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Teaching in a collaborative mathematic learning activity with and without a social robot

Sara Ekström[1] · **Lena Pareto**[1,2] · **Sara Ljungblad**[3]

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Abstract

There is a growing interest in whether social robots, which are embodied and exhibit human-like behaviour, can be used for teaching and learning. Still, very few studies focus on the teacher's role. This study focuses on how a teacher acted in a learning-by-teaching activity with 20 children. In this small-scale field experiment, the teacher's interactions and teaching actions were observed when the teacher scaffolded a learning activity where children played a collaborative digital mathematics game to strengthen their mathematical reasoning and conceptual understanding of arithmetic. When playing, the children were acting as tutors for a tutee, according to the learning-by-teaching principle. In one scenario, the tutee was a younger child; in the other, the tutee was a social robot. Twenty 30-minute game-playing sessions are observed, video-recorded, and transcribed. The study explores the teacher's interactions and teaching actions in the two scenarios and discusses the results from the perspective of the teacher's role, social norms, and teacher digital competence. The interaction and thematic analyses show similarities and characteristic differences in the teacher's interaction patterns in the two scenarios. The teaching actions are similar on a structural level and differ regarding the types and distribution of teaching actions. In the child-child scenario, the teacher directs most teaching actions to both players, and the actions are didactic (mathematical) scaffolding. In contrast, in the child-robot scenario, the teacher only addresses the tutor, and the scaffolding is socially oriented. Implications for a teaching practice involving social robots as learning companions are discussed regarding teachers' presence and participation, types of social robot knowledge that go beyond digital competence, and new challenges introduced by using social robots as learning companions in the classroom. The study contributes new insights into the teacher's role and actions when teaching with a social robot in a collaborative learning situation, which is relevant for educational research and teaching practice.

Keywords Social robots · Learning-by-teaching · Teaching actions · Embodied interaction · Game-based mathematics learning

Extended author information available on the last page of the article

1 Introduction

Social robots for teaching and learning is a growing field of research. Robots have hitherto been used in educational environments to visualize programming or increase knowledge about robotic technology. Nowadays, social robots are also investigated in Human-Robot Interaction (HRI) research for education (Angel-Fernandez & Vincze, 2018; Belpaeme et al., 2018; Benitti, 2012; Mubin et al., 2013) acting in the role of a teacher, assistant, tutor, or peer (An et al., 2022; Belpaeme et al., 2018; Pandey & Gelin, 2017; Sharkey, 2016; Woo et al., 2021). Social robots have also been assigned the role of a novice learning companion in combination with the theory of learning-by-teaching (Pandey & Gelin, 2017), referred to as care-receiving robots (Tanaka & Matsuzoe, 2012), teachable robots (Walker et al., 2016), novice robots (Belpaeme et al., 2018) or robot tutees (Chandra et al., 2020; Pareto, 2017; Serholt et al., 2020).

Knowledge about using social robots in a real school context, i.e., with ordinary school teachers, real group dynamics, and the complexity of a natural classroom environment, is missing (Rosanda & Starcic, 2019). Technical challenges often make it challenging to achieve autonomous and natural child-robot interaction in the wild (Kim & Tscholl, 2021; Serholt et al., 2020), such as challenges in the robot's speech recognition (Alnajjar et al., 2021; Ekström & Pareto, 2020; Kim et al., 2021; Serholt et al., 2020). Other concerns include broken robot components and unexpected robot behaviour due to technical problems (Serholt et al., 2020). Despite these challenges, it is only in the real world, i.e., in the classroom, that robots designed for learning can be realistically tested (Salter et al., 2008) to understand their potential role in the classroom.

Most educational robotics research focuses on child-robot interaction, ignoring or vaguely defining the teacher's role; consequently, discussions of teaching actions are generally lacking (Ceha et al., 2022). Nevertheless, the teacher is affected by a social robot entering the classroom (Ekström & Pareto, 2020; Mubin et al., 2013; Woo et al., 2021), and teachers' involvement is crucial for allowing pedagogical reasoning and action development during technology integration (Forkosh-Baruch et al., 2021). Social robots are advanced technologies, and teachers usually have no experience or confidence in using educational robotics for teaching (An et al., 2022). Thus, the role of the teacher in a child-robot learning activity deserves attention (Ahmad et al., 2016). By studying teaching actions in robot-augmented learning activities and comparing them with similar child-child activities, knowledge is developed regarding teaching possibilities and constraints of social robots in classrooms and demands for professional teacher learning.

This paper aims to discuss opportunities and challenges, dilemmas, and social consequences when robots are used as learning companions in education, from the teaching perspective, to complement previous findings from the same classroom study focusing on tutor learning, i.e., Serholt et al. (2020) and Pareto et al. (2022). Understanding teaching practices and learning environments is essential to assess if social robots are desired as a pedagogical tool. More critical research on social robot use in classrooms is needed, according to Hrastinski et al. (2019). Similarly, Rosanda and Starcic (2019) argue that robotic research needs to also focus on pedagogical outcomes and consequences, e.g., the teacher's pedagogical role in a robot-augmented teaching situation. Generally, when robots are studied in educational contexts, child-robot interaction or individual learning outcomes are explored (Rosanda & Starcic, 2019). This lack of studies results from the technical limitations of social robots and difficulties in integrating robots into educational contexts, even though the technical possibilities of using social robots can be expected to improve with technological development (Alnajjar et al., 2021). However, there are consequences of using social robots for teaching and collaboration in the classroom, which go beyond technical limitations that have not yet been studied to the same extent. Moreover, arguments for using social robots in education are from the perspective of students learning, e.g., increased student motivation, engagement, and concentration (Pandey & Gelin, 2017) and providing social presence, interaction, and affection (Kim & Tscholl, 2021), rather than from a teaching perspective. Likewise, the arguments against using social robots in education include that social robots can be ethically dubious and deceptive for children (Sharkey & Sharkey, 2021), which also becomes a concern for the teacher. Hence, more and longer studies on social robot use for teaching and learning in the classroom are called for due to little empirical evidence that robots benefit students' learning (Benitti, 2012; Konijn et al., 2020) and since children's perceptions (and most likely teachers' perceptions too) change as the robot interaction unfold (Chandra et al., 2020). For example, a study by Ekström and Pareto (2022) showed that teachers interchangeably treated the robot as a social actor or a digital tool within the same interaction sequence, depending on how the interaction unfolded.

This paper addresses the research gap by focusing on the teacher's role and actions when teaching with a social robot in the classroom. Few studies highlight and problematize the role of the teacher when using social robots for teaching and learning. This paper aims to contribute to an increased understanding of how the teaching situation changes when a robot is used as a learning companion to children in the classroom by comparing how teacher interactions and teaching actions differ in a collaborative mathematics learning activity with and without a social robot. Moreover, this paper problematizes social situations or dilemmas concerning using social robots in mathematics education beyond technical limitations from a teaching perspective. In the background below, we first highlight the role of the teacher and how it is affected by the use of technology in general and social robots in particular. Then, we highlight social or socio-mathematical norms in the classroom and new requirements for digital competence. The purpose is to problematize the role and responsibility of the teacher when the teaching context includes social robots. After that, we describe the research design of the small-scale field experiment where we observe the teacher's actions and interactions when scaffolding two different peer tutoring scenarios: one where children in the sixth grade teach a robot to play a digital mathematics game and one where the same children teach a younger child instead of the robot. In both scenarios, the teacher's scaffolding actions are examined.

The aim was to compare a human-human situation with a human-robot counterpart, with the following research question: *How does teaching in a child-robot collaborative mathematics learning activity differ from a corresponding child-child learning activity, and what implications can the use of social robots in the classroom have for the teaching practice?* Thus, the study explores the teacher´s interactions and associated teaching actions in these two scenarios and investigates systematic differences.

The results are discussed from the perspective of the teacher's role, social norms, and teacher digital competence, all concerning social robot use in the classroom.

2 Background

It is well-known that introducing digital technology in education has consequences for teaching and learning. Introducing new technology may affect the teacher's role and require new teaching skills (Hassan & Mirza, 2020; McKnight et al., 2016), even redefining teaching (Keiler, 2018). For example, it is challenging for teachers to make informed decisions about using digital technology to support students' learning (An et al., 2022; Conole & Wills, 2013), and new didactic tools in learning environments affect the approach to teaching, the teacher's different roles and responsibilities, as well as the didactic planning of activities in the classroom (Keiler, 2018). Hence, it is unsurprising that using social robots for educational purposes introduces new challenges for the teaching practice, particularly when the robot is used as a social actor in the classroom and not only as a didactic tool (Ekström & Pareto, 2022).

2.1 The teacher's role

This study connects to a socio-cultural perspective of teaching and learning. Any new tool or technology may change the conditions for the teaching practice, affecting learning and communication, social activities, interaction, and students' experience of inclusion in school. A teacher's role is multifaceted and includes being an educator, supervisor, collaborator, communicator, facilitator, mentor, co-learner, and data analyst (Hassan & Mirza, 2020). The teacher's ability to interpret the context of the learning activity, improvise, and switch between different roles is crucial to support students' learning (Vangsnes & Økland, 2018). Furthermore, it is the teacher's responsibility to create an open and inclusive environment, to support all students' participation, and to stimulate a climate where students feel safe expressing confusion and engaging in learning activities. If social robots are used for teaching and learning in the classroom, teachers will adapt their methods and actions to incorporate this as a tool (Smakman et al., 2021). Research about the teacher's role in a robot-augmented learning activity is still scarce, including how the teacher's role and the relationship with students may be affected (Hrastinski et al., 2019; Mubin et al., 2013). Also, which role the robot is assigned will be crucial for pedagogical success in the classroom (Louie et al., 2021). Overall, the relationships between human and robot actors in collaborative learning situations need to be better understood since they give rise to ethical considerations and dilemmas that teachers must reflect on and act upon when they occur.

2.2 Social norms in mathematics and classroom communication

Social norms guide any social setting and affect how relationships emerge and change, including the norm system of a classroom. Discussions with several students can be demanding for the teacher as these specific social norms, even socio-mathematical norms, are constantly negotiated and established (Yackel & Cobb, 1996). The negotiations support maintaining a particular system. Breaking social norms can be disruptive. Thus, introducing a robot as a social actor becomes a socially disruptive experience as it violates established social norms (Serholt et al., 2020). Social norms include expected and negotiated behaviours, essential to any school environment, as they are interwoven in any culture. Norms also affect speech and nonverbal communication, such as body language, which is used both consciously and unconsciously, for example, to emphasize speech or feelings. Even if social norms are strong, personal and cultural differences exist in preferences for emotional expressiveness, personal space, and touch concerning communication. For example, in human interaction, the need for personal space increases with our alienation from people (Knapp et al., 2013). A related aspect connected to the social norms perspective is social cognition, in which students extract meaning from behaviours, make attributions, and infer characteristics of the teacher and other students.

The teacher can create a positive classroom climate, an essential component of an effective, inclusive learning environment. Some researchers argue that there is a difference between more general social inclusion and inclusion in the learning community at school (Nilholm & Alm, 2010). There can even be a conflict between school norms and goals that some students perceive their peers want them to pursue, and students who are disruptive to the norm can be unpopular with peers (Bru, 2006). Research suggests that individuals' reasoning and sensemaking processes can not be separated from participation in the interactive constitution, where mathematical meanings are shared (Yackel & Cobb, 1996). Student-centered mathematics teaching can develop students' collective construction of mathematics by encouraging them to think, articulate their thinking, and make them discuss their own and other's ways of thinking in class discussions (Kooloos et al., 2022). The teacher's engagement can then be concerned with reorienting students and asking questions that provoke thought. Such a question-asking role can also be assigned to the robot, as is the case for the robot studied here; for more details, see (Pareto et al., 2022). In general, learning to communicate mathematically is a central aspect of what it means to learn mathematics (Moschkovich, 2002; Pourdavood & Wachira, 2015). Thus, mathematics learning is not necessarily primarily about completing procedures, solving word problems, and using mathematical reasoning but also about developing sociomathematical norms (Cobb et al., 1993; Elrod & Strayer, 2018), presenting mathematical arguments (Forman, 2013), and participating in mathematical discussions (Lampert, 1990; Erath et al., 2021; Kazemi & Hintz, 2023) while negotiating the general classroom norms.

2.3 New demands for digital competence

If social robots are to be used in education, more research on their implementation is needed, alongside a plan for appropriate professional training of teachers (Istenic et al., 2021). Digital technology has empowered teachers in various ways and implied a more technology-oriented and complex role (Hassan & Mirza, 2020). Skantz-Åberg et al. (2022) have described what professional digital competence can mean for active teachers. They use an umbrella concept for teacher professional digital competence

(TPDC), including seven different aspects: (1) technological competence, (2) content knowledge, (3) attitudes to technology use, (4) pedagogical competence, (5) cultural awareness, (6) critical approach, and (7) professional engagement (Skantz-Åberg et al., 2022). For example, technological competence comprises a teacher handling digital technology and solving technical issues in the classroom. At the same time, cultural awareness concerns the classroom and understanding that social and cultural conditions affect classroom behavior. Having a critical approach means that the teacher chooses appropriate digital technology for teaching and collectively reflects on their teaching practice in general, i.e., a critical approach entails a holistic view of technology in both education and society (Skantz-Åberg et al., 2022).

Today, there are two interpretations of teachers' digital competence; the first interpretation means that a teacher must be able to use digital tools in an effective way to combine technical, pedagogical, and content-related knowledge, while the second interpretation is broader and is about teachers needing to be able to use digital resources in a sustainable, safe and ethical way, which means understanding how social robots as a specific technology affects people, society and the environment (Falloon, 2020). Digital development in society affects both the teaching profession and the education system, and teachers' professional digital competence is dynamic and complex since it is continuously affected by societal development (Kelentrić et al., 2017). This implies that teachers have a collective responsibility, as their critical, scientific, and ethical competencies are affected by societal changes. In such a dynamic process, the concept of TPDC must be continuously defined and redefined (Skantz-Åberg et al., 2022). Like most people, teachers have limited knowledge of advanced technologies like social robots and AI (Hrastinski et al., 2019). Still, they are prerequisites for teachers to be able to critically relate to if, how, and when robots should be used as educational technology. For example, future teachers may have access to and know how to interact with different kinds of robots, and thus, the consequences of using robots in teaching must be better understood (Rosanda & Starcic, 2019), and ethical issues should be highlighted, and discussed (Hrastinski et al., 2019). However, increased programming skills can improve insights into the possibilities and limitations of robot technology in teaching practices (Ekström & Fuentes, 2020).

3 Method

This qualitative study is based on a single case, i.e., a small-scale field experiment in a semi-authentic classroom setting. An exploratory case study aims to make detailed investigations of a specific case to generate insights into a novel situation (Yin, 2014). The study object is the embodied interactions and conversations between the actors in a learning situation, consisting of a tutor and a tutee playing an interactive game and a teacher scaffolding the tutoring activity. The tutoring activity consists of playing a two-player collaborative mathematics game displayed on an interactive whiteboard, where the tutor is always human, and the tutee is either a social robot or a younger child. The game-playing sessions are led by the class teacher but technically supported by researchers and, thus, a semi-authentic setting. Sessions are observed and video-recorded, providing access to social action and interaction with technology and allowing for repeated views, detailed analysis of interaction, and making several analytical perspectives of the same situation possible (Heath & Hindmarsh, 2010). This study examines the teacher's interactions, focusing on the difference when the tutee is a social robot compared to a younger child. This is one of several studies in the research project *"Student Tutor and Robot Tutee"* (START). In the START project, the robot tutee is co-designed with teachers and children to be experienced as an inquisitive learning companion (Barendregt et al., 2020), and this study was conducted after the final iteration of the co-design process.

3.1 The collaborative arithmetic game

The learning activity is based on a digital mathematics game that has been shown to strengthen students' mathematical reasoning and conceptual understanding of arithmetic by using a distinctive graphic representation with coloured blocks instead of numbers (Pareto, 2014; Pareto et al., 2011, 2012). The game played in this study is called *"Find the sum up to 100"*, and the players must collaborate and agree on one card each that yields the search-for sum, see Fig. 1. The collaborative gameplay is based on playful interaction where the players must consider different points of view, negotiate their ideas, and develop a shared solution (Mazzoni & Benvenuti, 2015). A game sequence includes ten game rounds, i.e., ten cards to each player.

Originally, a teachable agent acted as the tutee, but this idea was further developed, and the agent was replaced by an embodied social robot (Pareto, 2017; Pareto et al., 2019). Kim and Tscholl (2021) argue that robot embodiment engages children to interact much more than other non-embodied digital tools. The social robot used in this study was the humanoid robot Pepper from SoftBank Robotics, which was connected to and steered by the game via a local wireless network. Besides the game and the robot, the learning activity also consisted of a wall-mounted interactive whiteboard displaying the game. The setup of the START system is shown in Fig. 2. The robot had no opportunity to learn anything but could be experienced as learning more about arithmetics and the game because, as the child played better and answered the questions more correctly, the robot asked more relevant and deep questions.

Previous studies with the START system showed that teacher roles such as technical facilitator and interaction mentor were necessary in the classroom when the learning activity was carried out, supporting the playing child in interacting with the robot (Ekström & Pareto, 2020; Serholt et al., 2020). This paper is based on the same

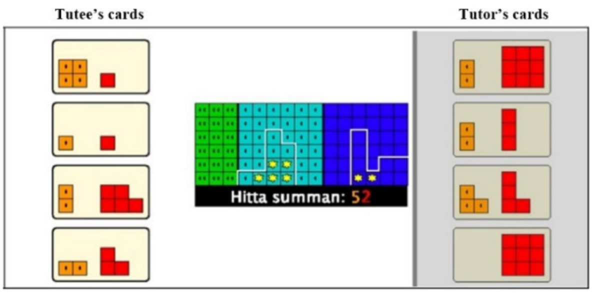

Fig. 1 The graphical arithmetic game used in this study

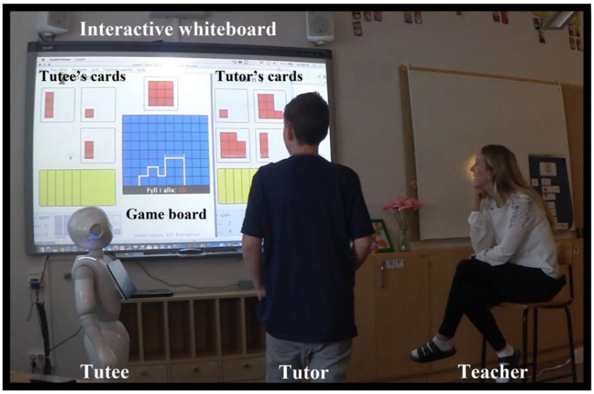

Fig. 2 The learning activity with the child tutor, the robot tutee, and the teacher

game-playing sessions as in Serholt et al. (2022) and Pareto et al. (2022). However, these previous studies did not focus on how the teacher acted but instead had a student learning perspective, and hence, it was relevant to explore further.

3.2 Research design

Our research design of a single-case small-scale field experiment where video-recorded observations of embodied interactions of the learning activity in situ are analyzed is suitable for explorative research and is used in other robot studies. For example, Kim and Tscholl (2021) used a similar approach when studying children's embodied interactions with a social robot, and Kopcha et al. (2021) when studying children's computational thinking while programming a robot. Kim and Tscholl (2021) argue that embodied interactions occur between actors with a body shape (i.e., including humanoid robots), providing an experience of bodily movements and processes. Our analysis focused on the embodied interactions between the teacher, the playing child(ren), and the social robot, but not interactions with the game or the interactive whiteboard.

The study was conducted in a classroom in a primary school in Sweden, and it was the fourth study within the START project. The activity was planned with the teachers, and 35 min were reserved for each game-playing session. The game sessions took four full days, spread over two weeks. The teacher participated in all sessions, and the tutors in two sessions each: one with the robot tutee (the child-robot scenario) and one with a child tutee (the child-child scenario). The two scenarios were counterbalanced to avoid ordering effects. At the beginning of each game session, the teacher introduced the players to each other, gave a brief game presentation, and then stayed nearby. A "find-the-pair" game consists of 10 mini-problems, in which the two players need to choose one card from each player that together makes a given mathematical result (for example, a sum). There is always one pair matching the goal, but the task for the players is to find the pair by reasoning together and finding smart strategies to avoid having to compute and check all combinations in their heads (4 times 4 cards makes 16 combinations). Once a card is chosen, it cannot be retracted, so the players need to negotiate and discuss a joint proposal before deciding to play successfully. The tutor and tutee were free to collaborate by discussing mathematics and strategic choices to the extent they wished, although the tutor was assigned the role of tutor and encouraged to teach the tutee. When the 10 mini-problems in a game were completed, the players received a summary of their joint performance. Then, the players were allowed to play again if time remained. A played game session typically involved two games.

In both scenarios of the field experiment, the mathematical collaboration between the tutor and the tutee was decisive for the teacher's actions. Due to the explorative nature of the study, the teacher did not receive any instructions to act in a certain way and thus acted independently to support the learning activity. However, it was decided that the teacher should scaffold both scenarios as appropriate. Due to the communicative nature of the activity, the robot's social features, and the teacher's presence, social interactions occurred between all three participants. In this study, the teacher's activity during the above-described learning activity was under investigation.

3.3 Participants

A total of 20 children and one teacher participated in the study. The ten children acting as tutors were in sixth grade (*N=10; 5 girls; 12 to 13 years old*), and the ten acting as tutees were in third grade (*N=10; 6 girls; 9 to 10 years old*). The participating teacher was the sixth graders' regular teacher in mathematics who, along with the younger children's teachers, randomly selected the children to participate. The sixth graders and the teacher had some previous experience with the START system by playing a similar game and interacting with the robot (Barendregt et al., 2020; Serholt et al., 2020). Most sixth graders participated in the design process and interacted with the robot in groups on three previous occasions for about 30 min each. The teacher participated in the design process but only interacted with the robot twice, for about 15 min as a tutor and 30 min as a teacher. The third graders had no experience with the game or the robot. Except for one game-playing couple who happened to be brothers, the co-players were not familiar with each other.

3.4 Data collection and analysis

The game sessions were video recorded using two cameras to make all actors, including the game board, visible. Using video observations in case studies effectively captures details (Knoblauch, 2009). The purpose of the dual cameras was to capture the whole and the details of who interacted with whom and thereby be able to perform interaction analysis of the embodied conversations and interactions as proposed by (Jordan & Henderson, 1995). After completing the game sessions, the verbal dialogue was transcribed using the digital transcription tool ScriptMe and then double-checked manually afterward. The interaction analysis was carried out using the tool MAXQDA, which supports qualitative data analysis of video recordings (Oswald, 2019).

The preliminary verbal transcriptions were then supplemented using the video recordings to augment the transcripts with the participants' nonverbal communication necessary for the interaction analysis, such as communicative gestures and to whom the speaker addressed a verbal action. A verbal action is a coherent utterance containing one or more sentences connected in time and content. A non-verbal action is a significant gesture, e.g., dancing, clearly pointing to a card on the game board, or actively seeking eye contact with someone. Most of the non-verbal gestures occurred in interactions between the tutor and tutee, but sometimes the teacher (re)acted on the players' non-verbal gestures, for example, when the teacher explained the robot's actions or encouraged the players to pay attention to each other.

Then, the coding of interactions was conducted as a two-step process: first, interaction actors, i.e., who interacts with whom, were coded, and then all interactions involving the teacher and one other actor representing a teaching action were coded. If the teachers directed a teaching action to both tutor and tutee, it was coded as one teacher-tutor and one teacher-tutee interaction. The coding of actors was straightforward, whereas the teaching actions were coded inductively in several iterations, not based on a predetermined theory. Instead, the teaching action themes and sub-themes emerged during analysis when teaching actions were compared and categorized based on the overall motive of a specific action. A teaching action can belong to more than one (sub)theme if the teaching action has more than one objective. After the thematizing, a work inspired by Braun and Clarke (2006), a comprehensive analysis emerged that classified teaching actions in the learning activity. A theme clarifies a pattern in the data material, which in this study is teaching activity and action that captures something essential concerning the research question (Bryman, 2016). Here, for an action to be defined as a teaching action, it must have a teaching purpose relevant to the ongoing learning activity. This definition is based on activity theory's understanding of human actions, where an activity has an objective, and is composed of conscious actions acted out through unconscious operations (Kaptelinin & Nardi, 2006). Below, we refer to the types of teaching actions as a teaching activity.

After the interactions were coded, the frequencies of actions and interaction types were computed. Combining a qualitative interaction analysis with a frequency analysis describes the empirical material through examples and the typicality of the coded data (Erickson, 2012), providing a more detailed description. There were 1955 teacher interactions between the teacher and the tutor or tutee, counting actions in both directions. With few exceptions, the teaching actions were directed from the teacher to the tutor or tutee. Altogether, there were 1726 teaching actions.

4 Results

The game sessions lasted about 25 min each on average. The time difference between the two scenarios was small; game sessions lasted for approximately 26 min (M=*26 min 29 s;* SD=*06 min 8 s*) in the child-child scenario and for approximately 24 min (M=*24 min 20 s;* SD=*4 min 51 s*) in the child-robot scenario, see Table 1.

The teacher alternated between active verbal participation and silent activity monitoring during the game sessions. On average, the distribution between active verbal participation and silent monitoring was 31,2. It was similar in both scenarios: only slightly higher child-robot (M=*33,0%;* SD=*7,7*) than in child-child (*M*=30,4%; *SD*=14,3). A higher standard deviation value in the child-child scenario means that the teacher's verbal participation in each game session varied more when the tutee

Table 1 The average time for the game sessions and the teacher's average activity distribution in the two scenarios

		Teaching activity	
Scenario	Time	Verbal participation (%)	Silent monitoring (%)
child-child	24 min and 20 s	30,4	69,6
child-robot	26 min and 29 s	33,0	67,0
Overall	25 min and 25 s	31,2	68,8

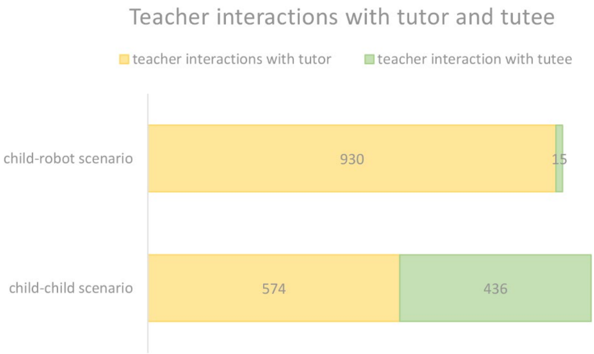

Fig. 3 The number of teacher interactions with the players (tutor and tutee) in the two scenarios

was a younger child and not a robot. The teacher left the classroom a few times due to external circumstances, but TF stayed and supported both the child(ren) and the robot when needed. Hence, there was always a teacher or a TF nearby.

4.1 Number of teacher interactions with the players

A quantitative analysis visualizes the number of interactions during all accomplished learning activities. The analysis of teacher interactions with the two players shows that the distribution of teacher interactions differs substantially between the two scenarios, see Fig. 3.

The teacher interactions in the child-child scenario were relatively evenly distributed, see Fig. 3, where the teacher interacted with the tutor 574 and the tutee 436 times, respectively. However, in the child-robot scenario, the teacher mainly interacted with the tutor, as 930 out of 945 interactions were between the teacher and the tutor. When the teacher interacted with the tutee, it was usually an utterance addressed to both players, such as "*Great job!*" or "*You received ten stars together!*".

The total number of teacher interactions was slightly higher in the child-child scenario than in the child-robot scenario, with 1010 compared to 945. The difference can be explained by the fact that the technical facilitator (TF) interacted with the child 230 times in the child-robot scenario and thus probably replaced some teacher interactions. TF's interactions with the players were otherwise marginal (between 5 and 20) and primarily concerned with practical matters, like "*When will it end*?". Still, this result was expected as TF's role in the classroom was to support the teacher in technology management and robot interaction only.

4.2 Types of teaching actions in the learning activity

Teaching is situational and contextual and hence influenced by many factors, including the characteristics of the individual actors and unforeseen changes in the contexts. The result shows that the same teaching actions occurred in both scenarios but differed in frequency. The thematic analysis revealed five types of teaching actions: (1) assisting interaction, (2) engaging in game-play, (3) providing feedback to the players, and (4) managing the learning activity, see Fig. 4. There were more teaching actions in the child-robot scenario than in the child-child (1056 and 670, respectively). In the child-robot scenario, there are slightly more teaching actions than teacher interactions, which can be explained by the fact that the teacher mainly assisted the tutor in the child-robot interaction in several ways during one interaction. Conversely, in the child-child scenario, there are fewer teaching actions than interactions, which can be explained by the fact that the teacher often directed a teaching action to both players simultaneously, i.e., both tutor and tutee receive the same support.

The analysis shows that the dominant teaching activity in the child-robot scenario was assisting the child-robot interaction, which was not needed to the same extent when two children collaborated and played together. Conversely, the analysis shows that the teacher provided more feedback and acknowledgments when two children were playing, which was not needed to the same extent when the child was playing with the robot since the robot tutee was designed to provide feedback and acknowledge the tutor. In addition, it also appears that the teacher became more engaged in the game-play when two children played than when one child played with the robot. The analysis also shows a managing activity, which means that the teacher handles the practical and technical aspects of the activity, which is done to approximately the same extent in both scenarios.

Further, each theme (teaching activity) consists of several subthemes (teaching actions), which may be unique to a given scenario or shared between both. These

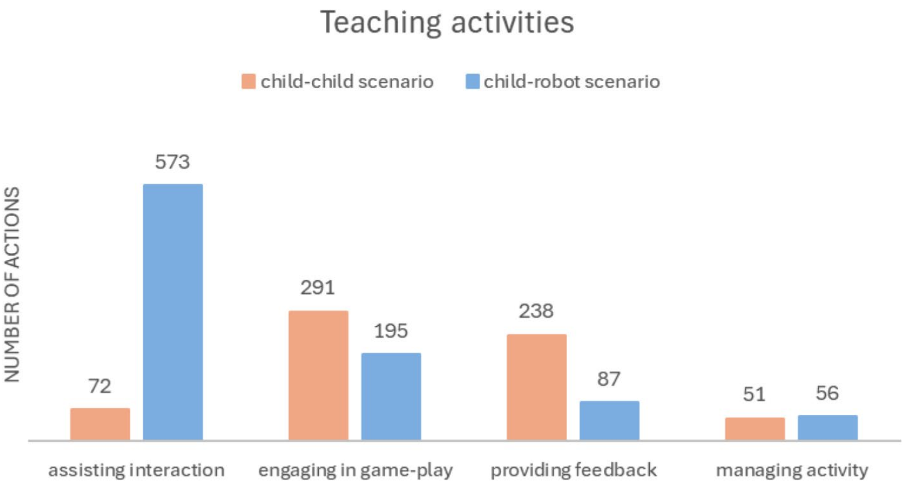

Fig. 4 The teaching activities and their frequencies within the two scenarios

teaching actions are analyzed below and provide a more detailed picture of the difference between the two scenarios.

4.2.1 Assisting the interaction between the co-players

The analysis shows that the teacher assisted the tutor-tutee interaction in several ways, especially in the child-robot scenario, see Fig. 5. A discernible teaching action in the child-robot scenario was that the teacher ***assisted in the verbal communication*** between the child and the robot. The assistance consisted of direct instructions such as *"Say 40!"* or *"You can say that the red ones are singular, and the orange ones are tens."* and of guidance and encouragement, e.g., *"Try again!"* and *"You are doing the right thing."*. The teacher also explained the limitations of the tutee's speech recognition: *"He [the robot] cannot handle such long sentences. So, you can try to just say twelve like this: 12."* or *"You only get one chance to say. Unfortunately."*. Furthermore, the teacher assisted verbal interaction by explaining the questions asked by the robot: *"Now he [the robot] wonders, are there always two pairs that fit together?"*. The analysis clearly shows that the teacher intended to make the verbal communication between the child and the robot flow.

Another characteristic teaching action in the child-robot scenario was that the teacher ***explained the robot's behaviour*** in various ways. The explanations were about the robot's playing behaviour and its more general social behaviour. The teacher guided the child tutor regarding the robot's interactive gaming behaviour: "*Now you can tell him [the robot] which one to play."* Or *"Now he chose himself and clicked [on the card] as you said."* The teacher also explained the robot's questioning behaviour: *"If you [the tutor] click on a card, he [the robot] usually asks a follow-up question,"* as well as its social gestures, for example: *"Here comes the helicopter, it seems to be his [the robot's] gesture of victory"* and *"now he [the robot] thought you were funny."* Finally, the teacher tried to justify the robot's behaviour when perceived

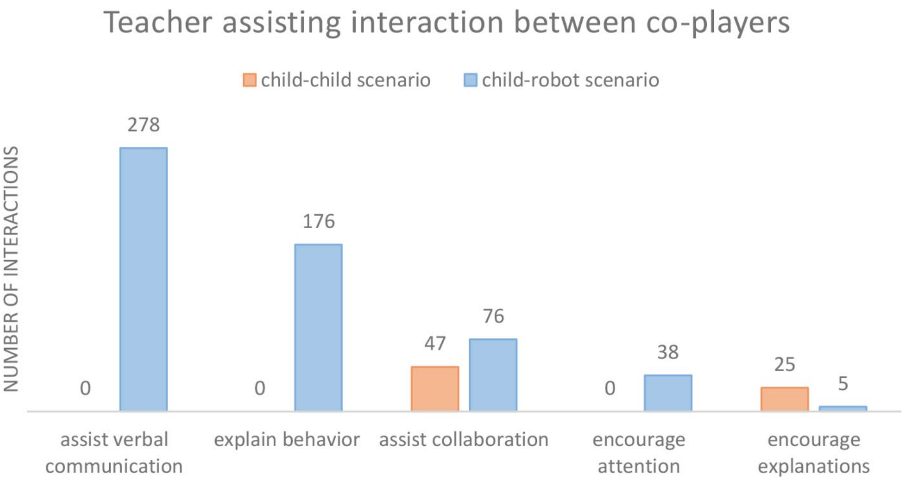

Fig. 5 Different teaching actions assisting the tutor-tutee interaction. Assisting interactions were more common in the child-robot scenario

as absent by saying that the tutee was *"a little bit tired"* or *"absent-minded before lunch."* It can be interpreted as the teacher explaining the robot's behaviour to the tutor to increase the child's understanding of the robot.

Moreover, the teacher ***encouraged the child and the robot to pay attention to each other***. On the one hand, the child needed to pay attention to the robot´s questions, which needed to be answered to facilitate collaboration. Hence, the teacher encouraged the child to be prepared for the upcoming questions: *"Click ok. Then you will see what he [the robot] asks."*. On the other hand, the robot sometimes lost attention when the child was physically distant or too quiet; then the teacher encouraged the child to keep the robot attentive: *"I think he [the robot] wants you to be closer."* Or *"Clap your hands."*. So, the child was encouraged to pay attention to the robot and to act so that the robot remained attentive to the child.

The teacher ***assisted with the collaboration*** in both scenarios. However, the analysis reveals that it was more apparent in the child-child scenario. In this scenario, the teacher highlighted the importance of collaboration in a way that does not appear in the child-robot scenario. For example, the teacher said, *"Feel free to discuss and help each other."* And *"Calculate together."* When both players were children, *another* teaching action more common in the child-child scenario than in the child-robot was that the teacher ***encouraged mathematical explanations*** like *"You may explain how you think."*. In the child-robot scenario, the teacher encouraged clarification rather than explanations, such as "*Can you tell what number it is?"*.

The analysis shows that the teacher assisted the child-robot interaction in several ways, mainly by assisting the playing child to understand the robot's verbal and non-verbal behavior. i.e., the robot´s social limitation. Assisting verbal communication, explaining the co-players behaviour, and encouraging attention to the co-players were not required teaching actions as two children were collaborating. Instead, the teacher assisted the interaction by enabling the human players to explain their mathematical thoughts to each other, which is more in line with the aim of the learning activity.

4.2.2 Engaging in gameplay

The teacher was engaged in the gameplay in both scenarios by explaining the game, relevant mathematical concepts, and the game´s graphical representation. Moreover, the teacher gave hints about card choices, supported calculations and strategies, and encouraged mathematical reasoning. Overall, this activity was more comprehensive in the child-child scenario, especially regarding supporting teaching actions, see Fig. 6.

The analysis reveals a tendency for the teacher to ***support calculations and strategies*** more often in the child-child scenario. For example, the teacher said: *"I do not think you can get the sum 5 in any way. But maybe you can get the sum of 15 instead?"* to support the children's calculations. To support their strategic thinking, the teacher said things like: *"First, you have 40+20, which is 60, then you have 8+5..."*. A teaching action that was more common in the child-robot scenario had a slightly opposite character. In this scenario, the teacher instead took the role of the tutor's co-player: The teacher ***hinted at which card*** the child tutor should choose instead of mentoring the two co-players, e.g., *"Now let us see ... It is the second at*

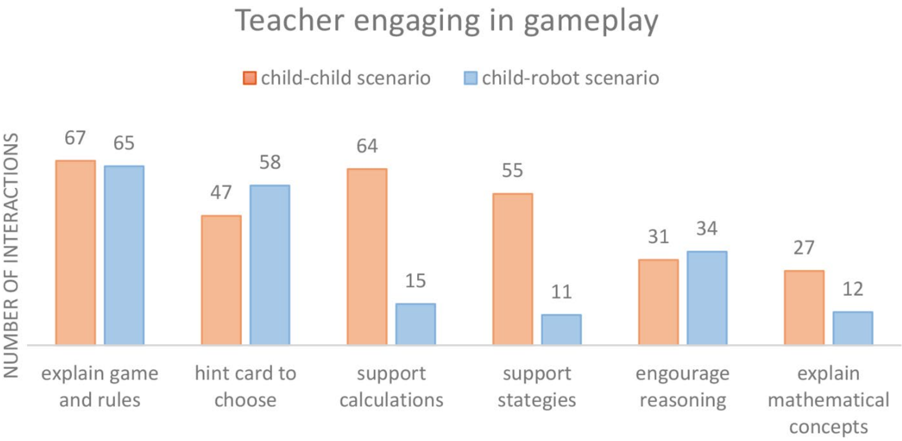

Fig. 6 Teaching actions showing engagement with the gameplay. This teaching activity appeared relatively even in both scenarios, but the distribution of teaching actions differed

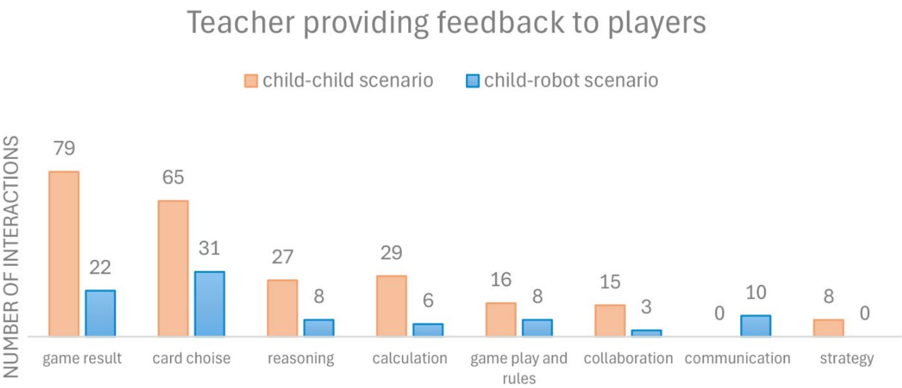

Fig. 7 Different teaching actions providing feedback to tutor and tutee, a teaching activity generally more common in the child-child scenario

the bottom." From this, it appears that the teacher acted as a supportive mentor to both children in the child-child scenario but fell into the role of co-player to the child tutor in the child-robot scenario.

4.2.3 Providing feedback

During the game sessions, the teacher provided more feedback in the child-child scenario than in the child-robot scenario. The teaching actions in this teaching activity acknowledge all conceivable parts of the game, from choosing cards and mathematical reasoning to game results and collaboration, see Fig. 7.

Above all, the analysis shows that the teacher performed more actions to give feedback on successful playing and correct card choices when two children were playing compared to game sessions with a child and a robot. This result is explained by the fact that related studies show that the robot tutee gives more feedback and confirms the child tutor to a greater extent than the child tutee does (Pareto et al., 2022). ***Acknowledging game results*** in the child-child scenario includes statements like *"It feels like this is going really well."* or *"10 stars - full score. Nice!"* while ***acknowledging card choices*** are shorter confirmations such as "*Yes*, *it [the card] is 45."* or "*Yes exactly. Click on it [the card]."* These teaching actions were also present in the child-robot scenario but to a lesser extent. Moreover, when acknowledging the game result, the pronoun was often changed from plural to singular, e.g., "*Now you [the child tutor] get a star*."

In addition, the teacher also provided feedback related to the ongoing mathematical conversation. In the child-child scenario, the teacher ***acknowledges mathematical reasoning***, ***calculations***, ***and collaboration*** with feedback like *"Very well explained!"*, *"Great! 16 plus 41 is 57."* and *"I think you help each other very well."*. In the child-robot scenario, the mathematical reasoning was instead internal, where the teacher acknowledged the child tutor to take time to think rather than explain verbally. Only on a few occasions did the teacher acknowledge the collaboration between the child and the robot, and then with some hesitation: *"You did not need much help from me; it was you and Pepper who handled it all. Maybe mostly you, but…"*. There was only one teaching action specific to the child-robot scenario, and that was ***acknowledging verbal communication***, exemplified by statements like: *"Now you [the tutor] said the right thing!"* and *"Just go ahead [and play] and drop that [question]."*

The analysis shows that the teacher acknowledges the children's shared mathematical actions in the child-child scenario. In contrast, the same actions in the child-robot scenario are fewer and often directed solely at the child tutor. In addition, the teacher acknowledged the tutor's verbal communication with the tutee in the child-robot scenario, which did not happen in the child-child scenario.

4.2.4 Managing the learning activity

During game sessions, the teacher needed to manage the learning activity, e.g., monitoring time and verifying motivation to continue the gameplay or solve practical and technical problems. These teaching actions were approximately equally frequent in both scenarios. The practical problems were, for example, where the robot would be placed, which became a problem if the child tutor needed a chair to reach the cards on the interactive whiteboard. The technical problems during the game sessions were usually due to breakdowns of either the game or the robot, problems that also were difficult to detect immediately. As mentioned before, the awareness of possible technical problems was why the technical facilitator was present. Problems arose in the borderland between practical and technical, such as the volume of the robot's speech or selecting a feasible mathematics game.

The fact that the technical facilitator (TF) was in the classroom during all game sessions entailed that the teacher developed an understanding of the learning activity in general (in both scenarios) and the social robot in particular (in the child-robot scenario). Most of all, the teacher seemed to learn about human-robot interaction. For example, the teacher asked: "*What kind of answer does he [the robot] want there?*".

Furthermore, there was more interaction between TF and the teacher in the child-robot scenario, where TF sometimes explained the terms of the interaction: "*It is only when it [the robot] has just asked a question it will listen for [a response].*" But more often supported the teacher when (s)he assisted the child tutor in the interaction with the robot tutee.

5 Discussion

The results are discussed from the perspective of the teacher's role, social norms, and teacher digital competence, all in relation to using or not using a social robot in the studied learning activity.

5.1 The teacher role

The teacher's task was to scaffold the tutoring activity using the collaborative mathematics game, and the results show that the teacher's activity was different in the two scenarios, with and without a social robot. The empirical data revealed that the teacher was equally active in both scenarios: approximately the same amount of interactions and the same ratio of verbal activities versus silent monitoring in both settings. However, the three active participants (the teacher, tutor, and tutee) grouped differently in the two scenarios and created different alliances. In the child-child scenario, the teacher engaged more in the actual gameplay and interacted with both players almost as much. The teacher often treated them as two equal students and scaffolded them around the mathematics game, even though her assigned role was to support the tutoring activity between the tutor and tutee as a mentor. Instead, the teacher often engaged in the roles that Hassan and Mirza (2020) denote as collaborator and co-learner, and the three of them worked together, playing and interacting with the collaborative mathematics game ("*Now we have to think about which cards go together.*"). All three focused on the whiteboard and discussed options, strategies, and how to make smart choices. In the child-robot scenario, on the other hand, the teacher was mainly in alliance with the child tutor and, to a large extent, ignored the robot tutee. Her main focus was either to help the tutor understand, communicate, and interact with the robot tutee ("*You can say: Find sum 69*.", "*Say it [your answer] one more time*, *but a little more clearly*.", "*Now he [the robot] thought you were funny*." or "*Now he [the robot] played the card himself*") or to discuss options and strategies with the tutor only ("*There is no way you [the tutor] are going to add up to zero with those [cards]."*). Either way, the main alliance was teacher and tutor versus tutee and game. Here, the teacher more often acted as a communicator or supervisor rather than a collaborator, according to the roles of Hassan and Mirza (2020). Hence, different implicit subgroup alliances were formed as the othering, i.e., a "we and them" division within the socio-technical learning system. However, some situations did not follow these patterns. For example, in the child-robot scenario, when the child tutor got immersed with the robot tutee and/or the gameplay and the teacher took an outsider role observing the activity, or in the child-child scenario when the collaboration was not proceeding as smoothly as desired, then the teacher intervened to support their interaction to re-establish an inclusive, comfortable social situation for all (human) players. The robot tutee did not receive such concern; instead, the teacher ignored the robot and did not spontaneously include it in the alliance, as illustrated by "*Now you [the child] get a star*!" and "*Maybe with one of these [some cards]… Let us [teacher and child] see*, *maybe we*…".

The character of the teaching actions also differed between scenarios. In the child-robot scenario, the teacher mainly assisted with the interaction, whereas in the child-child scenario, (s)he primarily engaged in the game and provided feedback (see Fig. 4). There are several plausible explanations for this difference. One reason is the difficulties that the child-robot interaction introduced. Another explanation is the different enactment of the tutee role, where the robot tutee was designed to be proactive and take the initiative by asking questions about situated mathematical strategies and calculations related to the game and providing frequent feedback and encouragement to the tutor. Hence, some actions were already provided by the robot tutor and were unnecessary for the teacher to fulfill in the child-robot scenario (see Figs. 6 and 7). The younger child tutees were generally very quiet and let the tutor take the most initiative and drive the conversation; hence, the teacher's role became to provide feedback and acknowledgments. Related findings of these differences concerning tutor learning are reported by Pareto et al. (2022). In the child-robot scenario, the teacher seemed to prioritize assisting the tutor's interaction with the robot by saying what the tutor was expected to say, when, and in what way, and helping the child understand the behaviour of the unusual learning companion (see Fig. 5). For example, when there was repeated miscommunication between the child and the robot, the teacher dictated to the tutor precisely how to respond to the robot concerning mathematical questions. This means that the effort of maintaining a smooth interaction and the goal to stimulate mathematical learning collided, and the teacher seemed to subconsciously prioritize the latter. Favoring a positive and inclusive social environment is a reasonable choice, but the behaviour may have affected the mathematical learning opportunities for the tutor.

In general, the different teaching actions in the two scenarios can be explained by the teacher taking the roles and the actions needed based on how the collaborative learning activities unfolded, as advocated in Vangsnes & Gram Økland (2018). An observation was that the interaction with the robot tutee was almost non-existent: the teacher never spoke only to the robot. However, the robot was designed to interact with one human at a time and did not allow for a three-party discussion as occurred in the child-child scenario, which may be one explanation for this behaviour. Another explanation can be that the teacher was uncomfortable communicating with the robot, yet the teacher expected the children to adhere to the social role-play. This lack of social teacher-robot interaction may affect the children's engagement in collaborating and learning since the teacher is a role model, and the robot's role is crucial for pedagogical success in the classroom (Louie et al., 2021). A previous study shows that teachers switch between viewing the robot as a digital tool and a social actor (Ekström & Pareto, 2022). Depending on how the activity proceeds and whether social or technical concerns arise, one of these perspectives dominates, and the teacher acts accordingly. The difference in the teacher´s interaction pattern between the two scenarios suggests that the teacher does not fully treat the robot as a social actor even though the robot is assigned this role in the social narrative of the learning activity. Note, however, that the study is too small to claim statistical significance; rather, the frequencies are highlighted to illustrate characteristic differences in interaction patterns and performed teaching actions between the two.

5.2 Social norms

Previous research has shown that teachers are essential in sustainable robot-augmented learning environments (Ahmad et al., 2016). This paper shows that the teacher actively supported and made the collaboration between a child tutor and a robot tutee more productive, but it also reveals how the teacher handled a child-robot learning activity where the robot sometimes violated social norms. The purpose is to discuss situations perceived as awkward from a social norms perspective that arose in the social learning situation involving a social robot tutee. We will focus on how the teacher acted in these situations, not to judge her behaviour but to uncover and discuss how spontaneous and reasonable behaviours in a teaching situation raise questions about how to treat a robot with social behaviours in a collaborative learning setting from ethical, social, and education perspectives.

The first example is related to the perception of the robot as uncanny. One child tutor showed clear signs of perceiving the robot as creepy and did not want to get close to the robot. This entailed that the child was on the border of the robot's pre-programmed zone of proximity, and hence, the interaction was repeatedly interrupted. When the child-robot interaction was interrupted, the robot said goodbye and asked why the child was leaving, making the child even more uncomfortable. The child's need for personal space appeared to be larger than the robot's designed behavior allowed, related to the level of alienation the child felt toward the robot described in Knapp et al. (2013). The teacher explained the robot's behavior by saying: "*He thinks you're leaving*," and encouraged the child to move closer. In our opinion, the teacher behaved as a trusted adult and proxy for the situation, as in the study of Yip et al. (2019).

The following examples illustrate when the robot's behaviour is perceived as awkward or rude since it violates common human social norms by exaggerated or unusual behaviour. On a few occasions, the robot laughed out loud or pretended to be a helicopter when the two players successfully completed a game round. Several tutors became uneasy with such behaviour and looked to the teacher for affirmation and support. She tried to comfort them by excusing and rationalizing the robot's behaviour: *"Now he [the robot] thought you were funny."* and *"Here comes the helicopter; it seems to be his [the robot's] gesture of victory."* It is interesting to note that the robot is talked about as a social actor in these explanations since they refer to human social norms rather than providing a technical explanation that it is programmed that way, which would have been another option. Other examples of robot behaviours perceived as rude were when the robot interrupted the tutor in the middle of long elaborated explanations or when the robot turned around 180 degrees and kept looking out the window in the middle of a dialogue with a tutor. Also, the teacher acknowledged the robot behavior's weirdness and provided rationalizations of social human character: i.e., that *"long explanations are too difficult for the robot"* and that the *"robot was tired."*

However, even if the above explanations of the robot behaviours were socially rationalized, the way the explanations were communicated would not have been socially acceptable in a human setting. For example, the robot tutee was often ignored, talked about, or even laughed at, not socially cared for, and not treated as included in the social group, so it is neither inclusive nor caring from an ethical perspective. Note that we are not arguing that the robot should be treated this way; we are simply pointing out a discrepancy in the approach towards the robot when the same message implies" social actor" by content but implies "technical tool or device" by format. This observation is related to the dual role of the robot tutee, perceived as both a social actor and a digital tool depending on how it acts, as reported in Ekström and Pareto (2022). Still, we have identified situations where both perspectives are present in the same actions. This indicates that we are yet somewhat unsure of how to act in relation to robots in a social learning setting such as the classroom. On the one hand, the role play and the idea of the robot as a learning companion imply it should be treated as a social actor; on the other hand, the robot's limited and sometimes norm-violating behaviour must be handled somehow. These observations raise questions about what social norms we expect when interacting with a social robot; are they the same as for humans or others? For example, is it okay to say that the robot tutee is stupid, or do human social norms also apply to robots? Will we develop specialized social norms for human-robot collaboration over time? We argue that a nuanced discussion of human-robot social norms in various social settings is called for.

5.3 Teacher digital competence

Having a vital role in all learning contexts, teachers typically develop their digital competence throughout their teaching career (Kelentrić et al., 2017) and need a broad digital competence according to the TPDC suggested by Skantz-Åberg et al. (2022). As the teaching actions in the two scenarios with and without a robot differed substantially, teachers considering using social robots should be aware of the effect a robot may have on teaching and learning. Our study suggests that teachers need in-depth knowledge of various technical aspects of verbal human-robot interaction and how the specific robot is designed to act as a learning companion. For example, they need to know where and when the robot can perceive what a child is saying, how it interprets spoken language, and what the robot is programmed to listen to. The technical understanding also includes knowledge of how the robot uses sensors to react to the tutor's actions, for example, cameras, which further means that teachers must be able to ensure that the children's integrity is maintained. In other studies, teachers have expressed concerns about the users' integrity and that a social robot can be used for surveillance (Hanell, 2018; Louie et al., 2021; Rosén et al., 2021; Smakman et al., 2021). Moreover, teachers must be competent in securely handling and interpreting collected data to use social robots for teaching and learning (Smakman et al., 2021). Another competence that the teacher needs is to mediate the interaction and show care for the child in the learning activity so that the robot does not become creepy from the child's perspective (Yip et al., 2019).

In addition, we believe that teachers need knowledge about social robot interaction, e.g., what social aspects the robot application exhibits and how these may be explained to a child without deception. This study has a pre-arranged deception in the role-play, which may reinforce the teacher's willingness to explain the robot's behaviour with human characteristics and liken the robot to a younger child, etc. In previous studies, teachers have expressed concern that social robots could directly affect children negatively (Serholt, 2018; Smakman et al., 2021) and in the long term (Ahmad et al., 2016; Istenic et al., 2021). An overestimation of the robot's functionality or cognition can promote misplaced trust and lead to deception, whether intended or not (Rosén et al., 2021; Sharkey & Sharkey, 2021; Smakman et al., 2021).

Furthermore, teachers must be competent in reflecting on the consequences and taking an ethical stance when introducing social robots in the classroom. This study shows that including social robots in the classroom raises questions of which social norm systems are appropriate in situations involving robots, what views of social robots are desirable to convey to children, and how teachers should act accordingly. We argue that these competencies are beyond what is included in today´s definition of teachers' digital competence, which is already highly challenging.

5.4 Limitations

The current study has several limitations, including technical limitations of the social robot, the participants´ robot experiences, and the overall study design. For example, the limitations of the robot tutee implied that the teacher was occasionally required to resolve technical breakdowns and continuously compensate for the robot's technical limitations, whereas the latter meant that the teacher functioned as an interaction mentor, meditating on the child-robot interaction in several ways. However, the role of an interaction mentor requires insight into the robot's pre-programmed dialogue, how the robot interaction functions regarding timing (the robot could not speak and listen simultaneously), and what and how to utilize speech recognition effectively. Such interaction troubles and robot failures are well-known in human-robot interaction (Alnajjar et al., 2021; Honig & Oron-Gilad, 2018; Serholt et al., 2020). Another aspect was to synchronize the behaviour of the collaborating actors, e.g., coordinating the turn-taking between tutor and robot and ensuring joint attention to the shared goal (Bütepage & Kragic, 2017). Despite continued technological advances, these challenges will likely persist for some time because social teaching and learning activities are dynamic and complex. And finally, more ethical challenges will likely arise when teachers no longer experience technical limitations with the robot tutor.

The limited experience among the participants can be divided into two parts. Partly, the number of participants was limited because the study is resource-demanding, and partly, the participants' experience of working and interacting with a social robot was limited. However, since most teachers and students still have little or no experience with social robots in the classroom, we consider the participants, who had been a part of the co-design project for two years before, to be more experienced than average and, therefore, well-prepared for the robot-augmented learning activity. Still, their behaviour towards the robot tutee may change as they get even more experienced (Chandra et al., 2020). Furthermore, there may also be cultural differences that affect human-robot interaction. Nonetheless, the participants probably learned diverse things to various degrees while participating in the learning activity. The robot did not learn anything from the robot; it only developed in relation to the child. Also, it restarted at a low skill level every time a new child started playing. The children probably developed knowledge of the game and its arithmetic content and were, therefore, likely to be at a higher level on the second occasion. The research design should compensate for that at the group level by being counterbalanced. The same reasoning also applies to the teacher, who likely learned things while the study was going on about the game and the robot interaction, a change that the counterbalancing has hopefully mitigated.

Lastly, the study design also has limitations. The study does not show whether the learning activity impacts children's learning in arithmetics, nor does it investigate whether interactions with a social robot have any ethical consequences. Hence, more long-term studies are needed, preferably focusing on children's learning, whether social robots enhance understanding, and what type of learning evolves. Equally important are further studies with different ethical perspectives on child-robot collaboration in educational contexts, as the idea of the robot as a social actor poses many ethical challenges. Future research should also include more teachers and can advantageously focus on the teacher's expanded role as an interaction mentor.

6 Conclusion

Previous research has indicated that social robots can positively affect learning if used as tutees in a learning-by-teaching scenario. Further, collaboration and verbal interaction with the robot may strengthen the child's mathematical reasoning about arithmetic. Together, this was the point of departure on which we based our small-scale field experiment, in which we posed the research question: *How does teaching in a child-robot collaborative mathematics learning activity differ from a corresponding child-child learning activity*, *and what implications can the use of social robots in the classroom have for the teaching practice?*

The study showed similarities and characteristic differences regarding teaching actions in the child-robot scenario compared to the child-child scenario. The similarities were on the overall structural level; the amount of gameplay, the number of accomplished games, and the teacher's division of active participation versus silent monitoring were the same in both scenarios. The characteristic differences were found in which types and distribution of teaching actions the teacher found needed. There were two characteristic differences in the teaching actions;

1) In the child-robot scenario, almost all verbal teaching actions were directed to the tutor only (98%), compared to 57% in the child-child scenario.
2) The learning situation was socially scaffolded (i.e., communication and collaboration support were needed) in the child-robot scenario, whereas it was didactically scaffolded (i.e., mathematical thinking was encouraged, and didactic feedback was given) in the child-child scenario.

These characteristic differences indicate the following implications for a teaching practice with a social robot:

- Teachers' presence and participation are as important in a child-robot learning situation as in a child-child collaboration, but the teacher's role and responsibility are different in the two settings.
- Teachers must scaffold collaborative learning situations both socially and didactically and adapt to the situation by compensating for participants' various abilities (i.e., the robot's limited social behaviour and the younger child's limited mathematical knowledge). However, to do so, teachers must know the social robots' general features, the specific application used, and the particular robot's behaviour and limitations in a social setting with school children.
- Using social robots as learning companions in the classroom introduces new challenges beyond technical issues concerning social norms, collaborative climate, and social cultures in the classroom. Educational researchers and practitioners need to reflect on what social robots as learning companions mean for the classroom culture regarding human social norms, subject-specific classroom norms, inclusivity, and equity in the classroom, as well as if and how teachers can support and scaffold these new learning situations in ethical and sustainable ways.
- Current descriptions of teachers' digital competence must include competencies needed to manage a social robot as a didactic tool in a classroom without support.

6.1 Scientific contribution and future research

The results of this study contribute to new insights regarding didactic, social, and practical challenges when using social robots as learning companions in the classroom from a teaching perspective. We address the research gap and focus on the teacher's role and actions when teaching with a social robot. Further, we problematize having social robots as learning companions in the classroom, a problematization that goes beyond technical and design issues and raises questions of social norms when humans "collaborate" with robots. From a broader perspective, the study raises general questions about the possibilities and boundaries of using and developing social educational robots in collaborative learning situations and how the teaching practice and our understanding of teachers' digital competence need to adapt accordingly. Finally, the study contributes practically to schools and teachers that consider using social robots as learning companions in their teaching practice by raising awareness of these plausible implications for their teaching.

Due to the study's limited scope regarding teacher participation, study duration, and type of collaborative learning situation, other larger and longitudinal research studies with authentic classroom settings and a holistic socio-cultural view of learning are called for to evolve this research concern.

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Data availability The participants in this study have not consented to the video data being shared publicly to protect their privacy. However, the authors will make the anonymous transcripts supporting this article's conclusion available upon request.

Declarations

Ethical approval The teacher, as well as all the children, gave written consent to participate in the study. In addition, all children's legal guardians gave written informed consent for the children to participate, all following the Declaration of Helsinki. Overall, the study was carried out following the recommendations of CODEX—Rules and Guidelines for Research established by the Swedish Research Council. According to Swedish law, the protocol did not require ethical approval, as no sensitive personal information was collected. The results in this article are derived from a subpart of the data used in one author's doctoral thesis (reference to thesis). However, previous results have been expanded and deepened through further analyses and discussions, resulting in new perspectives and more elaborated discussions and conclusions regarding teaching with social robots as learning companions, compared to the thesis.

Competing interests In this study, there are no competing interests to report.

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Authors and Affiliations

Sara Ekström[1] · **Lena Pareto**[1,2] · **Sara Ljungblad**[3]

✉ Sara Ekström
sara.ekstrom@hv.se

[1] Department for Studies of the Individual and Society, University West, Trollhättan, Sweden

[2] Department of Education, Communication and Learning, University of Gothenburg, Gothenburg, Sweden

[3] Department of Computer Science and Engineering, University of Gothenburg, Chalmers University of Technology, Gothenburg, Sweden