed to be able to handle various situations, especially technical faults, that may arise (Causo et al., 2017). In addition, teachers need support to implement robots in their teaching because it requires a lot of resources in the form of competence, both technical and pedagogical, premises, tools, and of course the robot itself (Causo et al., 2017). Dimensions in teaching that deal with ethics and social norms remain to be considered (Pandey & Gelin, 2017). Furthermore, teachers reflect on ethical issues regarding robot use in teaching. Issues include data security and privacy but also possible negative consequences of child-robot interaction (Serholt et al., 2017). Teachers believe that the use of robots in the classroom, in the long run, can affect human interaction and worry about whether the human and empathic aspects of relationships are affected (Hrastinski et al., 2019).

There is still a lot to learn about the dynamics that arise when a robot is used in a classroom, including more knowledge about the human–robot interaction, and especially about the one-to-many interaction (Causo et al., 2017). Designing learning activities with robots requires a precise understanding of the robot's role and its implications for learning (Yadollahi et al., 2018). Teachers who have used robots in teaching experienced some practical and technical problems with the robots. Among other things, language recognition was somewhat limited, especially when several children interacted with the robot at the same time (Majgaard, 2015). Teachers' perceptions of the use of humanoid robots for teaching and learning are also explored in a study by Chalmers et al. (2022). The focus of the study was to investigate how the use of robots fitted the curriculum and whether the use had a pedagogical value or not. The results showed that the teachers perceived a value in using humanoid robots as they enhanced the curriculum in several ways and engaged the students in a wide variety of subjects, from mathematics and robotics to language learning. The teachers experienced that the use of robots in the classroom helped the student to develop different skills, e.g., computational thinking, problem-solving, communication, and collaboration skills. However, the study also showed some challenges, especially of a technical nature. For example, there were problems with the robot's voice recognition, which led to challenges in the child-robot interaction. Moreover, some problems arose with the robot's hardware as well as its internet connection. All these issues led to frustration among those involved."

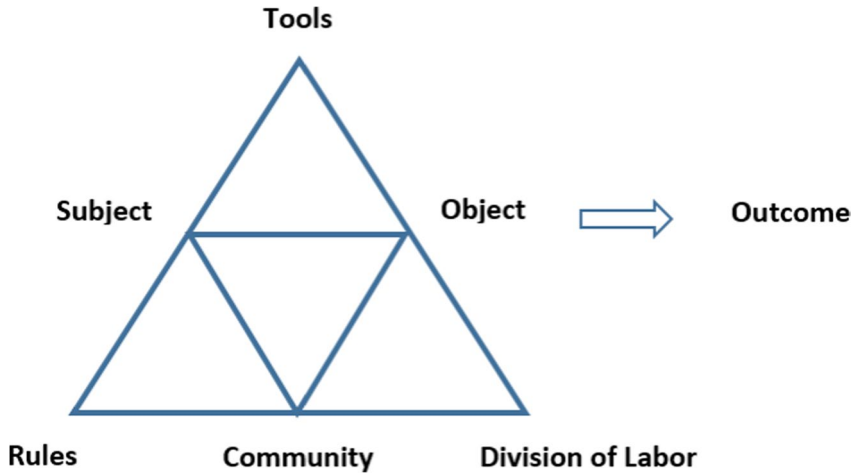


Fig. 1 The activity system by Engeström (1987)

2.2 Theoretical framework—Activity Theory

In this study, the social educational robot is used in a collaborative learning activity in a classroom. We have chosen activity theory as an analytical lens since the theory is appropriate for the analysis of human activity. Through the activity theoretical model, the complexity of a learning environment can be recognized by adding social, historical, and cultural conditions (Engeström, 1987). Engeström's activity system model is used as a framework for analyzing human needs, tasks, and outcomes. The model is represented as a triangle with interrelated key dimensions and is used to capture and change multi-mediational processes in human activity, see Fig. 1.

The activity system is based on six interrelated dimensions that together contribute to the activity's outcome (Engeström, 1987). The dimensions represent the following: The subject is the starting point for the analysis and constitutes the subject's actions. The object is what the subject's activity is aimed to accomplish, and tools are mediating artifacts that the subject uses to achieve the object. The dimension of rules consists of implicit as well as explicit regulations that govern the subjects' actions in the activity. The community includes all individuals sharing the same object in one way or another. Finally, the division of labor describes how work is shared within the community and includes issues of power and status. Activity systems are not static but evolve constantly due to various contradictions within and between activity systems. By identifying contradictions, conflicts, or tensions in an activity system, intentional or unintentional changes in any part of the system can be elucidated and later studied in more detail (Engeström, 2001). However, identifying contradictions does not automatically lead to transformations.

Activity theory has previously been used to study technology use in educational contexts (Murphy & Rodriguez-Manzanares, 2008; Nussbaumer, 2012; Roth et al.,

2009). Reasons for using activity theory as a theoretical lens include the coverage of many aspects of the educational environment: the background, perspective of students and teachers, and the entire departmental environment. In addition, development over time can be handled in the theory (Murphy & Rodriguez-Manzanares, 2008). For example, (Ceha et al., 2021) use activity theory to analyze teachers' expectations of social robot behaviors in different roles. (Boz & Alleksaht-Snider, 2021) use activity theory to study and analyze teachers' professional learning in a course focusing on coding and robotics. Also, (Utterberg et al., 2019) uses activity theory to study how the introduction of a digital textbook affects mathematics teaching.

3 Method

The focus of the study is teachers' perceptions and ways of talking about a humanoid robot regarding a child-robot collaborative learning activity. The result is based on the teachers' voices as captured in their discussions, statements, and reflections on the learning activity in general and the idea of using a robot-augmented game in teaching in particular.

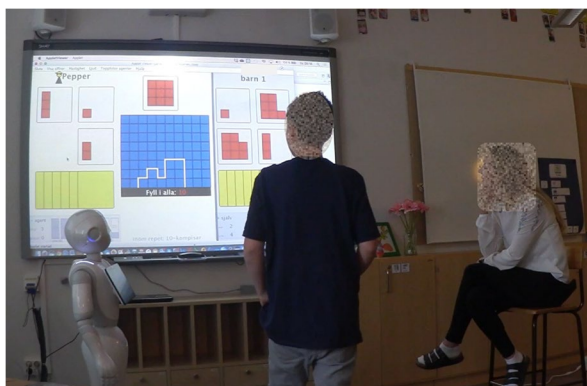
3.1 Research context

The study consists of eight sub-studies discussing the same activity: a robot-augmented gameplay in which a child plays a digital math game together with a social robot¹. The digital math game in the study consists of different minigames using an illustrative graphical representation where numbers are represented as cubes in different colors. All minigames are combined card- and board games, where players take turns choosing cards to lay on the common game board. In the chosen minigame, the players need to collaborate and select one card each which sum is the current goal, to score. The idea is that the players should discuss strategies to find cards and check the sums before they agree on which cards to play (Pareto, 2014). If the goal is achieved, a star is awarded as a reward.

The gameplay involves child-robot collaboration, and the activity is based on the theory of learning by teaching. Thus, the child has been assigned the role of tutor and the robot the role of a tutee. As a tutee, the robot asks questions about the game and its mathematical content with the expectation that the child, in the role of tutor, will explain his or her mathematical thoughts and ideas (Pareto et al., 2019). The robot and the child play the digital math game on an interactive whiteboard, and besides the players, there is also a teacher and possibly one or a few classmates participating in the learning activity, see Fig. 2. Here, the social robot has the didactic purpose of stimulating the child's mathematical reflection and learning. According to Bütepage and Kragic (2017), human–robot collaboration is a sequence of

¹ The robot Pepper from SoftBank Robotics.

Fig. 2 The collaborative game-play activity



interdependent actions toward a shared goal. Collaboration is an ongoing process that requires entrainment as well as taking turns and joint attention. In the collaborative context, the robot interacts with the child and imitates a learning behavior.

3.2 Participants and sub-study arrangements

In this study, data were produced from eight different arrangements where teachers from two municipalities reflected on the learning activity described above, which were exposed to them in various ways during the co-design process. The main purpose of the co-design was to design the robot's role as a stimulating and productive learning companion for the children. Therefore, both teachers and children were involved in various design workshops and related follow-up arrangements, which captured the participants' actions, experiences, and opinions about the role of the robot. However, the data produced during the co-design process also led to an increased understanding of the learning activity as a whole. In total there were 92 teachers involved, of which six were participating in more than one arrangement. The most engaged teacher, whose students were also involved in the co-design process, participated in 5 different arrangements. The data was produced on various occasions for two years, from 2018 to 2020.

The variation in arrangements is a result of the ambition to conduct a co-design process out in the schools together with teachers and students in their authentic contexts, which is challenging in many respects. First, teachers have limited time for extra-curriculum activities. Second, the social robot is a scarce resource that is cumbersome to transport to the schools, and the study setup requires an available classroom equipped with an interactive board that allows connections via a local network. Third, the study was mainly conducted during the Covid pandemic's restraining participation further. Hence, we had to be highly pragmatic in our study design. Moreover, taking all opportunities to engage stakeholders in guiding and informing the design process is a common approach in participatory design, and in these situations, relevance has priority to rigor. The unifying aspect is that all participating teachers were exposed to *the same learning activity*: a robot-child mathematical game-playing scenario using the same game and

the same robot in different phases of development, but the means of exposure and the methods of data production varied as described below and in Table 1:

- 1) By illustration: viewing a video recording of a wizard of Oz child-robot gameplay session
- 2) By robot experience: taking part in a game playing presentation with a live demonstration of the robot
- 3) By role-playing participation: participating in design workshops role-playing the tutor-tutee roles during gameplay
- 4) By illustration of authentic learning activity: viewing a video recording of an authentic robot gameplay session
- 5) By participating in an authentic learning activity: participating as an observer in an authentic robot gameplay session
- 6) By authentic participation: participating as a teacher during robot-child gameplay sessions

The arrangements can be divided into three phases, reflecting the type of teacher involvement and level of engagement with the learning activity per se: a phase of concept reflection, a phase of experiencing, and a phase of exploration.

The first three arrangements characterize a *phase of concept reflection*. In these, the teachers were exposed to the learning activity and their task was to reflect on the concept of using a social robot as a collaborative learning companion in teaching, and the possible pedagogical benefits and challenges of such activity. In total, this phase included 79 teachers with no previous experience using robots. In the first arrangement, the survey enrolled teachers engaged in previous projects using the game without the robot, while teaching mathematics in 2nd to 6th grade in primary school. A web questionnaire was distributed to these teachers asking for their spontaneous reflection on this new augmentation of the game. 17 teachers responded. They were asked to watch a video clip of a child-robot game-playing session and then answer a web-based questionnaire of how they perceived the idea of augmenting the game with a robot tutee to stimulate learning of the child tutor. Since they all had previous experience of using the mathematics game, they were able to imagine and reflect on what augmenting the game with a social robot can do to the learning situation. The second and third arrangements involved teachers voluntarily participating in workshops organized by the authors on a teacher development day at the University. In arrangement 2, all teachers received a realistic illustration of the learning activity through a thorough presentation of the activity and the same video clip as in arrangement 1. They were also exposed to a live demonstration of human-robot interaction consisting of a short dialogue with the Pepper robot. Arrangement 3 is somewhat different since the particular learning activity was not presented to the teachers, but they got a live demonstration of a human-robot interactive dialogue, and they discussed the concept of social robots in teaching in general terms.

Arrangements 4 and 5 can be characterized as a *phase of experiencing* since the 14 participating teachers experienced the learning activity themselves in some

Table 1 Participants in this study

Phase	Study arrangement	Focus within arrangement	Method	Type of exposure to the child-robot learning activity	Type of data production	Teachers' pre-knowledge of game/robot	Number of teachers
Phase of concept reflection	SA1	Discussing the idea of the robot-augmented math game	Distributed open-ended questionnaire	By illustration	Questionnaire responses	Familiar with game, not robot	17 (all new)
	SA2	Discussing opportunities and challenges with the learning activity	Workshop at the University	By illustration	Teachers' notes	None	17 (all new)
	SA3	Discussing the use of a social robot in education and role distributions	Workshop at the University with an open-ended questionnaire	By robot experience	Questionnaire responses	None	45 (all new)
Phase of experiencing	SA4	Exploring the collaborative child-robot interaction by acting in fictive gameplay sessions imagining the robot	Design workshop at four schools	By illustration and by role-playing participation	Audio recording of the discussion	Limited pre-knowledge of game, not robot	14 (most new, two a part of SA1)
	SA5	Discussing the learning activity after the children's first play sessions	Semi-structured interview at two schools	By participation in or illustration of authentic activity	Audio recording of interviews	Limited pre-knowledge of game and robot	3 (all a part of SA4)

Table 1 (continued)

Phase	Study arrangement	Focus within arrangement	Method	Type of exposure to the child-robot learning activity	Type of data production	Teachers' pre-knowledge of game/robot	Number of teachers
Phase of exploration	SA6	Exploring the learning activity by acting in real gameplay sessions	Design workshop at school	By role-playing participation	Audio recording of role-playing scenarios	Limited pre-knowledge of game and robot	3 (one a part of SA4, one a part of SA4 to SA5)
	SA7	Discussing the teacher's actions and role in the learning activity	Structured written interview	No additional exposure than arrangements 4–6	Teacher's written interview responses	Familiar with game and robot	1 (a part of SA4 to SA6)
	SA8	Exploring the children's second play session by acting in authentic gameplay sessions	Design workshop at school	By authentic participation	Video recordings of activity	Familiar with game and robot	1 (a part of SA4 to SA7)

way. The teachers enrolled voluntarily based on an invitation during a presentation and came from four different schools. They all had no or limited previous experience of either the game or robots. Participants in arrangement 4 were given the same thorough and realistic illustration of the learning activity as in arrangement 2, which included both presentation and video clip. They received no physical experience with the robot tutee only through the video clip illustrating the robot, instead they engaged in a design activity. During the design workshop, the participants collaboratively constructed desirable dialogues for given game-playing scenarios, where they imagined the robot collaborating with a child. Arrangement 5 was a follow-up to arrangement 4 where teachers observed authentic child-robot game-playing sessions with students from their respective classes, one teacher observed live, and two teachers viewed video recordings.

Finally, the last three arrangements characterize a *phase of exploration*. This phase engaged three teachers from the same school. Their pre-knowledge varied; teacher one had no previous experience with either the robot nor the game, teacher two had experience from arrangement 4, and teacher three had experience from both arrangements 4 and 5 as she participated in the design process and observed her students playing with the robot in arrangement 5. In arrangement 6, the teachers explored the learning activity by role-playing game scenarios themselves together with the robot. The teachers took turns acting in the role of the math teacher, the child tutor, and an observing peer, respectively. In arrangement 7, the teacher involved in the entire design process was interviewed. The questions focused on teacher actions and responsibilities within the learning activity and intended to explore the role of the teacher. In the final arrangement 8, this same teacher was acting in an authentic learning activity in which two of her students took turns playing and collaborating with the robot.

3.3 Data production

The research has a mixed-method approach and data are produced from eight different study arrangements. In total, data production resulted in responses to two web-based questionnaires, one workshop at the university where the teachers' notes were collected and compiled, two audio recorded interviews, and one interview with written responses, in total six design workshops at schools where five were audio-recorded and one was video-recorded. All audio recordings and the audio track from the video were transcribed before the analysis began. A summary of the different data sources and what was requested in each study arrangement is found in Table 2.

3.4 Data analysis

All data produced within the eight different study arrangements were analyzed using the tool MAXQDA, which supports data analysis with mixed methods (Kuckartz, 2010) and creates an opportunity to work systematically with qualitative data (Oswald, 2019). In the first coding phase, all data were analyzed qualitatively through an inductive bottom-up approach to content analysis, and the accomplished

Table 2 Compilation of the study's various data sources

Study arrangement	Task / question / focus	Data production
SA1	The teachers' spontaneous reflections on the concept of the robot-augmented digital math game	A web-based questionnaire with five questions about the concept was sent to teachers who have previously used the math game
SA2	Discuss opportunities and challenges for children and mathematics teachers in the complex learning situation?	A workshop where teachers in groups wrote potential opportunities and challenges on post-it notes
SA3	What happens when a robot becomes a social actor in the classroom?	A workshop where teachers answered a web-based questionnaire after reflecting on the teacher's role in relation to the robot's intended role
SA4	Design a suitable and developing robot-child dialogue and discuss what behavior the robot needs to have to be experienced as a natural tutee	An audio-recorded workshop where teachers first role-played a possible child-robot game session and then discussed a pre-recorded game session
SA5	How does the learning situation work? How should the robot and the child act as a tutor and a tutee? How should the teacher act and what role do (s) he has?	An audio-recorded semi-structured interview focusing on three predetermined themes
SA6	Play the robot-augmented game alternately in the role of teacher, child, or peer	An audio-recorded workshop where teachers played the robot-augmented digital math game
SA7	Reflect on the teacher's actions, role, and responsibility in the learning activity. What do teachers need to learn to use robots in the classroom and what pedagogical values or risks emerge?	A structured interview with seven questions where the teacher wrote the response
SA8	Play the robot-augmented game in the role of teacher with a child and a peer	A video-recorded workshop where a teacher played the robot-augmented digital game in an authentic setting

thematization was inspired by Braun and Clarke (2006). In thematic analysis, relevant themes are generated through a thorough examination of all produced data (Braun & Clarke, 2006). Initially, both authors studied all the transcripts to get an idea of what the teachers had talked about. During the process, potential themes emerged which were discussed and negotiated continuously to find eligible inclusion criteria for each theme. This elaboration resulted in four main themes of discussion topics related to the robot-augmented learning activity. Each theme was then scrutinized further, which resulted in a few more subthemes. After the thematic coding was completed, the themes were also viewed quantitatively, by counting the occurrences of distinct themes and subthemes. Combining frequency analysis with qualitative thematic analysis is advocated to convey not only the themes' content by examples but also the distinctiveness of the theme in relation to all coded data (Erickson, 2012). Finally, the thematic analysis was divided into the three design phases to explore whether there were any changes in the teachers' perceptions of the robot between them.

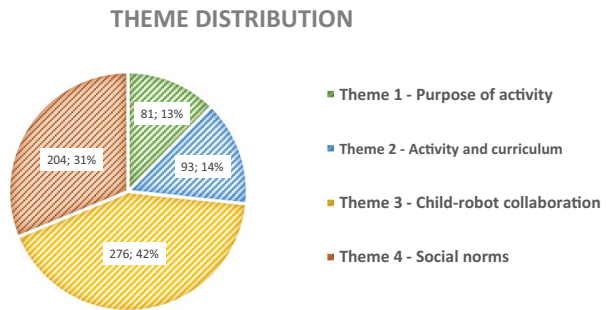
During the thematic analysis of what the teachers talked about, another perspective emerged, viz in what way the teachers talked about the robot. A more thorough analysis of how the teachers talked about the robot revealed two distinct perspectives on how the teachers perceived the robot: 1) as a social actor and thus treated in a similar way as a human being or 2) as a digital tool equated with, for example, a computer. Consequently, a second coding phase arose in which the data material was coded into these two perspectives. Similarly, way as in the first phase, the data were primarily analyzed qualitatively and then supplemented with a quantitative analysis of the frequency of the different perspectives within the previously emerged themes and sub-themes.

3.5 Activity theoretical analysis of learning activity

The objective of this learning activity is to stimulate productive and relevant teaching and learning in mathematics and the subject is the teacher's actions or intended actions. In this collaborative learning activity, a child plays a robot-augmented digital math game, which is described earlier. The game is played on an interactive whiteboard and therefore the game and the interactive whiteboard are considered tools. The pedagogical idea of the activity is learning-by-teaching, and the collaboration is based on a role-play where the child is assigned the role of a tutor and the robot is designed to act as a tutee. Role-play is used to establish a social relationship between the robot and the student and means i.e., that robots can display and/or detect non-verbal social signals (Engwall & Lopes, 2020). In this type of collaboration, the robot can be seen as a learning companion with which children must discuss and negotiate their ideas (Mazzoni & Benvenuti, 2015). Collaboration can also be defined as a sequence of interdependent child-robot actions toward a shared goal (Bütepage & Kragic, 2017).

In addition to the robot and the playing child, the activity also includes the teacher and possibly one or more peers. Hence, the child, the teacher, peers, and colleagues from the community. Besides, the activity is regulated by rules that the actors need

Fig. 3 Thematic categories emerging from the analysis



to comply with. The rules are partly pedagogical, i.e., fulfill the purpose and relevant curriculum goals in the current teaching context, and partly practical, i.e., the robot's technical limitations, as well as the game playing rules. In addition, there are social norms that all actors should follow, such as establishing an inclusive work climate, having appropriate behavior, and showing respect for other actors. Finally, there is also a division of labor within the community, which is the division of roles in the role-play as well as the teacher's responsibilities within the gameplay.

The remaining question is where in the activity system the robot should be placed? One option is to interpret the robot as a mediating tool; the other alternative is to interpret the robot as an artificial yet social actor being part of the community. The way teachers talk about the robot indicates that both interpretations of the robot are present.

4 Findings

In total, 654 teacher phrases from the material were coded and categorized into themes and subthemes. The four main themes that the teachers discussed most, concerning the use of a social robot as a collaborative companion in the learning activity, were 1) the overall purpose of the activity (81 phrases), 2) the activity concerning the curriculum (93 phrases), 3) child-robot collaboration (276 phrases) and 4) social norms in the robot-augmented learning activity (204 phrases), which is presented in Fig. 3.

In the first theme teachers reflected on motivations of such activity in teaching including possible benefits and challenges. The theme was further categorized into six subthemes of purposes: motivation for the students, variation of teaching, individualization of the activity, student assessment and evaluation, social interaction issues, and finally the robot tutee as a role model. The second theme concerned in what way the activity can meet the curriculum objectives, and potential learning outcomes for the students. The theme was divided into four subthemes concerning subject knowledge (i.e., mathematics), associated skills, digital competence, and cognitive awareness. The collaborative child-robot interaction is in focus in the third theme, which consists of four sub-themes: collaboration and division of roles, and two limiting factors, i.e., the teacher's knowledge and the robot's characteristics.

The fourth theme contains statements about social norms, existing norms as well as expected norms in a robot-augmented classroom. The additional subthemes discuss work climate, social trust, and relationships. The themes and their respective subthemes are presented in Table 3.

The themes are described below, first quantitatively with numbers of coded phrases occurring in each subtheme, and in which phase of the investigation that the phrase is produced. Then each subtheme is described qualitatively and illustrated by quotes from teachers' phrases. Due to the amount of data, variation in data production methods, and the nature of data, the quotes are referenced at the level of arrangement and not the individual teacher. The type of arrangement is more relevant than who in a group discussion makes a statement, for example. The study arrangement is referenced in parenthesis after each quote, denoted by SA1-SA8 from Table 1.

4.1 Theme 1: The purpose of using the activity in teaching

The objective of the learning activity is to stimulate teaching and learning in mathematics by using a robot-augmented game. It is mainly in the first design phase, called concept reflection, that teachers discuss the purpose of the learning activity. The most common idea is that the robot can increase students' motivation, and the idea remains through all design phases. Initially, the teachers also state that the robot can contribute to more varied teaching. However, in the phase of experiencing they rather reflect on whether the activity can contribute to individualized teaching and whether the robot can be a role model or not. This information is summarized in Table 4.

Within the subtheme of **motivation**, the teachers reflected on whether the robot can increase children's interest, motivation, and engagement, and reasons for this. The teacher who participated in all design phases states that: "*Thanks to the robot, students gain interest and become motivated*" (from SA7) but other teachers also adhere to this view saying "*It is great fun to have a robot. It is just luxury! They [the children] are looking forward to that and it does not matter which game they play. It is just great fun!*" (SA4). They think the robot can be particularly beneficial to children having difficulties with mathematics, or for students not appreciating mathematics: "*I think it is a good motivation. That someone who thinks that ten-buddies² are difficult ... You can go and do this with a robot*" or "*now we do this with the robot today*" (SA4). The teachers anticipated that their students would appreciate the intended role-play and said it could be "*very motivating and fun to help a robot buddy understand math better*" (SA1).

Moreover, the activity was considered to generate more varied teaching, and thus **variation** is the next subtheme. In general, the teachers talked about "*variety*" (SA 2) and "*another type of teaching*" (SA 2). They stated that the activity "*is a good complement to the rest of the teaching*" (SA 1). However, they thought that

² Ten-buddies refer to the number pairs which sum is 10.

Table 3 Thematic categories emerging from the analysis

Exploring teachers' perceptions of a collaborative child-robot learning activity							
Purpose of activity		Activity and curriculum		Child-robot collaboration		Social norms	
Motivation	Evaluation	Subject knowledge	Digital competence	Collaboration	Knowledge	Work climate	Relationship
Variation	Social interaction	Skills	Cognitive awareness	Role division	Robot characteristics	Social trust	
Individualization	Role model						

Table 4 Codes in different subthemes and phases within theme 1

Subtheme	Concept reflection	Experiencing	Exploring	Total occurrences
Motivation	10	16	10	36
Variation	13	2	0	15
Individualization	4	5	0	9
Evaluation	5	0	0	5
Social interaction	9	0	0	9
Role model	3	4	0	7
<i>Occurrences in phases</i>	<i>44</i>	<i>27</i>	<i>10</i>	<i>81</i>

the activity could be difficult to control and “*hard to repeat*” (SA 2) because the robot and the child will interact with each other as two social actors where neither the social interaction nor the dialogue reappears. Subtheme 3 discusses the topic of **individualization**. According to the teachers, the activity will “*individualize teaching*” (SA2) and they see it as an opportunity “*to catch up with more students individually and challenge them*” (SA2). Beyond this, a teacher talked about children learning in different ways. “*The robot is suitable for some children. It does not have to fit the whole class, but it does fit some (children)*” (SA5). In addition, the teachers talked about the robot’s capability to give the children continuous feedback. These statements were categorized in the subtheme **evaluation**. The teachers believed that the robot could provide teachers with information about individual child’s progression or about the class’s general level of knowledge. An opportunity for the teacher to make an “*analysis of individual students’ answers*” (SA2) as well as an “*analysis of the group’s needs*” (SA2).

In most of the statements above, the teachers perceived the robot as a didactic tool useful for teaching and learning. Conversely, other statements rather emphasized the robot as a social actor. Within the subtheme **social interaction**, teachers stated that the robot could be experienced as a social interaction companion. “*I think the student-robot relationship can be exciting*” (SA1). The teachers believe that the children may build relationships with the robot, of a somewhat limited kind. “*You can discuss more with a person. However, sometimes a robot can suffice*” (SA1). The teachers talked about the robot as a suitable companion for social interaction for some children and mentioned very shy children, children with special needs, and children with autism. They stated that the robot can be “*good for students who do not want to work with others*” (SA2) and assumed that “*shy (children) may dare to talk and tell*” (SA2).

In addition, the teachers talked about that the robot might become a social role model, and hence, it could be used for “*social training*” (SA2) and “*attention training*” (SA2). Statements like these are included in the subtheme **role model**. The teachers also mentioned that children, while interacting and collaborating with the social robot, might develop their social skills. “*We [the teachers] work a lot with social interaction. And the language and everything.*” (SA4) “*Maybe they [the*

Table 5 Codes in different subthemes and phases within theme 2

Subtheme	Concept reflection	Experiencing	Exploring	Total occurrences
Subject knowledge	1	26	4	31
Skills	3	36	6	45
Digital competence	3	1	2	6
Cognitive awareness	2	9	0	11
<i>Occurrences in phases</i>	9	72	12	93

children] imitate the robot, then it [the activity] would be beneficial. Something that would be very positive in these groups” (SA4).

4.2 Theme 2: Curriculum objectives that the activity may fulfil

Teachers were generally positive towards the activity, especially as it relates to concrete curriculum goals. It is mainly in the phase of experiencing that the teachers discussed curriculum goals, and they talked about developing relevant skills or deepening the students’ subject knowledge. Within this design phase, the activity’s potential to develop students’ cognitive awareness is also mentioned, referring to that students gain an increased understanding of their learning process. Quantitative details are shown in Table 5.

Further, it was considered desirable that the activity was level-appropriate, and some statements support the idea that the activity can contribute to learning in mathematics in the subtheme **subject knowledge**. The teachers mentioned several mathematical areas as well as specific concepts, for example: *“It [the activity] will certainly help some students who have difficulty with ten-buddies [a mathematical concept]” (SA4)*. Teachers mentioned central mathematical concepts and terms, fluency in mathematical calculations, and expressed an expectation that the robot, through its questions, can contribute to increased mathematical understanding. A teacher wanted *“that Pepper asks rewarding questions that make students think and think about why they do as they do” (SA5)*, another that the robot says: *“Tell me how you were thinking, using mathematical concepts” (SA4)*. However, some teachers were worried about the efficiency of the learning activity: *“As a teacher, you are very stressed; they [the children] have to do a lot. I think it takes quite a long time for them [the children] to answer a few questions” (SA5)*. *“The game itself works well, but maybe it [the robot-child gameplay] was a bit slow. You [the teacher] are so used to everything going fast” (SA6)*.

The teachers mentioned that the activity could develop different mathematical skills, categorized in the subtheme **skills**. The teachers believed that the child-robot interaction can contribute to developing children’s reasoning and communication skills: *“because what you want is to get the children to talk to him and explain” (SA6)*. They considered it important that children *“can reason math, talk math. It is a math language required for the national tests” (SA4)*. One conclusion is that *“the*

Table 6 Codes in different subthemes and phases within theme 3

Subtheme	Concept reflection	Experiencing	Exploring	Total occurrences
Collaboration	6	36	29	71
Role-division	14	60	24	98
Knowledge	8	35	10	53
Robot characteristics	2	10	32	44
<i>Occurrences in phases</i>	<i>30</i>	<i>141</i>	<i>95</i>	<i>266</i>

robot means that the students need to talk about mathematics, which means they develop important skills.” (SA5). Furthermore, teachers mentioned problem-solving and strategic thinking skills: *“They [the children] get to think in several steps and devise strategies”* (SA1) and think the robot should ask *“some strategic questions”* (SA4). Besides subject knowledge, teachers discussed children gaining **digital competence** from the activity, learning about digitalization in general, robots, and programming: *“An exciting future, considering the recent addition in our curricula regarding digital resources”* (SA1).

The above examples concern the robot as a subject-specific didactic tool, but the teachers also talked about the robot as a mean to raise children’s (meta)**cognitive awareness**: by affecting the children’s learning process in different ways, e.g., to support children’s language development skills by role-modeling proper language use and a varied vocabulary so children were *“fed with Swedish words and concepts in mathematics”* (SA4); to change focus from *‘finding correct answer’* and *‘getting more points’* to *‘developing mathematical understanding’*; and to make children aware that they *“learn from teaching others”* (SA2). The teachers think that the robot’s question *“forces the student to describe his or her understanding”* (SA2) and *“reflect about why they do as they do”* (SA5).

4.3 Theme 3: The role-division in the collaborative learning activity

The collaboration within the learning activity is based on a role-play where the child is assigned the role of a tutor and the robot is designed as a tutee. In addition, there may be both teachers and peers taking part in the activity and all these actors influence the progress of the activity. In several ways, teachers negotiate with themselves about the role division, the defined role of the robot and how it relates to other actors, and in what way the collaboration can take place and be encouraged. Factors that limit the division of roles also emerge within the theme. In the phase of experiencing, it is primarily the teachers’ lack of knowledge that becomes apparent, while in the phase of exploring it is rather the robot’s characteristics, which can be seen in Table 6.

The first subtheme is **collaboration** as the teachers seemed to agree that a developing and social collaboration between the playing child and the robot is desirable. They wanted the child and the robot to converse and work together.

“This is a collaboration exercise” (SA4) where *“you assume that they [the child and the robot] are collaborating”* (SA4). Moreover, they emphasized the mutual success of the child and the robot during the game sessions. *“Now you and Pepper got a point”* (SA8) and *“You got four stars together!”* (SA8). However, it turned out to be somewhat unclear to the teachers who are collaborating with whom. *“Every other time it is Pepper and every other time it is us [the child and the teacher]”* (SA8) and *“Good cooperation between the two of you [the child and the peer]. And Pepper too.”* (SA8). The teachers also mentioned some possible obstacles to the intended collaboration. They mentioned, among other things, that the collaboration could suffer if the child has difficulties with the Swedish language or weak mathematical knowledge. The robot should *“not use any words that may be difficult for students”* (SA5) and *“How do you progress in the game when no one knows?”* (SA2). It also turned out that the child on several occasions became a single player. *“You have four stars!”* (SA8) and *“Take any card you want, still you do not get any points”* (SA8). These obstacles emphasized the digital character of the robot rather than its social skills.

The next subtheme is **role division** and several teachers considered it important that the role-division of the robot and the child were clarified both before and during the gameplay session. It is important *“that the student understands his [or her] role as a teacher”* (SA2) and a teacher thought that *“it will be a better learning situation when they know: you are going to teach Pepper”* (SA5). According to the teachers, this could be done through a clear introduction but also during the game session through the robot’s statements and behavior. *“It must be clarified before; that you [the child] should teach the robot and that it [the robot] may answer incorrectly in the beginning”* (SA4). They believed that this clarification can be done partly through a statement confirming that the robot is the tutee and partly by creating an experience that the robot learned during the game session. *“The boy [playing child] was happy when the robot thanked him for teaching him”* (SA1) and *“it is important that they [the children] experience that it [the robot] does not know anything from the beginning and that something happens if they [the children] teach it [the robot]”* (SA4). However, the teachers themselves had a hard time keeping track of the role-play and who should ask whom about what. *“He [the robot] should be perceived as a playmate who has a little less knowledge. It is hard to rethink”* (SA4).

The teachers also stated, *“The children enter the role [as a tutor] with different capabilities”* (SA5) and they felt that *“they [the child and the robot] were asking each other too few questions”* (SA4). They believed that *“they [the children] need to be active participants and dare to take action”* (SA5). However, the teachers felt that the robot could not ask about everything the whole time. *“It [the robot] must not be unbearably annoying. Then they [the children] will not be able to play”* (SA4). The teachers agreed that it is important that the robot does not reveal that it already knows everything. It is important *“that it [the robot] does not become; ‘I know all this, ‘I will teach you this’. He must not reveal himself”* (SA4). Despite this, a wish was expressed that the robot could support the children’s learning as an, so to speak, undercover tutor. *“Can he say the word in a way that can appropriate even if the child did not say it?”* (SA4).

In addition to the robot and the playing child, the teacher is also an active part of the learning activity and the study revealed different thoughts about the teacher's role. Above all, they thought that the teacher needed to be able to interact with the robot. The teacher *"needs to find his (or her) role together with the robot"* (SA2). Nevertheless, the opinion of the role of teachers varied, with some believing that the teacher should be an organizer, an observer, or even an assessor of knowledge, while others considered that the teacher should adopt a more central and supporting role in the child-robot interaction. *"You [the teacher] need to be there and support... Yes, and keep some focus."* (SA5). Another teacher felt that she should *"encourage communication and reasoning ... and the use of mathematical concepts."* (SA7). It turned out that the teacher needed to *"remind [the child] to talk to the robot and make suggestions on what to answer [to the robot]"* (SA7). For example, the following comment was uttered during the gameplay session: *"Try saying yes or no or something like that"* (SA6). Since there may be other children in the surrounding context, the teachers reflected over the role of peers. The teacher was also considered responsible for including peers in the interaction. One teacher considered that *"it [the robot] needs to be able to interact with two [children] because we often send two away to work"* (SA5). Conversely, another teacher reasoned about whether it is possible to involve the peers in the activity or not. *"For the person sitting next to the playing child for 15 min; 'Is it a learning situation for that child?'"* (SA5). In general, the teachers believed that it *"can be a challenge [for the peers] to wait their turn."* (SA2) Some statements demonstrate the inclusion of both peers and the robot during the game session. However, there are also examples of the child-child interaction becoming dominant.

It seems that the teachers' limited knowledge of interacting with social robots may limit their experience of the robot as a social actor. Firstly, the teachers considered it a challenge to *"learn how to interact with and/or programming Pepper"* (SA2), which indicates that a social robot is a tool that teachers must learn to master. In addition, the statement: *"You [the teacher] can start the activity by giving them [the children] examples of some phrases that they can say to the robot"* (SA5) highlights that the robot is considered a pre-programmed tool that teachers, as well as the children, must learn to handle. Hence, this sub-theme is about the teachers' **knowledge**. Moreover, the teachers' insufficient pre-understanding of the aim of the learning activity, as well as their preconceived ideas of robots, may have entailed that the robot was not fully accepted as a tutee. *"Why is he [the robot] doing wrong? Shouldn't he always do the right thing?"* (SA4) Reflections on lack of knowledge can also be assigned to the child because the interaction and the expected collaboration with the robot can be complicated if the playing child has mathematical difficulties or problems with the Swedish language. However, *"Teachers must know more than the students about how to use the robot!"* (SA2) is a statement that summarizes this subtheme. A statement indicating that the experience of the robot as a social actor may improve over time was as follows: *"It seemed that it [the robot] interacted with them better this time than last"* (SA5).

Within the subtheme **robot characteristics**, the teachers remarked on several characteristics of the robot that limited its ability to be perceived as a social actor. Most of all, they experienced problems with verbal communication. The teachers

Table 7 Codes in different subthemes and phases within theme 4

Subtheme	Concept reflection	Experiencing	Exploring	Total occurrences
Work climate	1	65	41	107
Social trust	2	49	11	62
Relationship	12	11	12	35
<i>Occurrences in phases</i>	<i>15</i>	<i>125</i>	<i>64</i>	<i>204</i>

stated: “*Maybe I should have told them before, that they should talk louder with Pepper.*” (SA5) and “*I know that the students also had to repeat themselves and try to speak clearly. I thought we might have it easier, but we did not. It was just as difficult for us.*” (SA6) The teachers felt that the robot had difficulty interacting with more than one person at a time since the robot “*focuses extra on the person in front of it.*” (SA6) and there might be a social “*challenge if the robot is disturbed and turns to others when the child is thinking.*” (SA2) On one hand, the teachers thought it would be “*desirable for the robot to ask more open-ended questions that invited conversation*” (SA7) and on the other hand, it happened on several occasions that the robot misinterpreted the children’s answers and that the dialogue thus became strange. The interaction was also made more difficult due to various technical breakdowns. “*Now it [the robot] stalled again*” (SA8) and “*the robot has crashed*” (SA8) are just two examples of statements made. Another social problem that several teachers mentioned is that the robot, and thus the learning activity in general, was too slow. “*It takes twice as long. However, in five years, maybe he [the robot] is faster?*” (SA5) According to the teachers, “*there is a risk that they will not learn as much math as they would in a regular lesson because a lot of time is spent answering the robot ‘correctly’.*” (SA7).

4.4 Theme 4: Social norms in the collaborative learning activity

The robot used in the learning activity is a digital tool but is intended to function as a social actor, which can create both opportunities and challenges. Whether the robot is partially or fully accepted as a social actor, it probably affects the social norms that prevail in the classroom. This means that the teacher, together with the children, needs to renegotiate these and adapt them to the learning activity. Within this category, most of the statements are about the work climate and arose later in the design phases. Positive statements about the importance of inclusion and encouragement are interspersed with more negative and exclusive ones. The teachers’ expressed thoughts about the child-robot relationship were not so many but occurred to the same extent in all three phases, see Table 7.

The teachers expressed thoughts about social norms in the child-robot interaction and mentioned in several ways the importance of creating an inclusive climate. These thoughts fall within the subtheme **work climate**. The teachers considered the child and the robot to be positive and encouraging towards each other in the

ongoing collaboration. *“It is very good and very important to be encouraging”* (SA4). Besides, they had several suggestions with short comments such as *“Good idea!”* (SA4) and *“Thanks for helping me!”* (SA4) Although the collaborating players must stay friends, the teachers felt that the child and the robot must be able to have different opinions. *“They can be a bit... Disagree. Disagree, you can think differently”* (SA4).

Most often, the teachers talked about an inclusive climate where the robot was assumed to be a social actor. However, a more exclusive approach also emerged. For example, there are several occasions when the teachers, as well as children, are excluding the robot from social interaction by ignoring its questions, laughing at the robot when it makes mistakes, and giving inappropriate comments like *“You [the robot] are not as stupid as you look”* (SA4) and *“He [the robot] is a little sluggish your friend”* (SA6). During game sessions, there was also a tendency for the teacher to exclude the robot and consider the child as the sole player, *“You have four stars!”* (SA8), which sometimes led to the teacher and the child playing together instead. *“Pepper has to start. However, we are the ones who choose Pepper’s cards as well.”* (SA8) Furthermore, the teachers mentioned that there was a risk that the children could become violent towards the robot. If the children become frustrated, there is a risk that *“it can probably be broken before the activity is finished”* (4) or *“they will do like this, and it will fall over”* (SA4).

In the subtheme **social trust**, the teachers talked about enabling social trust between the actors. In this case, social trust means an understanding of the robot’s specific characteristics and possibilities for interaction, along with establishing appropriate social norms for the context. In one way, the statements in this subtheme indicated that the teachers wanted to interpret the robot’s personality in human characteristics to create trust. For example, they reasoned about the perception of the robot, i.e., what gender and age the robot has as well as the name. *“The robot may be perceived as an adult”* (SA4) and *“is Pepper a male or a female?”* (SA4). Moreover, they added human characteristics to the robot. *“He [the robot] is a little ashamed...”* (SA4), *“It became sad”* (SA8), and *“He [the robot] wanted to rest a bit. He felt warm”* (SA8). Furthermore, they considered it important to have eye contact and comprehensible body language. *“It is good that they [the child and the robot] look each other in the eyes, as a human being should do when they talk”* (SA4), and *“He [the robot] could have nodded a little”* (SA4). They also reasoned that the spoken language must be comprehensible. *“Pepper must speak the children’s language”* (SA5). In part, the teachers regarded the robot as a social actor in prevailing social norms, something that becomes clear in the following statement: *“Yes, but Pepper suggests it [a specific card]. Then the student must answer”* (SA4).

However, the robot was not always considered a social actor and some teachers also felt that it should be stated. They thought that the robot should clarify its social limitations. *“When it [the robot] does not understand [...] it may say: ‘I do not understand. I am just a robot.’... So, it becomes clear to the user [the child]; it is still a machine, and it has limitations”* (SA4). Some teachers also mentioned that the robot could be perceived as *“staring”* (SA4) and as *“a mind reader”* (SA4) when the robot does not look at the whiteboard during the game. All this limits the robot’s opportunities to be perceived as a social actor.

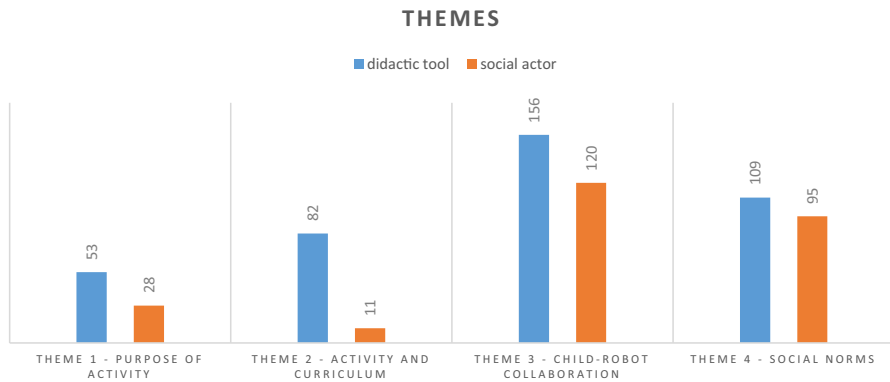


Fig. 4 The occurrences of different perspectives of the robot among themes

Statements that the robot is too static also reveal that the teachers experienced a lack of social trust. In addition, teachers believe that it is difficult to replace children's earlier, perhaps more digital, perceptions of robots. *"After all, children's image of robots is that they cannot make mistakes"* (SA4). This was supplemented by the fact that they wanted to assign the robot digital attributes in the form of various sound effects. *"Can it play a little music? Something that can be a confirmation that you are doing the right thing"* (SA4).

The idea of learning activity as a temporary complement to teaching may limit the possibility of experiencing the robot as a social actor. The subtheme **relation** includes the relationship the child or teacher has with the robot and in many cases, it means a non-continuous relationship between the robot and the children. The teachers mentioned that it might be *"a challenge to end"* (SA2) and that it is difficult to *"have a relationship without deciding for yourself"* (SA2) when the meetings do not take place continuously. This also makes the transitions between the game sessions irresolute. *"The question is whether we should change ... Do you want to play for another 10 min?"* (SA8). Other challenges also emerged, and some were about the fact that the wait for the next meeting with the robot is long. *"You do not need to talk much about the robot because they will just be upset by it. Nevertheless, if anyone should ask, you can say that everyone will meet next year"* (SA8). Although there was a concern that children see the robot as a toy, teachers often use the word 'friend' or 'buddy' when talking about the relationship the robot has with the child, which indicates an idea of a social relationship. They felt that it is not possible to just *"come with a robot and say: Now you have a robot!"* (SA4). Instead, you need to plan for a natural interaction and socialization between the actors before the collaboration begins. Hence the picture of the child-robot relationship is twofold, *"I think the student-robot relationship can be exciting to try!"* (SA2) and *"Letting Pepper be a "smart friend" means a lot of focus on Pepper"* (SA4).

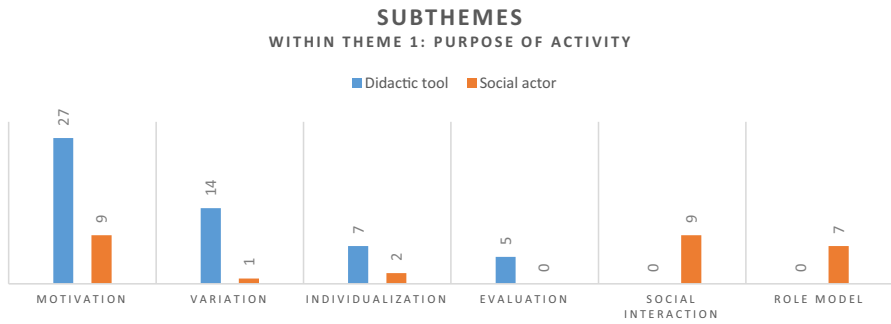


Fig. 5 The occurrence of different perspectives of the robot within the theme purpose

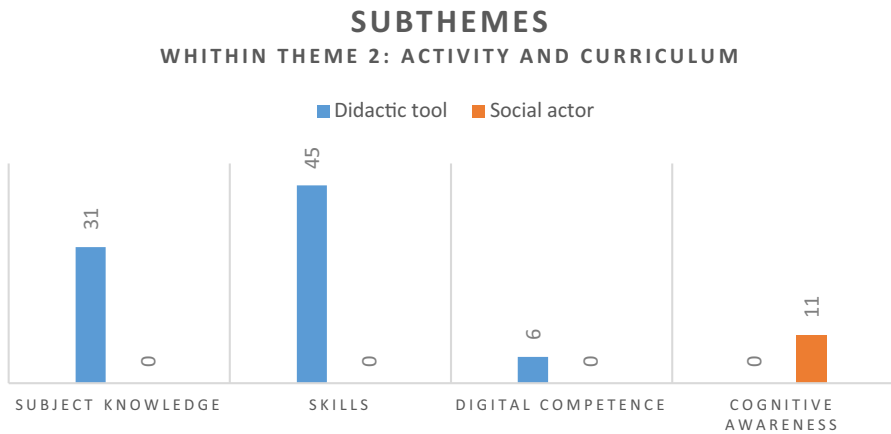


Fig. 6 The occurrence of different perspectives of the robot within the theme curriculum

4.5 Emerging perspectives of the robot

The analysis of the quantitative part of the study shows that the robot was more often talked about as a didactic tool than as a social actor. This fact applies to all themes even if there are differences between the different subthemes, which will be highlighted below in Fig. 4.

Regarding the **purpose** of using the activity in teaching, the robot was perceived as a didactic tool, which can increase interest and motivation, contribute to varied and individualized teaching and provide continuous feedback on knowledge development. At the same time, the teachers talked about the robot as a social actor, a friend to whom students need to pay attention and who has the potential to support children’s social development. This change in perspective is shown in Fig. 5.

The perspective of the robot as a social actor also changed through the design phases. For example, the teachers talked about the social interaction with the robot as motivating for the students in the phase of experiencing, while they switched to

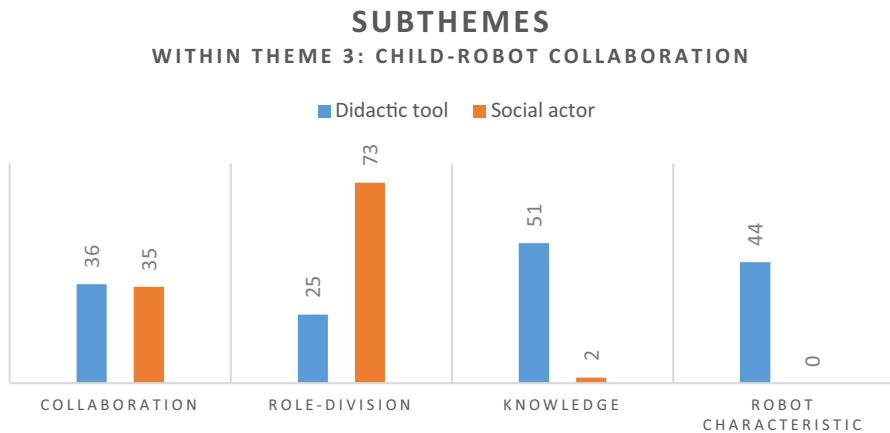


Fig. 7 The occurrence of different perspectives of the robot within the theme collaboration

a more materialistic approach in the phase of exploring, where the robot as modern technology was motivating for the students.

The activity's connection to the **curriculum** shows a similar pattern, see Fig. 6. The teachers primarily saw the robot as a didactic tool, which could be useful for achieving different curriculum objectives, such as subject knowledge and relevant skills, such as strategic thinking, mathematical reasoning, and communication. Conversely, statements also emerged that showed that they perceived the robot as a social actor. It was primarily about the robot's ability to support more general curriculum goals such as social and cognitive development, i.e., developing a future citizen.

In several ways, the teachers accepted the robot as a social actor, a tutee who collaborated with the playing child as well as peers. Within the theme of **collaboration**, there are subthemes where the teachers talked about the robot as a social actor more often than as a digital tool, or at least equivalent, namely in role-division and collaboration. The frequencies are presented in Fig. 7. The reason why the robot was still not fully perceived as a social actor was partly due to the teachers' limited knowledge of the robot, the game, and the activity in general. In addition, it was partly due to the robot's technical limitations, especially the robot's capability for speech recognition.

Even within this theme, a change in teachers' view of the robot can be discerned. During the phase of experiencing, the teacher talked about encouraging the child-robot collaboration, but during the phase of exploring, when the game was running, the robot was forgotten and solely the child's actions were noticed. Moreover, the teachers in the latter two phases seemed to accept the intended division of roles and in several ways encourage a social child-robot collaboration, even if they occasionally expressed a wish that the robot supported the child. The subthemes that contribute to the didactic perspective dominating are knowledge and robot characteristics, and it is mainly during the phase of experiencing that the teachers' lack of knowledge is made visible. The teachers who participated during the last phase have also

SUBTHEMES WITHIN THEME 4: SOCIAL NORMS

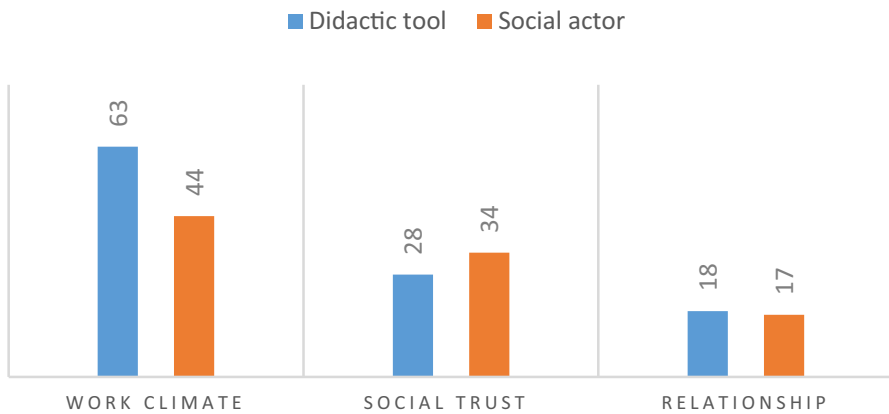


Fig. 8 The occurrence of different perspectives of the robot within the theme social norms

participated in the earlier phases, which indicates that they may have learned something through their participation. On the contrary, it is for the robot's properties as its limitations become most visible during the last phase, the exploratory.

Within the theme of **social norms**, the two different perspectives are almost equally frequent in the teachers' statements, see Fig. 8. The results show that the dominant perspective alternates between both subthemes and design phases.

What stands out in this theme is that the teachers in the phase of experience worked actively to create an inclusive climate where the robot is invited to the community as a social actor. However, the teachers in the exploratory phase did not manage to maintain the idea, and instead, they broke several social norms, provided that the robot is a social actor. The table also shows similar patterns for the sub-theme relationship, where the teachers in the second phase consider it important that the child has a continuous relationship with the robot. Something that during the game sessions in the phase of exploration seems to be forgotten and the child-robot interaction ends abruptly.

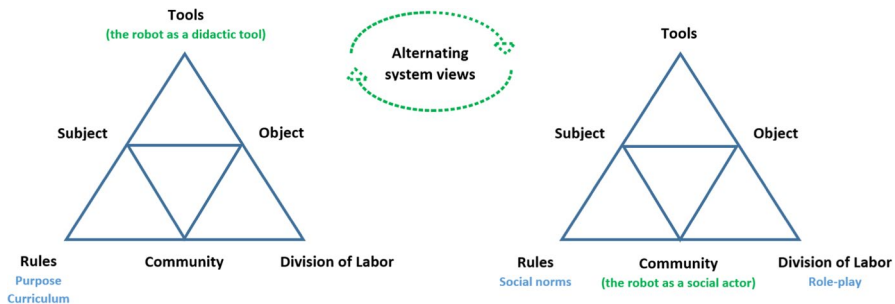
4.6 The activity-theoretic interpretation of the robot

Since the use of social robots in teaching essentially has a didactic purpose, the robot should be defined as a tool in the activity system. At the same time, the robot aims to interact and collaborate as a social actor and should thus be defined as part of the community, see Table 8.

The teachers talked about the robot both as if it was a didactic tool and a social actor almost simultaneously, which means that their perception of the robot seems to alternate. A duality arises, that involves alternating system views. The change takes place within all themes and their associated subthemes, both during a design

Table 8 The dimensions of the activity system

Dimension	takes the following expression in this study
Object	stimulate productive and relevant teaching and learning in mathematics with a robot-augmented game
Subject	the teacher's actions (including intended actions and decisions)
Tools	the robot as a didactic tool , the math game, and interactive whiteboard
Community	the robot as a social actor , the playing child, the teacher, peers, and colleagues
Rules	the functionality of the robot, the curriculum, the teaching practice, and social norms
Division of Labor	the role-play, teaching responsibilities
Outcome	development of both teaching and learning

**Fig. 9** Two alternating system views of the activity system

phase and over time. This indicates a constant renegotiation of the view of the robot, which probably affects both the learning activity and the actors involved. For teachers, renegotiation can mean learning, which may lead to a better understanding of the role of the teacher in relation to the child-robot interaction.

By using a twofold activity system, this duality can be understood, see Fig. 9. In this description of the activity, teachers' views of the robot can freely alternate between being a didactic tool and a social actor.

5 Discussion

In general, the participating teachers believed that the learning activity could support their teaching and they considered that the social robot could contribute to fulfilling several aspects of the curriculum. Above all, the teachers believed that the robot might stimulate the students' ability to communicate their mathematical thoughts. *"It [the robot] asks other questions than what a (human) friend does. It [the robot] is undividedly positive, something that a (human) friend may not always be."* (SA5) The teachers in this study believe that the use of social robots can support the curriculum objectives and develop relevant skills is in line with the results obtained by Chalmers et al. (2022).

The teachers in the initial phases were predominantly positive. They accepted the intended role-play and the robot as a collaborative learning companion. Moreover, they wanted to create an inclusive work climate and reasoned about how the robot could contribute to the child's social development. However, it seemed difficult to practice well-developed communicative skills with the robot. Results that are consistent with previous research (Belpaeme et al., 2018). Despite this, it emerged that the robot has advantages, including the fact that it asks other/better/more questions than a human learning companion does. The teachers expressed doubts, as well as difficulties, with using a social robot in teaching. For example, they experience the activity as slow, and they consider it a risk that students learn less than in regular teaching since the children spend most of the time responding to the robot in a way it can interpret. This result also confirms the study that Chalmers et al. (2022) did where problems in verbal communication were perceived as limiting. These doubts and difficulties also affect the intended role-play in different ways, which was most evident in the last phase when the teacher experienced the robot in an authentic setting. It seems that the teachers at an early stage of the design process discussed a vision of the robot, but when the design process goes from ideas about the robot's potential to the harsh realism of the robot's limitations, other statements emerge. Furthermore, when the robot was seen as a digital tool, it had a rather short-term goal, to develop knowledge and skills in a limited area of mathematics, while the robot, when considered a social actor, had a more long-term mission to influence the child to become more aware of his or her learning.

To some extent, the teachers and children treated the robot as a social actor. This is consistent with results from previous studies where children also established a friendly relationship with social robots (Kanda et al., 2004; Pereira et al., 2010). The teachers tried to have an inclusive approach, encourage collaboration, and create mutual trust between the actors in their assigned roles to achieve social acceptance. However, the robot was also perceived as a digital tool. Most often, it was because humans excluded the robot from the prevailing social norms or because the robot itself violated these norms.

The changes that took place, such as the switch of playing child and the shift between different game occasions, also reinforced the image of the robot as a didactic tool even though the teachers referred to the robot as a friend. Thus, it does not seem obvious whether the robot should relate to prevailing social norms or whether the social norms should be adjusted to the robot as a social actor. People are polite to computers in the same way they are to people if computers are perceived as social actors, which indicates that social norms apply to media (Reeves & Nass, 1996). If technology violates social norms or is perceived as impolite, the median is perceived as being socially incompetent rather than deficient. For a media to be experienced politely, the interaction needs to be qualitative, i.e., with clarity and relevance, and in a reasonable quantity (Reeves & Nass, 1996). Even when it comes to media and technology, there are social norms that need to be met, such as saying hello and goodbye, having eye contact when talking, and adapting the dialogue to the person you are interacting with. The latter requirements were partially met by the robot in the interaction, as several experienced eye contact and inclusive behavior. The quality of the verbal interaction did not always meet the expectations as several teachers

experienced problems with verbal communication, both regarding misunderstandings, inappropriate comments, and unnecessary repetitions.

There is a desire to make tools, e.g., robots, invisible in use, and technology can become invisible when it fades into the background of the participants' experience (Takayama, 2010). Nonetheless, factors are affecting the robot's ability to be perceived as invisible in use, e.g., that the robot feels reliable, predictable, and familiar, and that the person interacting with the robot experiences a sense of control (Takayama, 2010). In the same way, some factors make the robot visible again, such as that it is annoying or absent when it requires a lot of time and conscious attention, when it is difficult to understand, or the robot does not function when needed. On some occasions, the learning activity worked as planned, and the robot acted predictably in its role as a tutee, which means that the robot was fading away into the context and the social interaction took the foreground, i.e., the robot becomes invisible in use. However, due to technical breakdowns and unfamiliarity, the robot became visible again.

After all, the teacher seems to have an important role in the learning activity. Still, the teacher was considered to be in charge of the teaching. Besides, the teacher should also support the activity so that aim and objective can be achieved by asking complementary questions and helping children stay focused. The teachers also felt that the teacher needed to support the child-robot interaction and the role-division, including child, robot, peers, and teacher. Since the teacher has the final responsibility for both the children's knowledge development and the social aspects of the work climate, the teacher also needs to be responsible for adapting the appropriate social norms to this new activity. Altogether, the use of social robots in the classroom poses challenges for all actors involved. When there were peers nearby, the teacher wanted to involve them in the learning activity, which led to both technical problems (the robot had difficulty with voice recognition) and social challenges (as the robot was excluded in various ways). The teachers also experienced the activity as both slow and cumbersome to complete. However, they agreed that the activity was stimulating for some children, and someone suggested that it should instead be carried out outside the classroom: "*Maybe in special education but this [activity] is not suitable in a classroom situation.*" (SA1) and "*It's a special need teacher activity, not a classroom activity, is it?*" (SA5).

If the teacher perceives the robot as a didactic tool, it may negatively affect both the commitment and the collaboration. Nevertheless, if the teacher mainly perceives the robot as a social actor, then it implies other requirements for how the robot should be treated, i.e., updated social norms that also include the robot. The question is whether a teacher needs to be aware of when he or she switches between these two perspectives and whether the teacher needs to be able to do so intentionally. Moreover, could teachers learn to combine these two alternating views to use a social robot as a didactic tool in a pedagogically and socially sustainable way? When teachers talked about the robot as a didactic tool, it could be considered as a mediating tool that teachers use in their teaching. Then the robot makes the children aware of relevant mathematical knowledge and skills since the mediating tool frames central mathematical concepts and supports the children with their problem solving and verbal reasoning. On the other hand, when teachers saw the robot as a

social actor, it could be considered a part of the community. This implies that the children receive a collaborative learning companion who also supports their cognitive development. However, it also means that prevailing social norms must be renegotiated and developed. What determines whether a robot is accepted and treated as a social actor in the community? The findings show that the robot's technical shortcomings are a limiting factor for social interaction. Furthermore, the teacher's familiarity with the new learning activity also seems to limit the robot's opportunities to be perceived as a social actor. Through increased knowledge, the teacher may be able to handle the robot's limitations so that it becomes easier for the children to accept the robot as a part of the community. The question is whether the alternating view of the robot limits the learning activity's opportunities to achieve its objective or whether an awareness of such duality can be used to enhance the learning activity in some way?

Upcoming studies on the described learning activity will study teachers' actions in authentic game sessions. The aim of the forthcoming studies is also to investigate whether there are new dimensions of teachers' digital competence specific to the use of digital tools with social characteristics in education.

6 Conclusion

The results of this study show that the way teachers perceive and talk about the social robot in this collaborative child-robot learning activity is alternating between two dual perspectives: The robot is perceived both as a didactic tool and as a social actor and the teachers switch between these two perspectives within the same activity. The perspective where the robot is perceived as a didactic tool is characterized by a wish to achieve relatively short-term goals with increased knowledge in a defined area, while the other perspective, where the robot is perceived as a social actor, rather has a long-term goal to support children's general development.

Which perspective is dominant depends partly on how involved the teachers are in the activity; whether they reflect on the concept in general or actively explore their role in it. This duality implies that the robot is alternating between two different dimensions in the activity system, *videlicet* between being a tool and a part of the community. We mean that this duality should be considered when exploring humanoid robots in education, concerning the design of social robots as well as the use of social robots for educational purposes.

The study contributes to an increased understanding of how teachers perceive social robots as a mean for teaching and learning. Understanding the perceived duality of social robotics may contribute to the further development of educational robots' design. In addition, the emerged alternating activity systems may also be a contribution to activity theory, as a new way to represent social activities including robots as activity systems, for other similar studies where social robots are used to achieve predetermined goals.

In further research, it would be interesting to study in which situations the different perspectives emerge as well as when and how the teacher switches between them. What situation triggers the transition between the perspectives? Furthermore,

it would be interesting to study what this duality means for the future design of educational robots. What design implications arise and in what kind of situations may the alternating system view of the activity system be useful? Future studies could follow up our study with more concrete, but also more in-depth, questions about what happens in the classroom during the implementation of a social robot in teaching. May technology that exhibits social characteristics affect teaching and learning, and thus also the teacher's role and actions, in different ways than other digital tools? How should teachers relate to a didactic tool, which the students in the learning activity should interact with as a social actor?

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Declarations

Ethics Statement This study was carried out in accordance with the recommendations of CODEX—Rules and Guidelines for Research established by the Swedish Research Council. The protocol did not require ethical approval according to Swedish law as no sensitive personal information about the subjects was collected. Both teachers and students gave written consent to participate in the study, as well as oral consent at the beginning of each game session. In addition, all child subjects' parents/legal guardians gave written informed consent for the children to participate, all in accordance with the Declaration of Helsinki.

Competing Interests The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be interpreted as a potential conflict of interest.

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