Social Robots for Reducing Mathematics Hiatuses in Primary Education, an Exploratory Field Study

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Abstract Since the outbreak of COVID-19 schools have gone into lockdown and teachers have had to teach pupils online from home. When pupils go back to school, standard, contemporary learning methods do not seem to be enough to reduce incurred hiatuses. Social robots are slowly becoming an integral component of our society and have great potential as educational technology. This study explores how social robots in classrooms can contribute to reducing mathematics-related hiatuses in Dutch primary education (pupils from four till twelve years old). A social robot as a tutor is evaluated by means of a field study with children (*n* = 43) to compare a class working with the robot, to a class working without the robot. Multiple factors on learning effect are taken into account by using a survey. Our results demonstrate that a robot can take the role of a tutor and practice with pupils. The results are of interest to researchers in the field of human-robot interaction as well as to educational institutes who wish to understand the implications of adopting robots in education.

Keywords: social robotics, educational robots, hiatuses, learning effect

University of Maribor Press

DOI https://doi.org/10.18690/978-961-286-485-9.46
ISBN 978-961-286-485-9

1 Introduction

Hiatuses have always been a reoccurring phenomenon within (primary) education and could have a negative impact on learning performance in the longer term (Luyten, Staman, & Vissch, 2013). Finding solutions to reduce hiatuses have always been an important subject in education, but has now become even more relevant due to the impact of the COVID-19 pandemic on schools (Rothan & Byrareddy, 2020). Many pupils are falling behind on their education because they are not able to physically attend school, which causes governments to take action and provide extra funds for reducing hiatuses (Ministerie van Algemene Zaken, 2020c). In addition, eight percent of the Dutch pupils in regular primary education in 2018/2019 were already suffering from hiatuses ("Leerlingen in (speciaal) basisonderwijs; migratieachtergrond, woonregio," 2020; Nederlandse Jeugdinstituut, 2019). One of the reasons for these hiatuses is the increasing shortage of teachers the Netherlands is currently facing (Cultuur en Wetenschap van Onderwijs, 2019). School leaders sending classes home, due to the absence of a teacher, possibly leading to performance loss, which also causes learning delays, is becoming a more regular phenomenon (Cultuur en Wetenschap van Onderwijs, 2019). A learning delay can have many adverse consequences, such as underperformance or inequality of opportunity (van Onderwijs, 2020).

COVID-19 has created large hiatuses in primary education (Keultjes, 2020; van der Heyden, 2020) and contemporary learning methods do not seem to be enough to reduce these hiatuses, therefore, new learning material must be developed. The Dutch government is currently investing 244 million euros for primary education into creating and developing extra learning materials to reduce COVID-19 related hiatuses (AVS, 2020; Ministerie van Algemene Zaken, 2020b). One of these solutions could be the use of social robots. They have been shown to be able to increase cognitive and affective outcomes and have achieved outcomes similar to those of human tutoring on restricted tasks (Belpaeme, Kennedy, Ramachandran, Scassellati, & Tanaka, 2018). One of the main benefits of social robots is their physical presence, which traditional learning technologies lack (Belpaeme et al., 2018).

For this study, the focus will be on exploring the use of a social robot for teaching mathematics to pupils in Dutch primary education. This study aims to answer the following research question: *'can social robots be used for reducing mathematics hiatuses in primary education?'* By answering this question, we aim to provide insights into a potential new learning tool for primacy education for reducing hiatuses for mathematics, which is, especially now, an urgent social issue.

This paper is structured as follows. First, the background and related work will focus on hiatus factors and social robots as two main concepts. This is followed by a description of the utilized research methods. Next, the paper details how the data was collected. Then, the methods and techniques for data analysis are presented. Based on the data collection and analysis, the results of this study are presented. This is followed by the conclusions drawn from these results. Lastly, the limitations are discussed, and future research directions are described.

2 Background and Related Work

To explore the effect of social robots on reducing hiatuses, the definition of the term 'hiatus' must be established. A hiatus is a subjective concept. It is defined as the disadvantage in a particular learning area that a person has, compared to 'the average pupil' with the same age and the same level of education (Bannink, 2021). In the next section, we will detail the concept of hiatuses, as well as the concept of a social robot.

2.1 Hiatus factors

Many factors influence the forming of a hiatus in education. Research shows that the most recurring factors are *autonomy* (Meusen-Beekman, Joosten-ten Brinke, & Boshuizen, 2001; Ryan & Deci, 2000b; Sierens, Vansteenkiste, Goossens, Soenens, & Dochy, 2009), *motivation* (Lak, 2017; Ryan & Deci, 2000a), *learning environment* (Meusen-Beekman et al., 2001; Weiser & Riggio, 2010) and *causality* (Miller, Ferguson, & Byrne, 2000; U.S. Department of Education Office of Special Education Programs, 2003).

Autonomy refers to the experience of choice and psychological freedom with respect to one's study activities (Sierens et al., 2009). It involves being self-organizing and having a sense of choice over one's study behaviour (Sierens et al., 2009). Sub-factors here are self-regulation (Ryan & Deci, 2000b), self-effectiveness (Meusen-Beekman et al., 2001) and basic needs (Meusen-Beekman et al., 2001). Competence, as an aspect of self-regulation and effectiveness, involves the experience of efficacy while completing a learning task (Meusen-Beekman et al., 2001). The need for relatedness, also an aspect of self-regulation and effectiveness, concerns feeling connected to others, like teachers or fellow pupils (Sierens et al., 2009). Home-tuition in The Netherlands was compulsory because of the COVID-19 pandemic (Ministerie van Algemene Zaken, 2020a). The feeling of being connected with others was reduced by studying at home (Odekerken-Schröder, Mele, Russo-Spena, Mahr, & Ruggiero, 2020). Through home tuition, the pupil will not be with others all day, but there will be online moments with others and, predominantly, offline moments without others ("Didactiek," 2020).

Motivation is an individual's drive or reason to achieve an action or performance, it can drive the person to a (desired) behavioural form (Karels, 2020). Motivation consists of a relationship between various factors, and can be divided into intrinsic and extrinsic motivation, including the biological (innate) and culture-dependent (learned) characteristics (Ryan & Deci, 2000a). In addition, the environment can play a role and several elements influence motivation. Descriptive studies have shown that some pupils enjoy mathematics, seek out mathematical problem situations, and excel in them (Middleton, 1995). Whereas others ('math anxious' students) have a fear of mathematics and avoid engaging in mathematical problem situations. In addition, although the utility and importance of mathematics are at least acknowledged by the majority of students even if not understood fully, this knowledge is not sufficient enough to motivate them to continue taking mathematics courses (Middleton, 1995).

Learning environment refers to the diverse physical locations, context, and cultures in which pupils learn (Education Reform, 2013). Since pupils may learn in a wide variety of settings, such as outside-of-school locations and outdoor environments, the term is often used as a more accurate or preferred alternative to a 'classroom' (Education Reform, 2013). The 'classroom' concept has more limited and traditional (Education Reform, 2013). Due to the COVID-19 pandemic, pupils have a disadvantage in social mobility (Cullinane & Montacute, 2020). The closing of schools has caused unpredicted challenges for everyone involved in the education domain (Cullinane & Montacute, 2020). These challenges mostly encompass (Cullinane & Montacute, 2020): 1) not being able to access additional support, 2) not having access to certain information online (due to the poor and rich gap), 3) widening the attainment gap due to extended lockdown(s), and 4) working in cramped housing conditions.

Causality is the demonstration of how one variable influences other variables in education. In this research, causality will refer to present disorders in the pupils. These disorders can be learning disorders such as Dyslexia or behavioural disorders such as Attention Deficit Hyperactivity Disorder (ADHD) or Oppositional Defiant Disorder (ODD). The presence of a disorder can have a possible negative impact on the learning ability of the pupils, which can lead to the pupil scoring worse than expected (de Meyer, 2019; Driessen, 1990; U.S. Department of Education Office of Special Education Programs, 2003).

2.2 Social robots

A social robot is an embodied object with a certain degree of autonomous behaviour that is specifically designed to socially interact with humans (Darling, 2012). The key elements for a social robot are the physical embodiment, social understanding and school behaviour, and interaction and communication with humans (Hameed, Tan, Thomsen, & Duan, 2016). There are different kinds of social robots, such as Pepper (humanoid and programmable robot) (SoftBank Robotics, 2021b), PARO (therapeutic robot) (Parorobots, 2014) and ROBEAR (nursing care robot) (Wilkinson, 2015). For this study, the focus will be on the NAO robot. The NAO robot is a humanoid and programmable robot with rounded features and is bipedal totalling 58 cm in height (SoftBank Robotics, 2021a). The NAO robot is the most often used robot in research related to social robots in education (Belpaeme et al., 2018).

Broadly speaking, there are three types of robots in education. These include 1) using a robot to learn pupils programming skills, 2) the robot being an object of learning as a means to understand what a robot is, and 3) a robot as a learning partner/social robot (for example, an assistant teacher or a fellow pupil).

The use of social robots has recently been explored in the educational domain and attention from researchers and practitioners is increasing (Kennedy, Baxter, & Belpaeme, 2014; Konijn & Hoorn, 2020). Robots can take the form of, for example, a tutor, learning buddy or teacher. Social robots have proved to have a positive effect on pupils (Kennedy et al., 2014; Kory-Westlund & Breazeal, 2019). Furthermore, the potential advantages of social robots in education are a reduction in costs and time because teachers and pupils are assisted better in class (Pachidis et al., 2019). However, there are different factors regarding the positive effect on reducing hiatuses within the field of mathematics, such as emotional stability and openness (de Meyer, 2019; Driessen, 1990; Streur, 2016).

Social robots have the potential to make positive contributions to a range of human-centred activities in education (Belpaeme et al., 2013; Broadbent, Stafford, & MacDonald, 2009; Dautenhahn & Werry, 2004; Tapus, Mataric, & Scassellati, 2007). Research shows that one-on-one tutoring can lead to significant learning improvements (Moriguchi, Kanda, Ishiguro, Shimada, & Itakura, 2011). Furthermore, several studies found a positive learning effect on different areas of expertise such as learning words (Baxter, Ashurst, Read, Kennedy, & Belpaeme, 2017; Moriguchi et al., 2011; Mubin, Stevens, Shahid, Mahmud, & Dong, 2013), science or technology (Mubin et al., 2013), motor task training (Baxter et al., 2017), weight-loss programs (Baxter et al., 2017), and reducing puzzle-solving time (Baxter et al., 2017). These studies indicate that robots take advantage of, and amplify, the human-likeness to anthropomorphize inanimate objects (human-like, not alive objects).

3 Research methods

The goal of this study is to explore to what extent a social robot can contribute to reducing mathematics hiatuses in primary education. To do so, we will use a mixed-method approach, consisting of both quantitative and qualitative methods. This mix provides the opportunity to achieve method and data triangulation (Webster, 2007). In the next sub-sections, we will first describe the field experiment, followed by the quantitative and qualitative research methods.

3.1 Field Experiment

Six Dutch primary schools were invited to participate in this study. One primary school positively responded. The field experiment comprises three phases; 1) the Bareka pre-test, 2) pupils using the robot for a set time, and 3) the Bareka post-test. Two of those phases include a standardized test referred to as Bareka, which is a learning method for indicating a child's level of mathematics proficiency. The Bareka method is divided into exercises, ranging from addition and subtraction to multiplying, deviations and fractions, graphs and percentages, content, weight, decimal numbers, number concept, length, perimeter, and area.

The Bareka learning method was translated to the robotics platform *Robotsindeklas,* used by the NAO robot. This existing platform is used for teaching pupils and students with social robots such as the NAO robot and the Alpha Mini robot (Interactive Robotics, 2021). By using this existing platform, we created a Bareka learning application for the experiment. To ensure that the NAO's content was compatible with the teaching material of the school, two experienced primary school teachers reviewed the application. The teaching material consisted out of a short explanation for each subject accompanied by practice exercises.

The experiment consisted of a control- and an experimental group, wherein the experimental group was provided with a social robot as a supplement to the regular teaching methods.

3.2 Quantitative research methods

Two classes were included in the field experiment, ranging from pupils aged ten to twelve years old. The experimental group ($n = 20$) was taught by a social robot in addition to the teachings of their teacher. The control group ($n = 23$) was taught solely by their teacher, using standard teaching methods. The social robot was used from Monday until Friday for 10 minutes per group of pupils (maximum of four pupils per group). The experiment lasted about five weeks (from the 18th of November, 2020 till the 18th of December, 2020). The teacher in the experimental group, was 36 years of age, and had thirteen years of educational working experience. The teacher in the control group was 52 years of age and had 31 years of educational working experience.

To gain insight into the actual development of the pupils, a knowledge test was conducted before and after the experiment. The first Bareka test took place at the primary school under the supervision of the teachers. The second Bareka test took place digitally due to COVID-19 restrictions (home-tuition). The *Bareka* results range from one to four, where one is insufficient and four is very good.

To gain insight into the impact of the social robot on the factors that influence the forming of a hiatus in education, we used a validated questionnaire ("Autonomietool," 2019; "Motivatietool," 2019). The questionnaire was utilized in the context of the field experiment, by using an experimental design that occurs in a natural setting (in class/school) (Allen, 2017).

The questionnaire was sent in December 2020, during the experiment, to both the control and the experiment group. The questionnaire measured two factors related to hiatuses: 1) autonomy and 2) motivation. We excluded other hiatuses factors because including all other factors would result in a too long and complex questionnaire for children. This would potentially have resulted in missing data or a lack of valid data. However, we included the motivation factor because it is an overarching factor of the other factors. Factors such as causality and learning environment were excluded from this survey because details of these factors were indirectly required to answer the research question and are subject to future research.

Motivation is split up into the sub-factors 1) intrinsic motivation, 2) identified motivation, 3) extrinsic motivation, and 4) amotivation. The questionnaires were constructed using Leerling2020 ("Autonomietool," 2019; "Motivatietool," 2019) and were combined into one survey of 24 questions, eight questions about autonomy ("Autonomietool," 2019) and sixteen about motivation ("Motivatietool," 2019).

3.3 Qualitative research methods

Semi-Structured Interviews

Two semi-structured interviews were conducted with teachers during the field experiment. A semi-structured approach is well suited for the exploration of the perceptions and opinions of respondents, and enable probing for more information and clarification of answers (Barriball, 1994). The interviews were conducted to elicitate information about the pupils and teachers and their knowledge regarding Bareka and the way mathematics is taught. In the interviews, the measuring instrument (knowledge test) was discussed as well as the usage of the social robot. This was required to create the learning applications for the robot and to establish its role in the classroom.

Focus group sessions

Because of COVID-19 restrictions during this study, it was not possible to physically observe the pupils while they were using the NAO robot. As an alternative, focus groups were set up, which enable discussion among pupils for a more holistic view regarding the use of the NAO and its learning materials. The focus group sessions were guided by the teachers.

A focus group was conducted with both groups at the end of the experiment. In each group, five focus groups were conducted. The focus groups consisted of four to six pupils who were around the same level of proficiency in mathematics. This number was chosen because it is the ideal group size (Kitzinger, 1995) and because of the total number of participants. During the focus group sessions, students were asked what the concept of motivation is and what motivates them, using the same focus group protocol.

4 Data analysis

The collected data was analysed using SPSS 27 and ATLAS.ti. SPSS was utilized for the analysis of quantitative data, while ATLAS.ti was utilized for the analysis of qualitative data.

4.1 Bareka pre-test, post-test and questionnaire analysis

To determine the difference between the performance of the control- and experimental group the data from the results of the Bareka test were analysed. A one-way analysis of variance (one-way ANOVA) was used to determine whether there were any statistically significant differences between the average of the two groups (control- and experimental group).

Using the Bareka data, the Hedges' g factor can be calculated in order to determine what the effect was of the progress of the pupils, taking into account the relatively small sample size (Hedges, 1981). The Hedges' g factor was calculated by using the sample size, average progress per group and the standard deviation of the progress measured. The value of the Hedges' g is related to the Cohens' d and can be used to determine the effect size (Becker, 2000). The effect size of around .20 is considered a small effect, .50 a medium effect, and .80 a large effect (Becker, 2000; Cohen, 1992).

A Cronbach's analysis was conducted on each questionnaire factor to measure the reliability per item. A Cronbach's alpha with a value of .7 is an adequate level of inter-item reliability (Field, 2017).

4.2 ATLAS.ti

After the interviews had been conducted, they were first transcribed and put in ATLAS.ti. In ATLAS.ti, two coding rounds of thematic coding were conducted by two research team members to reduce bias. Based on the hiatus factors that were defined earlier, themes were chosen to use for thematic analysis. This method is focusing on identifying patterned meaning across a dataset (Braun & Clarke, 2021). For example, a code could be controlled teaching, which focuses on extrinsic motivation.

5 Results

The results of the field experiment (Bareka tests), questionnaire, and focus groups are presented in this section.

5.1 Bareka pre and post-tests

The results of Bareka were determined by the one-way ANOVA test. There was a statistically significant difference between the begin average ($F(1, 24.872) = 23.292$ $p < .001$) and end average ($F(1, 21.668) = 18.840$ $p < .001$) of the groups.
The contrast test revealed that group A had a significant mean difference compared to group B in the Begin Average, $t(24.872) = -4.826$, $p < .001$ and it revealed that the experimental group had a significant mean difference compared to the control group in the End Average, $t(21.668) = -4.340$, $p < .001$, see table 1.

Table 1: Contrast test results

	Contrast	Value of contrast	SE	t	df	Sig
Begin average	1	-.4472	.09265	-4.826	24.872	<.001
End average	1	-.4010	.09240	-4.340	21.668	<.001

To determine the effect size, the Hedges' g was calculated. The calculated Hedges' g for the experimental group is 0.440 and for the control group is 0.6524. This means that there is a small positive effect in the experimental group and a medium positive effect in the control group, see table 2.

Table 2: Hedges' g results

Group	***n***	**Mean**	**SD**	**Hedges' g**
Exp.-Begin	18	2,673444	0,353707	0,4400
Exp.-End	18	2,835778	0,367611	
Control-Begin	23	3,120609	0,193880	0,6524
Control-End	23	3,236800	0,153894	

5.2 Questionnaire

A Cronbach's analysis was conducted on the Autonomy subscale of the survey. It was found that the subscale's alpha level did not have an adequate level of inter-item reliability (Cronbach's α = .54). However, further analysis revealed that by removing the item, *"My tutor always tells me what to do during class"*, the alpha could be raised (Cronbach's α = .64). Furthermore, the intrinsic motivation (Cronbach's α = .85), identified motivation (Cronbach's α = .78), extrinsic motivation (Cronbach's α = .70) and amotivation (Cronbach's α = .73) subscales of the survey had all an adequate level of inter-item reliability.

Table 3 shows the descriptive statics of each subscale, where the item *"My tutor always tells me what to do during class"* is removed. This ensured that the survey was more reliable.

Table 3: Questionnaire descriptive statics

Factor	Group	*n*	Mean	SD	SEM	Δ Mean
Autonomy	Experimental	20	3.875	.414	.092	.016
	Control	23	3.859	.399	.083	
Intrinsic motivation	Experimental	19	3.421	1.093	.251	.040
	Control	21	3.381	1.048	.229	
Identified motivation	Experimental	20	3.825	.770	.172	-.061
	Control	22	3.886	.763	.163	
Extrinsic motivation	Experimental	20	2.813	.996	.223	-.056
	Control	21	2.869	1.005	.219	
Amotivation	Experimental	20	1.625	.763	.171	-.011
	Control	22	1.636	.727	.155	

5.3 Semi-structured interviews

The interview method that was used is thematic analysis. There were themes generated that were focused on the hiatus factors. Example codes are shown in table 4. The results are based on the transcripts which are available upon request due to space limitations.

Table 4: Examples of coding results

Transcript	Code	Theme
"I work from my own agenda, because it has to be done."	Controlled teaching	Extrinsic motivation
"If children are very strong in mathematics and they have their own initiative and they want to do things, you can let them go more easily. And then I stimulate that."	Autonomy-supporting teaching	Intrinsic motivation, autonomy

The interviews mainly revealed that the teacher in the control group was in a more advanced phase of mathematics than the teacher in the experimental group. The pupils from the experimental group have a learning delay that takes more time to catch up to compared to the control group, according to the teachers.

The experimental group worked with the NAO robot. The value of the robot, in this context, would be to improve attention and motivation in the pupils, while the delivery and assessment are done by the human teacher.

5.4 Focus group sessions

The focus group sessions revealed that the children's interest in subjects differed. Mathematics, English and physical exercises were the most frequently mentioned subjects of interest. Also, the children agreed that playing games were fun (with or without the use of the social robot). The team deliberately not asked about the robot, which was only mentioned once. No link was made by the pupils between motivation and a social robot that can help them deal with learning disadvantages/hiatuses.

6 Discussion and Conclusion

This paper aims to answer the following research question: *'can social robots be used for reducing mathematics hiatuses in primary education?'* The ANOVA identified a statistically significant difference between the begin- and end average of the groups ($p <.001$). The contrast test revealed that there was a significant difference between the begin- and end average of the experiment group, compared to the control group. However, the value contrast is higher in the begin average (= -.4472) compared to the end average (= -.4010). In addition, the calculated Hedges' g for the experimental group is 0.440 and for the control group is 0.6524. This means that there is a small positive effect for the experimental group and a medium positive effect for the control group. It may be concluded that the robot had a small effect on the average of the Bareka results. However, the control group showed a larger positive effect (medium >.5 versus small <.5) compared to the experimental group. Though, it cannot be concluded that this difference is caused by the social robot, as the effect of the social robot cannot be isolated to attribute to the learning performance of the pupils in this study. The interview and focus groups have shown that pupils in the experiment group had more difficulty with mathematics, which can also be seen in Bareka's average results.

This study has several limitations that should be discussed. firstly, this exploratory study consisted out of a limited number of participating children (n = 43). More participants are preferable and will result in increased reliability and generalizability in future research. Secondly, the teachers did not have previous experience with the use of social robots, and had limited time to practice with the robot before the experiment. This resulted in the teacher and pupils experimenting with the robot during the first lessons and having difficulty using the robot and application, which affected the actual time to improve the learning effect using the robot. Lastly, while we argue that both groups are sufficient to determine a (potential) effect using the research methods presented, we discovered moderating variables that make it hard to isolate the effect of the social robot in this study setup, such as 1) the difference in intrinsic motivation regarding mathematics between both groups, 2) differences in mathematics progression and learning delays between both groups, 3) didactic styles and level of experience between both teachers, and 4) differences in diagnosis per pupil per group.

Overall, we conclude that a social robot can be used for reducing mathematic hiatuses, however, we could not conclude that a social robot is as effective as a human tutor. Furthermore, the high work pressure in primary education might have a negative effect on the use of social robots in primary education. Therefore, future research might focus on creating a plug and play social robot which allows teachers with limited robot experience to also experiment with this potentially promising technology.

Acknowledgements

We want to thank Bas Hazelet and Julia Frölich for supporting us setting up the experiment, the teachers that provided the information and the pupils that participated in the experiment.

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