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Exploring requirements and opportunities for social robots in primary mathematics education

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Abstract— **Social robots have been introduced in different fields such as retail, health care and education. Primary education in the Netherlands (and elsewhere) recently faced new challenges because of the COVID-19 pandemic, lockdowns and quarantines including students falling behind and teachers burdened with high workloads. Together with two Dutch municipalities and nine primary schools we are exploring the long-term use of social robots to study how social robots might support teachers in primary education, with a focus on mathematics education. This paper presents an explorative study to define requirements for a social robot math tutor. Multiple focus groups were held with the two main stakeholders, namely teachers and students. During the focus groups the aim was 1) to understand the current situation of mathematics education in the upper primary school level, 2) to identify the problems that teachers and students encounter in mathematics education, and 3) to identify opportunities for deploying a social robot math tutor in primary education from the perspective of both the teachers and students. The results inform the development of social robots and opportunities for pedagogical methods used in math teaching, child-robot interaction and potential support for teachers in the classroom.**

I. INTRODUCTION

Social robots can enhance traditional teaching methods and provide additional forms of learning support to students. Several studies already showed that social robots can successfully help students to learn new skills, such as in mathematics [1], [2], writing [3], and language teaching [4]. In addition to improving skills, social robots can help to increase both cognitive and affective learning outcomes [5]. Social robots can engage children during mathematics lessons [6], and make learning more fun [7]. Through their unique abilities for social, affective, and embodied interactions, social robots can enable students to improve their self-esteem [8], and motivation [9]. They can take several social roles and serve as tutor or teacher, as a peer or as novice [5], and provide personalized learning experiences. Social robots are also used to encourage interactive learning, by activating children in learning activities [10].

This research paper describes the first study performed within the SOROCOVA project. The project aims to study child-robot interaction and (further) develop social robots to support teachers and students in primary education. In addition to the existing problem of teacher shortages in many parts of Europe [11], the COVID-19 pandemic has disrupted education and exacerbated pre-existing educational inequalities worldwide [12]. Within the project, we aim to provide multiple learning modules over a two-year period for the same students who will progress from grade 6 to 7. The project's challenge is to determine how to design for such a long-term study. The project builds on existing social robot applications [1], developed for mathematics education in Dutch primary schools, grades 6 and 7, and focuses further on personalization as a key element to promote long-term engagement [13]. The objectives of these future mathematics learning modules is to reduce the accumulated learning delays among students and help to eliminate the learning gaps. The modules will be developed for a NAO robot [14], a commonly used social robot for educational purposes [5]. The NAO is already widely used as social robot in education. It allows to connect our research to international interests and efforts to reduce COVID-19 related educational disadvantages. In this way we can contribute to supporting teachers, stimulate new forms of education, and raise opportunities for further integration of social robots in the curriculum of primary education.

In addition, it has been found that teachers and students (within the European context) can be reluctant to use social robots for educational purposes [9]. Within SOROCOVA project, the aim is to involve end-users in each phase and keep them involved over time to shape the robot design and the mathematics learning modules' development. In addition to research questions addressed at the level of the human-robot interaction, in this project we not only involved the end-users as teachers and students, but the project is a collaboration between different Dutch parties (three universities, two municipalities, multiples primary schools and a robotics company). Involving these different stakeholders will hopefully support the spread of more knowledge about the potential use of educational social robots, helping the introduction and sustainability of robots in primary schools and their integration into daily classroom practice.

The key objective of the study described in this paper is to explore the opportunities and requirements for social robots (particularly a NAO robot) in the classroom from the perspective of teachers and students involved in mathematics education in upper primary education (grade 6). In this study we aim to identify the key design elements and choices for social robots to support teachers and students in the classroom.

This paper is organized as follows. Section II presents

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some related work. Section III presents the methods used in this study. Section IV presents the results obtained in the study. Section V discusses these results and presents the conclusions and future works of the study.

II. Related Works

An extensive review by Belpaeme et al. [5] provides insights into the opportunities of social robots for education. Social robots offer unique social dimensions, and can provide personalized learning experiences, supporting and guiding students in ways not available in today's educational environments. However, the review also exposes challenges regarding educational robots. These challenges concern issues in human-robot interaction, pedagogical functioning of the robot, and integration of the technology into daily classroom practice. The researchers emphasize that the deployment of social robots in education requires a closely integrated effort between all stakeholders. Also, the collaboration between the robot and the child is important in our specific context of primary education and learning. Rogoff's broad definition of collaboration [15] is fitting different contexts and defines collaboration as mutual involvements, engagements, and participation in shared endeavours, which may or may not serve to promote cognitive development. This definition can be used as a basis for our theoretical approach for collaboration in the context of learning between the child and the robot.

Adding supportive behavior to an educational robot can improve cognitive as well as affective learning outcomes [5], yet success may depend on several factors. In a study with children between 8-10 years old practicing multiplication tables with a NAO robot, Konijn & Hoorn [2] found that beyond-average students profited most from a robot exhibiting the social behavior of a tutor, whereas those below average benefited more from a robot showing neutral behavior. This implies that an educational robot should be able to adapt its social behavior to individual learning preferences, which needs further investigation.

Conversational turn-taking with an educational robot may help to foster deeper learning. When children applied the metacognitive technique of 'thinking aloud' in conversations with a robot teacher, this was found to promote learning gains and strengthen their involvement when performing cognitively demanding tasks [16]. Ligthart et al. [13], [17] investigated design patterns in an interactive storytelling experience for children. Results showed that when children were allowed to make their own robot-guided decisions in a story, they paid more attention, enjoyed the experience more, and could recall more about it. Child-robot conversations and personalization thus can be designed to increase attention, enjoyment and memory, fostering active learning. Investigating how these techniques can be used in robotics mathematics applications is a promising research opportunity.

In addition, conversation in the form of instant verbal feedback on errors can be expected to improve learning outcomes. Hindriks & Liebens [1] evaluated the design of a robotic mathematics tutor that provides feedback on specific errors made by children (aged 7-9 years old) when solving basic addition and subtraction problems. For the design of feedback mechanisms in future applications, the researchers recommend the implementation of advanced error classification algorithms and adaptation to children's performance levels.

Smakman et al. [18] investigated how a NAO robot can contribute to reducing math-related hiatuses in Dutch primary education. A social robot application is evaluated in a between-subjects experiment with two groups of students (n = 43). Results showed that a robot can take the role of a tutor and practice with students, however, the effects on learning outcomes were inconclusive and require further investigation. The researchers recommend considering moderating variables of 1) differences in intrinsic motivation regarding mathematics, 2) differences in entry levels of math skills, and 3) differences in pedagogical environments. Furthermore, a symbiotic interaction in which the robot can interact with the learner and adapts its behavior to the child's behavior and development is emphasized to be of added value for an effective learning process of children when interacting with robots [19].

The described studies show the potential of social robots in primary education. However, challenges remain regarding their implementation in daily classroom practice, on how they can effectively contribute to teaching and learning, and how their functionality and behavior can meet the needs of teachers and individual students.

III. Methods

The SOROCOVA project takes Design Science Research (DSR) [20] as an overarching approach. According to DSR, the first phase in the research process aims at 'Diagnosing'; developing a deep understanding of the situation at hand and defining requirements and opportunities together with stakeholders.

In line with the DSR model, this research concerns the "diagnosing phase" where we are exploring the perspectives of primary end-users, namely the teachers and students. The main aim of this current study is to explore the use of NAO robot as social robot in the classroom for mathematics education.

We adopted focus group [21], [22] as the qualitative method to reach the key objective of this current study. To this end, separate focus groups were held in the period October - November 2021 with grade 6 students from different primary schools, as well as focus groups with teachers involved in grade 6 from different primary schools. Separate focus groups for both primary end-users were chosen to avoid the influence of teachers' responses to the students' responses [23]. For the current study, we involved grade 6 students, which allows us to follow the same students' level in the upcoming follow-up studies within SOROCOVA project.

We organized three focus groups with teachers and three focus groups with students. Different activities were used depending on the target group (such as group discussions, open questions, and cards' sorting) for different goals and topics.

The research design was approved by the Amsterdam University of Applied Sciences ethical committee (under the reference 2021-137082). The teachers received an information letter in advance and signed an informed consent just before the start of their session. The students' parents received also an information letter in advance and signed an informed consent to allow their children to participate in the study. All the sessions were video-taped and audio-taped for further analysis.

A. Participants

The participants (teachers and students) were recruited from different primary schools around dam and Utrecht areas in the Netherlands. The sessions were hold physically in the different primary schools.

For the teachers' focus group, the total number of teachers was 18 (group 1 n= 7, group 2 n=6 and group 3 n= 5). Two sessions involved teachers from seven different primary schools, while the third session included teachers from one other primary school. All the teachers were involved in education of the grade 6. The three sessions were hold at three different primary schools.

For the students' focus group, the total number of students was 67 (group 1 n= 22, group 2 n=19 and group 3 n= 26) and were aged between 7 and 9 years old. The majority of students in the focus groups were from grade 6, but two schools had a group combining 5-6 and 6-7 grades. For these two groups all children participated in the study.

B. Procedure

1) Teachers' focus group: Each focus group session lasted between 60 and 75 minutes. For each focus group two researchers were involved (one leading the discussion and one helping and taking notes). The sessions were interactive including different activities (open questions and discussion points, brainstorming, showing videos, and card sorting) and using different materials (such as flip charts and post-its) to support these activities. For some of the themes, teachers were able to work together and reflect upon the themes.

The session started with an introduction and questions about the experience teachers had with robots. Then the session included two parts: understanding the current daily situation from the perspective of the teachers regarding mathematics education, and the opportunities that social robots can have in the classroom.

During the first part, three different themes were presented and discussed with the teachers: the current practices in mathematics education, the interaction teacher-student, and the issues that both teachers and students encounter in the daily practice of mathematics education at the classroom.

For the second part, the researcher started by showing the teachers two videos featuring the NAO robot: one introducing the robot, and one showing an example of use in the classroom. Then four different themes were presented and discussed: potential math activities by a robot, potential interactions with a robot, potential setting using robots and the added value of robots in the classroom. During the discussion of the second theme, we included a card sorting activity. Based on the identified social roles [5] and social behaviors [24], we developed a cards's deck including social roles that the robot can have and the different behaviors that the social robots can have towards the students. The cards's deck includes 3 social roles (teacher or tutor, buddy or friend, and novice) and 12 behaviors (such as assertive, encouraging, persuasive, competitive and funny) with examples of how the social roles or behaviors can be expressed by a robot. The card sorting activity helped the teachers to identify social roles and behaviors that can be embodied by the robots.

Fig. 1. Picture of card sorting activity during teachers' focus group

At the end of the sessions, the teachers received a small appreciation gift (a tea set with a robot-shaped tea infuser) for their time and participation in this study.

2) Students' focus group: The students' focus group sessions lasted one hour or a bit less to hold account with the attention span of the children. Like the teachers' focus group, the three researchers were involved, with two moderating each session.

The sessions were interactive involving different activities (plenary discussions, individual tasks, and in-pair work) and materials (forms and comic strips) were used. The setting of the students' focus group was comparable to the setting of the teachers' focus group. It started with an introduction followed by questions about their experience with robots, and then it included the same main two parts, namely understanding the current daily situation from the perspective of the students regarding mathematics education, and the opportunities that social robots can provide in the classroom.

During the first part of the session, three different themes were presented to the students: the content of the ongoing mathematics education, the interaction teacher-student, and the setting of mathematics education in the classroom. One researcher asked the students a set of questions, and the students took individual turns into answering and discussing them with each other and with the researchers. To understand further the current content of the ongoing mathematics education and what students think about the topics they study, each individual student received a form to categorize different topics in their mathematics education as difficult/easy and fun/boring topics (see Figure 2).

For the second part of the session, the researcher started by showing the students two videos: one introducing the NAO robot and one showing an example of its use in the classroom. Then the students elaborated on their perspective of potential use of the social robots in mathematics education. The students were paired up and received a random empty comic strip to work on it together. The researchers designed these comic strips based on three different experiences resulted from performing a mathematics task, namely 1) the sums are difficult, 2) the sums are boring, and 3) the sums are completed successfully (see Figure 3). These strips were created to allow students to design potential child-robot interactions based on one of the three experiences. The setting of the activty allowed the students to interact, exchange ideas and come up with creative interactions. In theory, students could take one of the two roles featured in the comic strips (either the robot or the student) and come up with possible interactions. With this activity we probed the creativity of students.

Fig. 2. Forms used as materials used during the students' focus group sessions

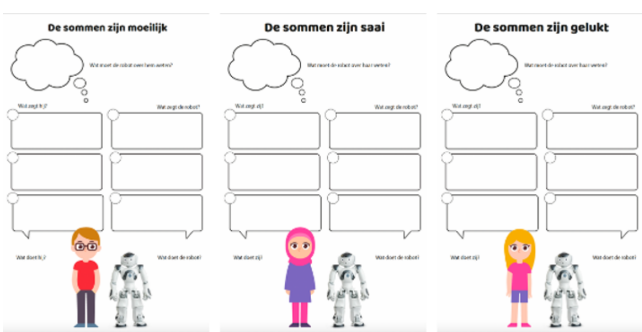

Fig. 3. Comic strips used during the students' focus group sessions

At the end of the sessions, in return for their time and participation, also the students received a small appreciation gift (a small wooden robot craft kit).

C. Data analysis

After all the focus group sessions, we transcribed the video recordings and the dialogues from the comic strips, and together with all notes we imported the files into Atlas.ti software.

We used a thematic approach to summarize the outcomes from the focus groups [25]. A team of three researchers worked on the analysis. The transcripts were read several times by two coders to have an overall idea of the content. Following this, codes were allocated to significant sentences or paragraphs. These codes were then aggregated and grouped into themes. They produced the codebook and themes, discussed the initial findings, and made modifications. Then, the third coder reviewed and validated the themes to establish common ground within the team. The final themes were largely descriptive and reflected the suggestions and the language of the focus group participants.

IV. Focus Groups' Results

Most of the participants in the focus groups (teachers and students) had little to no experience with robots. Few students saw or played with Lego robots or programmable robots either in the classroom, or in private situations (e.g., at home, in restaurant, and parents' workplace). Within the nine primary schools involved in the focus groups, three different textbook methods were used for mathematics education (namely "Wereld in Getallen", "Getal en Ruimte Junior", and "Pluspunt"). The textbooks are roughly based on the concept of Realistic Mathematics Education [26]. The classroom practice of most teachers is based on (direct) instruction models: the teachers give random turns to students, check with comprehensions questions, give extended instructions and offer the students the opportunity to work individually (or possibly with a buddy).

A. The current situation according to the teachers

How do teachers and students interact?

Teachers try to make mathematics education fun and engaging by giving the students appropriate attention that it is adapted to their level, by using different tangible materials (such as clocks and blocks) and visual materials (such as movies), and by introducing math games. Usually, the teachers adapt their activities and lessons based on their experience and what they know that works best with different students.

The teachers assess the levels of the students and the starting situation of the lesson to adapt the lessons. During the lessons, they give some students very short instructions, and other students basic instructions followed by extended instructions.

They use diverse cooperative working methods with students, while putting in practice some games (such as standing in line and ordering objects), but also allow individual work.

What are problems and issues according to teachers?

The teachers expressed concerns about several aspects in the current situation in mathematics education caused by the pandemic and lockdowns such as: delays in memorizing procedures (such as multiplication tables and operations with fractions), lack of time (to be able to recover from the learning delays), and the significant difference in students' levels. They also perceive that many students have a negative image of math; they experience math as difficult. On top of this negative image, teachers notice that students prefer to hear exactly what they have to do, and not be confronted with tasks the students perceive as unclear.

In general, teachers value practice and repetition of studied topics, but they feel this is not always possible as they must continue with other and new topics in the planned lesson schedules.

B. The current situation according to the students

What does mathematics educational content look like?

When we asked students' opinions on math topics (fun, not fun, difficult, or easy), we observed that the topics of addition, subtractions, multiplication, and division were perceived by the students as easy. In contrast, time and dates were perceived by students as difficult topics.

Students think that math is fun when they use different materials. They like having good explanations and knowing exactly what to do. They prefer activities that are tailored to their level. They find math boring when the topic is only studied from the book, like time and dates.

How do teachers and students interact?

The students mentioned that it is helpful when the teacher sits with them and gives extra explanation and step by step instructions, when they get notebooks with extra assignment, or when they get extra explanation on the blackboard. We asked students how teachers make math fun. The students mentioned the opportunity to determine their own pace to learn, working under the direct guidance of the teacher, and doing fun activities, such as games, stories, and challenges.

How do students prefer to do mathematics exercises?

Most students prefer to work alone or in small groups. Those who prefer to work alone, point out that they find it more pleasant to work in a quiet environment.

C. Towards the elaboration of end-users' requirements

In general, the students and teachers were enthusiastic about the opportunities that the robots can bring to classroom for mathematics education. The teachers believed that the robots could best take the role of a coach or tutor, and occasionally the role of a peer. They envisaged that social robots would be useful for repetitive tasks as well as for encouragement, listening, showing understanding, discussing and consulting with the students.

To summarize the requirements and opportunities for social robots in mathematics education, we combined the results from the focus groups with teachers and the focus groups with the students. From the performed analysis, we elaborated a list of inputs for requirements and opportunities (see Table 1) which came from both end-users namely teachers and students. These inputs are categorized into pedagogical methods (used in teaching) (R1 to R13), in child-robot interaction (R14 to R16) and classroom setting (R17 and R18) requirements.

V. Discussion and Future Work

In this study, we aimed at understanding the current situation in primary mathematics education, and identifying the requirements and opportunities of social robots in the classroom from the perspective of the primary end-users, namely teachers and students.

Based on the conducted focus groups, we were able to come up with a set of opportunities serving as input for requirements which resulted equally from both focus groups with teachers and students. The next step is to identify the user requirements, functional requirements and non-functional requirements. It is clear that not all requirements can be met in a limited series of interactions between student and robot. Therefore, we will first focus on investigating adaptivity and personalization, while utilizing the robots' opportunities for social and conversational interaction. Based on the previous research and the results from the focus groups, we expect that adaptivity and personalization will have a positive impact on the effectiveness of social robots in education. In the next studies, we will investigate how these concepts can positively affect students' learning outcomes, engagement (motivation and fun), and relationship-building with the robot.

Within this study, we focused on the perspectives of the primary end-users. The importance of including the opinion of future users at an early stage of development for social robot acceptance was noted before in the research by de Graaf et al. [27]. Although the model is focused on domestic social robot acceptance, we believe that this model applies also to social robots for mathematics education.

In one of the focus groups, teachers expressed the concern that it would be difficult for children to practice math through verbal human-robot conversations only, without a visual display. This connects to the outcomes of a study by Hoogland at al. [28] showing that students score better on problems with a visual representation than with a descriptive representation. A study by Zhexenova et al. [29] compared the effects of using different modalities when teaching literacy, and suggests that combining modes of verbal, visual and tactile communication can strengthen recognition and memory. These outcomes may inform design choices for future robotics mathematics learning modules, e.g., to combine an educational robot with a visual display or with tactile objects that can be manipulated while practicing math.

Teachers brought up the chance of children abusing the robot when practicing unsupervised, e.g., in school hallways. This is not an imaginary problem; the phenomenon of humans 'bullying' social robots has been described in several research papers (e.g., the study by Bartneck & Keijsers [30]). However, the study by Pearson [31] suggests that robots can be designed to encourage prosocial behavior with children and contribute to their moral development, which could prevent the abuse of social robots. How to implement this in educational robots should be further investigated.

Another concern mentioned in the focus groups with teachers is related to data management and privacy. Specifi-

TABLE I

OVERVIEW OF THE INPUTS FOR REQUIREMENTS AND OPPORTUNITIES PROVIDED IN THE FOCUS GROUPS BY TEACHERS AND STUDENTS.

#n	Input for Requirements	Extra Explanation	Source: Teachers	Source: Students
R1	The social robot must be adaptive (level, speed, pace)	Gives the students the appropriate attention at their level	x	x
R2	The social robot must be for all students	Is suitable to all students' levels (including plus students)	x	
R3	The social robot must explain strategies	Explains how to approach a problem, step by step. Includes intermediate steps when needed	x	x
R4	The social robot must check for comprehension	Checks how well students comprehend steps	x	x
R5	The social robot must be used for practice	Helps the children repeat after basic teachers' instructions. Helps in repetitive math activities	x	x
R6	Teachers must have an overview of the activities	The teachers can follow what the students are doing with the robot	x	
R7	Teachers must have an overview of the common mistakes	In case of wrong answers, for example, the teachers can see where it went wrong	x	
R8	The social robot must use didactic teaching	The robot uses didactic teaching with students, for example when asking questions	x	
R9	The social robot must give positive feedback and rewards		x	x
R10	The social robot must diagnose the students' learning		x	
R11	The social robot must assess the students' learnings		x	
R12	The social robot must allow social interactions with the students		x	x
R13	The social robot must have prior knowledge about the students	Example first name, preferences, hobbies	x	x
R14	The social robot must be engaging	Social robot can help enable students to remain engaged in learning math	x	x
R15	The social robot must motivate students		x	x
R16	The social robot must make math fun	Fun can be with games, dances, songs, movement, stories, jokes, and personalized depending on the student.	x	x
R17	The social robot must include visual/tangible materials	The social robot should include a screen and other materials (books, erasing boards, mirrors, clocks, cubes…)	x	x
R18	The social robot must allow group and individual work with students		x	

cally, teachers asked if the NAO robot should be connected to a school's online student tracking system, and how privacy and security can be guaranteed. These are important considerations for the final phase of the project, concerned with making a roadmap for implementation of the learning tool within the schools. Smakman et al. [32] acknowledge that next to data on learning progress, the storage of detailed data of affective signals can be intrusive. Including Privacy and Security, the researchers identify 17 moral values that might be affected by the implementation of social robots in primary education. These values should be addressed in discussions with stakeholders.

Now that we have explored and identified the specific needs of students and teachers, we will enter an iterative cycle of designing, developing and evaluating the first robot math modules in collaboration with teachers and students. During the entire SOROCOVA project, three cycles will be followed, in which three individual mathematics learning modules will be co-created. At the end of each iteration, a learning moment with stakeholders (with a focus on end-users) will be organized, to reflect on the results of the previous iteration. Finally, in the last three months of the research project, training modules on the use of the robots in mathematics education for teachers will be delivered, and a roadmap for further scaling up will be established in workshops together with all participating schools.

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