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RoboWijs

Een onderzoek naar het gebruik van sociale robotica in primair onderwijs ten behoeve van de ontwikkeling van technische en sociale vaardigheden voor leerlingen met een autismespectrumstoornis (ASS)

RoboWise: An investigation into the use of social robotics in primary education for developing technological and social skills in children with an autism spectrum disorder (ASD)

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Definitieve rapportage RoboWijs / Final report RoboWise

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Nederlandse samenvatting

Het driejarige praktijkgerichte onderzoeksproject RoboWijs onderzocht of en hoe het gebruik van robotica in de bovenbouw van het speciaal basisonderwijs bij kan dragen aan de ontwikkeling van twee belangrijke vaardigheden: vaardigheden voor het oplossen van technische problemen, en sociale vaardigheden. Het onderzoek is gericht op kinderen met een Autisme Spectrum Stoornis (ASS), voor wie de ontwikkeling van sociale vaardigheden een uitdaging is. RoboWijs bouwt voort op onderzoek dat heeft laten zien dat kinderen met ASS uit kunnen blinken als het gaat om computervaardigheden, en op onderzoek dat laat zien dat de inzet van robotica voor kinderen met ASS in therapeutische context gunstig kan zijn voor de ontwikkeling van sociale vaardigheden. RoboWijs is bijzonder, omdat het onderzoek juist niet in een therapeutische setting is geplaatst, maar zo getrouw mogelijk de reguliere onderwijssituatie heeft gevolgd. Lesmateriaal is samen met leerkrachten ontwikkeld; leerkrachten en niet de onderzoekers hebben de lessen uitgevoerd in het normale lesrooster in de lessen voor techniekonderwijs; de kosten voor de robotsystemen zijn in overeenstemming met de gebruikelijke (lage) budgetten van scholen. Veel energie is gestopt in het meenemen van de leerkrachten en in het uitproberen en optimaliseren van deelopdrachten. RoboWijs heeft een reeks van tien lessen ontwikkeld met als uiteindelijk doel een (Lego Mindstorms) robot zodanig te programmeren dat een parcours op een plattegrond van een supermarkt kan worden afgelegd en waarin de robot ook sociale ‘challenges’ moet uitvoeren, zoals vragen waar het broodbeleg staat. De programmeervaardigheden zijn opgebouwd door te beginnen met ‘unplugged’ opdrachten om computational thinking te stimuleren. Daarna is gewerkt met een simpel robotsysteem, de OzoBot, om te leren een robot opdrachten te laten uitvoeren en een parcours te laten volgen. Tot besluit hebben de leerlingen die daartoe in staat waren de challenges met de complexere robot, Lego Mindstorms, uitgevoerd, en hiertoe leren programmeren in Scratch. De invloed van deze taken op het sociale gedrag van de kinderen is onderzocht door de onderlinge interactie en samenwerking te observeren en te scoren in zogenaamde communicatiecirkels. Als een kind op een inhoudelijke passende manier reageert op wat een ander kind doet of zegt, dan is dat één rondgang binnen de cirkel. Door het aantal rondgangen te scoren en door de leraren te laten vergelijken met regulier gedrag van deze kinderen, konden we concluderen dat robottaken tot samenwerking kunnen leiden en daarmee tot versterking van sociale vaardigheid. Ook hebben de kinderen veel geleerd over robotica en toonden veel kinderen affiniteit en talent voor dit domein. Onze conclusies zijn geldig voor déze robottaken, uitgevoerd door déze kinderen, in déze situatie en onder begeleiding van déze leerkrachten. Het onderzoek is te zien als een ‘proof of concept’ studie met descriptieve aanwijzingen voor de effectiviteit. Het onderzoek is exploratief, niet vergelijkend, en te kleinschalig en te situationeel om zonder gecontroleerd interventie-onderzoek te generaliseren naar kinderen met ASS en hun leerkrachten in zijn algemeenheid, maar wel is aannemelijk dat deze benadering implementeerbaar en effectief kan zijn, zowel voor de ontwikkeling van technische en digitale vaardigheden als voor de ontwikkeling van sociale vaardigheden, en zowel in het speciaal onderwijs als in het reguliere onderwijs.

Introduction

Autism spectrum disorder (ASD) is a developmental disorder diagnostically characterized by deficits in social interaction and communication and the presence of restricted and repetitive behaviours and interests, also referred to as the "dyad of social impairments" (American Psychiatric Association, 2013). Children experience difficulties in forming relationships with peers and participating successfully in reciprocal interactions (Goldstein, 2002). Many autistic children are predisposed to experience difficulties in joint attention and react fewer and shorter to social cues.

The difficulties in social interaction in children with ASD are often visible in the school context, since this is an intense social context where they spend a considerable amount of time and interact a lot with other people (Bellini, Peters, Benner, & Hopf, 2007). In special education schools, the social context of school may be even more challenging for children with ASD since they have to interact with other children with the same problem. Teachers in special education indicate that limitations in the area of social skills of children with ASD contribute to various problems, such as conflicts with other children, and that social activities such as cooperating are very challenging to these children. Research confirms an association between social skills and behavioural problems in children with ASD as reported by teachers (Macintosh & Dissanayake, 2006). Furthermore, social skills may also interfere with academic performance (Bellini et al., 2007; Welsh, Park, Widaman, & O'Neil, 2001). In addition, the restricted and repetitive behaviours, and interests of children with ASD may also interfere with learning and functioning in school (Conroy, Asmus, Seller, & Ladwig, 2005; Gunn & Delafield-Butt, 2016). Obviously, these challenges of children with ASD also present teachers with challenges (Werkverband Opleidingen Speciaal Onderwijs, 2006). Teachers in special education spend for instance much time dealing with social-emotional and/or behavioural problems of children with ASD (Macintosh & Dissanayake, 2006; Werkverband Opleidingen Speciaal Onderwijs, 2006).

Meanwhile, schools and teachers also have the challenging task to provide these children with the skills and competencies that are necessary to participate in society in their near future, including the labour market. Some of these necessary skills are not subject specific and are sometimes referred to as 21st century skills. These include competencies for collaboration, creativity, problem solving and computational thinking (Voogt & Pareja Roblin, 2010; Thijs, Fisser, & Van der Hoeven, 2014; Van Graft, Klein Tank, & Beker, 2014). In addition to and in line with the need for participatory skills, the Dutch government has stimulated schools to implement science and technology in their curriculum. The Netherlands, like many OECD countries, face labour market shortages due to insufficient numbers of young people that are interested in and qualify for jobs in the area of technology. Research indicates that children lose aspirations for a career in science and technology at an early age, making it important to tackle this problem in primary schools (Turner & Ireson, 2010; Kerr & Murphy, 2012; ASPIRES, 2013). Children who have 21st

century and science & technology skills will have better chances later in life (Trilling & Fadel, 2009). In the 'Nationaal Techniekpact 2020' (2013) Dutch primary schools have promised to work on these problems and give science and technology a substantial and structural place in the curriculum by 2020.

However, progress in primary education has been slow (Inspectie van het Onderwijs, 2017; Techniekpact, 2021). Studies show that 21st century skills are also not yet systematically and effectively integrated in the current curricula of schools (Thijs et al., 2014; Van de Oudeweetering & Voogt, 2017). Primary school leaders indicate that their teachers struggle with low self-efficacy with respect to teaching science & technology and with a lack of skills for inquiry and design-based teaching pedagogies. Lack of skills and (related) confidence are also among the most important barriers that prevent teachers to make full use of ICT (Balanskat, Blamire, & Kefala, 2006). Studies with pre-service teachers and teacher educators also show that teachers are not adequately equipped with technological pedagogical content knowledge (Tondeur et al., 2012; Voogt & McKenney, 2017). Teachers struggle with an overloaded curriculum, making it difficult to simply allocate more time to science and technology (AVS, 2017). An integrated approach - to attain learning outcomes from more than one area with the same teaching materials - could be a solution but also presupposes pedagogical abilities that are not well developed (Gresnigt, Taconis, Van Keulen, Gravemeijer & Baartman, 2014). Combined with the challenges that special education schools and teachers already face it is likely that it is even harder to implement 21st century and technological skills in special education compared to regular education.

On the other hand, individuals with ASD frequently display remarkable skills in recognizing repeating patterns (Baron-Cohen et al., 2009). As a result, children with ASD commonly possess a high interest and talent towards technology and robots, attributable to the general predictiveness of technology (Pennisi et al., 2016). This remarkable skill may be a useful support when implemented in ASD treatment and therapy.

Studies show that the use of robotics can be an effective intervention for children with ASD in therapeutic settings. Robots offer children embodied interactions (in contrast to playing on a tablet or computer) in which they can practice social skills, such as imitation, joint attention, and turn-taking (Cabibihan, Javed, Ang jr, & Aljunied, 2013; Diehl, Schmitt, Villano, & Crowell, 2012; Warren et al., 2015). In addition, robots seem to function as social mediators since the amount of interaction between children with ASD and other children and adults increases through the presence of a robot (Hellendoorn et al., 2017; Scasselati, Admoni, & Mataric, 2012; Kim et al., 2013). Children with ASD are attracted to technological systems in general, including robots (Pennisi et al., 2016; Warren et al. 2015). A possible explanation for this attraction is that the way technological systems work fits with the so-called systemizing skills of people with ASD (Baron-Cohen, 2009) and the fact that robots are controllable, consistent, and predictable in their behaviour (Cabibihan et al., 2013; Pennisi et al., 2016).

While there is considerable research into the use of robotics with children with ASD in therapeutic settings, there is much less insight in the use of robotics in the school context for children with ASD (Mubin, Stevens, Shahid, Al Mahm, & Dong, 2013). Although studies indicate that the use of robots can be effective for different forms of learning, such as collaborative learning, discovery learning and problem solving, and for developing knowledge and skills in different areas (e.g. science, match, technology, language) and for specific skills such as programming (Alimisis, 2012; Altin & Pedaste, 2013), the systematic use of robotics in educational settings remains limited (Mubin et al., 2013; Altin & Pedaste, 2013). Studies show that this may be related to different factors including the lack of skills and confidence of teachers and the absence of well-defined curriculum and learning material for teachers (Balanskat et al., 2006; Mubin et al., 2013, Tondeur et al., 2012; Voogt & McKenney, 2017).

It can be concluded that implementing robotics in primary school curricula may be effective for the development of both generic and specific skills in a variety of areas for all children so as to contribute to future participation in society and on the labour market. Because of the deficits in social skills, repetitive and restricted interests, combined with the attraction for technology and systemizing skills, children with ASD may specifically benefit from robotics in school curricula. Studies indicate that applied research in educational contexts is required into the implementation and use of robots in existing regular education environments for children with ASD (Huijnen, Lexis, Jansens, & de Witte, 2016).

Developing the social skills of children with ASD is a challenge for both professionals in education and care. Developing technological skills with primary school children, whether with ASD or not, is a challenge for almost all teachers and schools. Several schools in the Netherlands who work with children with ASD are aware of the positive effects of social robotics in therapeutic settings. This triggered the collaboration between the researchers of Windesheim University and Utrecht University and schools for primary special education, concerning the question whether and to what extent robotics can be put to good use in educational settings. This project elaborates on a pilot plot project, discussed with Passend Onderwijs Almere in 2016, and funded by the Expertisecentrum Wetenschap & Technologie Noord-Holland/Flevoland. The pilot was conducted in the school year 2016-2017 with several teachers and groups of children with ASD at Nautilus, a large special education school in Almere specialized in ASD, and Dukdalf, a regular primary school in Almere with two so called 'structure groups' for children with ASD. We found sufficient indications that working with social robots could be beneficial for children with ASD. Based on the experiences and discussions with teachers the initial questions and set-up of this project were developed.

Set-up

To investigate the problems, we set up the research project RoboWise as a collaboration between research and professional experts from Utrecht University and Windesheim University of Applied Science and three schools for special primary education and their teachers in the centre of the Netherlands.

Research team

The research team consisted of two postdocs from Utrecht University, dr. Annika Hellendoorn and dr. Rianne van den Berghe, supervised by prof. dr. Paul Leseman from the department of Pedagogy and Education in the Faculty of the Social Sciences, and two investigators with expertise on autism spectrum disorder, special education, and teacher training, drs. Hans Petersen en drs. Lourens van der Leij, supervised by dr. Hanno van Keulen from the Windesheim lectorate Leadership in Education. Due to circumstances, Lourens van der Leij was replaced by drs. Erik Ploeger, also from Windesheim, with expertise on robotics in education. Rianne van den Berghe changed during the project from a postdoc position at Utrecht University to a position as teacher/researcher at Windesheim, but this did not affect her role in the project. Finally, Hanno van Keulen moved to Delft University of Technology. Six bachelor Social Science students at Utrecht University participated in the project as a part of their bachelor end project, to gain experience in data collection. These students observed classes in the pilot phase and helped develop the scoring system for scoring social skills. Of great help was the participation of Franziska Prummer, a Cognitive Psychology master thesis student at Utrecht University, who piloted the relations between robotic task complexity and the collaborative behaviour of the children. We were supported throughout the process by TechYourFuture, the Centre of Expertise Technology Education in Deventer. TechYourFuture hosted the website of the project, hosted online seminars, helped produce the products (lesson series, practical booklet), and helped organise the concluding symposium in September 2022.

Schools for special primary education (‘SBO’) and participants

The empirical part of the research took place at three schools for special primary education, specialised in children with autism spectrum disorder: Eduvier in Almere, Berg en Bosch in Houten, and De Evenaar in Nieuwegein. From each school, two, sometimes three, teachers participated, with their classes of children aged 9 to 13 years old (grade 4-6, in Dutch, ‘groep 6-8’). Typically, classes consisted of between 9 to 15 developmentally comparable children who may be of a different age. Teachers were supported by their principals and heads of educational development.

The teachers were all qualified for, and had substantial experience in, working with children with ASD. Only a few had some teaching experience with robotics; most initially had none.

Later in the project, a special needs after-school ('Buitenschoolse Opvang') institution specialized in children with ASD in Utrecht, joined the project on a voluntary basis and this gave the research team additional possibilities for piloting robotic tasks and for experimenting with observational scoring systems.

Research questions

The research questions of RoboWise were formulated at the start of the project. The main research question is whether and how the use of (social) robotics in schools for children with ASD, contributes to the development of technological and social skills, and, if so, how the use of robots can be structurally and effectively integrated in school curricula. This is approached with a comprehensive set of six sub-questions:

1. Which robotic systems, which aspects of these systems, and which educational activities contribute to the development of technological skills, such as for designing, building, programming, testing, and troubleshooting?

2. Which robotic systems, which aspects of these systems, and which educational activities contribute to the development of social skills, such as perspective taking and cooperation, especially with children in primary education with ASD?

3. How, and with which instruments, and with which accuracy can the development of technological and social skills in this context be determined?

4. Which factors (such as characteristics of the teacher, characteristics of the children, characteristics of teacher-student interaction, characteristics of cooperation with other children; frequency of activities) influence learning outcomes with respect to social and technological skills?

5. What do primary special education teachers need to become competent with respect to teaching robotics, especially to children with ASD, such as support with content knowledge, self- efficacy, educational design skills, inquiry and design-based teaching skills, observation, and interaction skills?

6. How can educational activities with robotics be aligned and implemented in the regular curriculum of special and regular primary education, so as to contribute to a learning progression for technological and social skills?

Project planning

The project was executed in three phases: start-up, piloting, and executing. The start-up phase in the first year of the project focused on literature study and developing mutual acquaintance between the researchers and the teachers. During the piloting phase robotic tasks were developed in collaboration with the teachers, piloted and improved, and ways to observe and score social skills were tried out, discussed and explicated. This phase ended in the lesson plan to be executed in the final phase. The piloting phase took far longer than originally expected, due to the Covid pandemic (see below). Because of the resulting time constraints, we combined the phases of executing the lesson plan and the data collection with the time slot planned for interpreting the data, developing the output, and writing reports.

Covid-19

The Covid pandemic struck hard during the project. All schools were heavily affected. Schools closed at (from the point of view of the project) a very inconvenient moment. Children with ASD need stability and predictability, so it took considerable time to start up after closures. Piloting and data collection was continuously interrupted and hindered. The schools faced even greater challenges. Teachers fell ill, some did not return to work, schools had to reorganize and reschedule constantly. One time, a lesson to be videoed was cancelled five minutes before the start because of a positive test result. The pandemic added to the already considerable problems schools currently face to cope with teacher shortage. Schools had to reorganize and had to reschedule experienced teachers that 'survived' the pandemic, and also escaped from burn-out caused by chronic shortages. In no case was drop-out related to the project. On the contrary, teachers were reluctant to quit, and the relevance of the project was never put to question by teachers or principals, but understandably, participating in a research project was not the school's top priority. The upshot was that all teachers that were involved at the start of the project were eventually replaced. This implied additional professional development efforts and disabled our options to do longitudinal studies on teacher development. We had to apply for an extension of the project to be able to produce the most important deliverables and could only complete data collection just before the summer holiday of 2022. Nobody had scheduled for this, and the research team also faced challenges due to other obligations and changes in personal situation. Enthusiasm for the project kept us, and the schools, going.

Ethical permission and data storage

The project was submitted to the Ethical Committee of Windesheim and approved. Participants and their parents/educators gave written consent on partaking in the project. Data (observation notes; videos) were anonymized as soon as possible and stored at Windesheim in JOIN for long time storage, by the Windesheim department for 'Documentaire Informatievoorziening en Archiefbeheer' (Div-A).

Data collection

Data collection was not a straightforward process. In this project, teachers were co-creators of the lessons. The lessons therefore are not really 'interventions' in the sense that the researchers control all factors that might influence outcomes apart from the lesson. The teacher is part of the lesson and therefore part of the data. Some activities may work with one teacher in one class, but not in others. 'Activity' is a concept with fuzzy boundaries: it is never the same in each reiteration. Therefore, we not only observed the lessons, but also observed contexts, gathered data on the context, and on the thinking and reflection of the teachers through discussions in meetings that we called the 'professional learning community'.

The teachers wrote reflection reports during the pilot phase and during the final execution of the lesson plan. We regarded the teachers as experts in assessing the social competences of their children. They work with them all day and know what their typical behaviour is and what is exceptional.

At the start of the project, we did not have a scoring system for scoring skills for technology and social skills. Developing such a system was an aim and thus should be presented in the results section. On the other hand, we of course used the resulting system to score our data, so it should be part of this section. For these reasons, we present the general approach in this section and more details and considerations in the next section, taking into account some redundancy.

Developing a scoring system

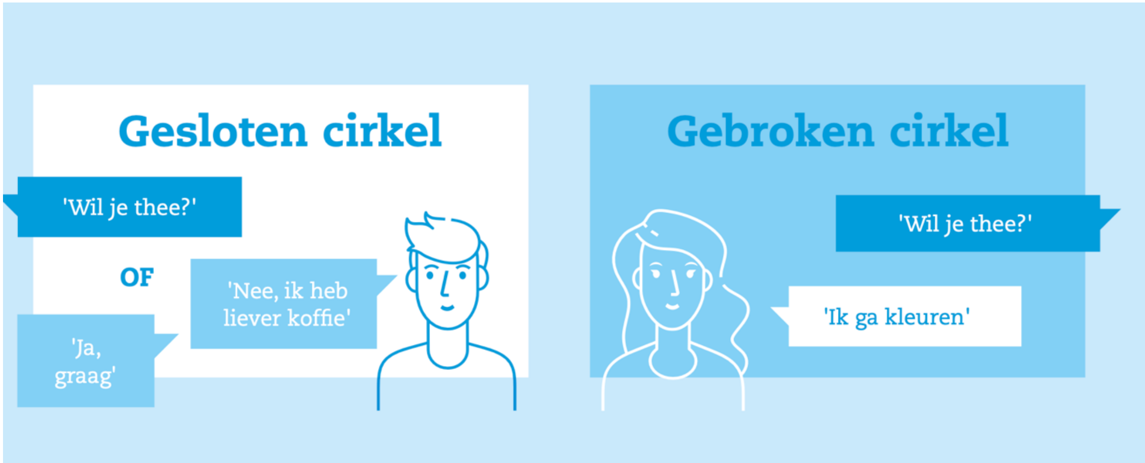
Our aim was to develop a system in which the robotic activity of the children can be used as an independent variable and the social behaviour as the dependent variable, thus allowing us to detect correlations and maybe deduce causal relations. During the pilot phase we therefore experimented with various ways of classifying the robotic activity and the cues for social behaviour.

For robotics, we first focused on content specific categories (e.g., building – programming – testing). We discarded this for two reasons: we could not find a robotic system that enabled design, constructing and programming within our experimental conditions (ease of use, cost). Also, our groups are small,and tasks are open, so similarities with respect to concepts that need to be specified in more detail, like 'building' or 'programming' did not occur on a scale that made comparison easy. Instead, we tried approaches that were less specific and settled on a scoring system based on difficulty of the task (simple – medium – complex) as perceived by the teacher.

With respect to social skills, we first had to operationalize this concept. We decided to focus on 'collaboration' (Lai, 2011). Based on studies conducted by Wainer et al. (2010) and Gal et al. (2016), along with the definition of the term collaboration by Bratman (1992), Lai (2011) and Liebal et al. (2008) as discussed in Section "*ASD and Collaboration*", the variables 'mutual support' (questioning; informing), 'negotiation' (instructing, accepting, disagreeing) and 'reciprocal interactions' (initiating, responding, nodding, gazing) were designated as conceivable key collaborative behaviors.

We tried out content-rich indicators like 'accepting', 'disagreeing, 'initiating' and 'responding'. We found these categories fuzzy and overlapping. We could not reach interrater consensus, so we decided to focus on 'mutual reciprocity' of the interaction as the key scoring signal.

We operationalized this further in terms of the concept of the 'circle of communication' (Dionne et al., 2011). This a promising way to observe and score social behaviour in terms of reciprocal and meaningful patterns of action and reaction during interaction. The focus is on two-way communication between two participants, which can be either verbal or non-verbal. The first step in the CoC is the opening of the circle and initiation of communication (Lal & Chhabria, 2013), which is followed by a response of the interaction partner. A CoC is continued by more alternating responses following each other until it is finally closed. A successful and complete communication circle relies on the acknowledgement of the response by the interaction partner (Ginsburg, 2019).



We noticed that interaction was not always a one-to-one pattern of action and reaction. Often, the pattern is more like action – reaction – reaction. The first child may say: "We should draw a red line here", and the second child may first nod (reciprocal action) and then negotiate: "I think green". So, a cycle of communication can consist of more than two signals.

We tried out versions of a scoring system with a group of 15 children, mostly boys, from the special needs after-school institution, ranging from age 7 to 13. The advantage of this after school situation was that there was less pressure on the teachers to continue with the lessons and the school curriculum. We could more easily repeat and retry an activity with the same children to estimate the effect. Activities of the children and interactions were videotaped using Panasonic HDC-SD60 camcorders. Valuable work on developing the scoring process was done by research master student Franziska Prummer.

Working in pairs, children were given the task to 'create a track' for the Ozobot robot. With respect to collaboration, they were instructed to 'work as a team'. Eight of these Ozobot sessions were used to investigate the relations between robotic tasks and collaboration, with a total of 2 hours and 10 minutes of video footage. Each session lasted between 10 and 30 minutes (M=16:17 minutes, SD=10:43 minutes).

To ensure validity of this coding-scheme and interrater reliability, 10% of the data was coded on these variables by a second coder. After comparison of the coded videos by both coders, an average percentage agreement level of 0.61 was achieved, which indicates a rather weak agreement level. The discrepancies between observers were discussed and resolved at a consensus meeting. Within this setting, we were able to score the difficulty of the tasks and the number of circles of communication, and we could label actions in terms of 'mutual support', 'negotiation', and 'reciprocal action'.

Hence, we decided to use these variables in the last stage of the project, the execution and observation of the lesson series. We concluded that we wer not able to use more detailed indicators (like initiating or questioning) because these indicators are not mutually exclusive, and we could not reach consensus.

Data collection during the execution of the lesson series

To enable the researchers to observe behaviour during the execution of the lesson series, the teachers formed groups of one, two or three children with comparable social skills. Of course, one child is not a group, but because children typically were highly motivated for robotics, working alone on robotic tasks could help develop the confidence to try working with another child in a future task.

We videoed the lesson series typically with one group of children in the focus, occasionally from a whole class perspective, or with the teacher as instructor in the focus.

Many tasks are short, and the researcher had the possibility to video other groups during a lesson. The researcher in general followed the advice of the teacher to focus on this group or another. Sessions that were videotaped lasted between 2 and 30 minutes.

During the execution of the lesson series, collaboration was accordingly assessed by scoring communication circles in correlation to a specific task. Tasks typically lasted between 2 to 10 minutes. The researcher started scoring by identifying a task based on the activities in the lesson plan and the researcher and the teacher labelled a task as easy, medium, or complex. Within a task, the researcher focused on the specific goal set by the children. This goal could be voiced explicitly or deduced from more implicit clues and became the name of the potential circle of communication, for example, 'draw a track for Ozobot', or 'programme the Lego Mindstorms robot to take a right turn at the green spot'. Circles of communication were scored for each verbal or non-verbal action that was followed by a fitting reciprocal reaction. Actions were also scored as 'mutual support'; 'negotiation'; and 'verbal or non-verbal reciprocal action'. A circle was scored 'broken' when the verbal or non-verbal behaviour of a child could not be interpreted as a logical continuation of the process.

We focused especially on the number of completed circles, compared to what could be expected. Expectations were derived from estimations of the teachers, who know the children very well and can compare their behaviour in the robotic tasks to behaviour in other lessons. We also focused on the relation between perceived difficulty of the task and the number of circles of communication. We wanted to find out if curiosity and commitment towards robotics could compensate for potential frustration caused by the challenging nature of tasks.

To ensure professional evaluation of children's behaviors, teachers of the children filled out a logbook and completed a questionnaire which assessed the children's social behavior, interactions, and collaboration in comparison to their usually observed behaviors. Initially, the teachers gave a short description and summary of the observed behavior throughout the task. Following this, three Likert-scale rating items were to be filled out, which each consisted of a five-point rating scale ranging from 'disagree' (1) to 'agree' (5). The teachers indicated if during the tasks they (Item 1) noticed more social behavior between the children than usual, (Item 2) if the children interacted with each other more than usual and (Item 3) if the children worked more collaboratively than usual. Afterwards, we discussed their observations and opinions, treating them as experts.

Scoring social skills is a form of high inference rating. As indicated above, we trained ourselves for interrater reliability by repeating the scoring process from video with a second researcher and discussing the ratings until agreement was reached. However, uncertainties remained in scoring non-verbal utterances (nodding, humming, looking at the other), leading to discrepancies in the total number of circles scored by different researchers. There was no disagreement on broken circles.

Results

We answered all questions both theoretically and empirically.

First, we performed a literature study to find out if it makes sense to apply robots in primary schools to foster both the social and technological skills of children with ASD and to derive clues for the choice of robotics systems and the educational activities.

We searched four databases (PubMed, ERIC, PsycInfo, and Scopus) using the following key word combinations: ASD OR Autism AND Robotics or Robots, ASD OR Autism AND Robotics OR Robots AND Education, ASD OR Autism AND Robots AND Social Skills, Robotics OR Robots AND Education, in all fields (title, abstract, key words, full text) using the period 2000-2020. We found 928 studies. 615 studies remained after the removal of duplicates. From this, we selected the review articles. This led to 52 studies. 36 studies were removed after reading the content carefully and concluding that the content did not match the goal of this study. Through scrutinizing the references in the remaining 16 studies, we included another 35 studies.

Second, we tested these ideas empirically in the schools during the piloting phase of the project and made our final choices for robotic systems, activities and scoring social skills in the definitive lesson plan.

Determining the robotic systems and robotic activities

The first two research questions focus on robotics:

1. Which robotic systems, which aspects of these systems, and which educational activities contribute to the development of technological skills, such as for designing, building, programming, testing, and troubleshooting?
2. Which robotic systems, which aspects of these systems, and which educational activities contribute to the development of social skills, such as perspective taking and cooperation, especially with children in primary education with ASD?

We found that many studies in the literature report on the *clinical* use of robots with the goal of improving social skills in individuals with ASD (Diehl *et al.*, 2012; DiPietro *et al.*, 2019; Pennisi *et al.*, 2016; Ricks & Colton, 2010). The clinical setting typically implies an individual approach and a laboratory setting. Usually, the robots in these studies are humanoid and are used as an interaction partner. Studies demonstrate that individuals with ASD are often highly engaged during interactions with robots and show better social-communicative skills, such as joint attention and imitation, when interacting with a robot compared to interacting with another person (Aresti-Bartolome & Garcia-Zapirain, 2014; Diehl *et al.*, 2012; DiPietro *et al.*, 2019; Pennisi *et al.*, 2016).

Pennisi *et al*. (2016) found that in 14 of 16 studies children with ASD manifested social behaviours towards the robot, and in half of the studies the robot better stimulated social behaviour development than an adult. However, Diehl *et al*. (2012) demonstrates that children with ASD show varying responses to robots. Some respond better to robots in terms of social-communicative behaviour, other children respond equally or worse to robots compared to humans. This may be due to the heterogeneity of the disorder. Several studies indicate that the effect of the robot depends on contingency. When robot behaviour is not random but depends on the child's behaviour, children with ASD show more social-communicative responses (Diehl *et al*., 2012; Feil-Seifer & Mataric, 2009; Stanton *et al*., 2018).

Research demonstrates that robots can play a role as 'mediator' or 'facilitator' for social interactions between individuals with ASD and other persons. The presence of the robot elicits and increases social behaviours and interaction (Diehl *et al*., 2012; Pennisi *et al*., 2016; Ricks & Colton, 2010). For example, a robot may encourage joint attention by drawing the child's attention towards a stimulus. Pennisi *et al*. (2016) point out that robots can also be a distractor, because the robot may absorb the attention of the child, making it harder to redirect attention to other persons.

Employing the robot as a mediator may benefit children in collaborative learning (Mubin *et al*., 2013), where groups of students work together to achieve a task. This may be specifically important for children with ASD who have social-communicative difficulties, since collaboration and communication are key generic skills important for success later in life (Ananiadou & Claro, 2009). Although research with typically developing children indicate positive effects (Anwar *et al*., 2019), only few studies explore the effects of robots on skills for collaboration between children (not between robot and child), in children with ASD. Research in which the robot is mediator rather than main interaction partner may fill a gap pointed out by several studies, which is the lack of proof that the skills children learn in interaction with the robot, generalize to social interaction with other persons, even though this is often the stated goal for interventions (Dautenhahn & Werry, 2004; Grossard *et al*., 2018; Ricks & Colton, 2010). Begum et al. (2016) pointed out that 'generalization training' to generalize the target behaviour to other persons and in different contexts, is not common in interventions. We found Wainer *et al.* (2010) who demonstrate improved collaboration among children with ASD between the first and last sessions of a robotics class that lasted several months and found that this partly generalized to a different context, and the study of Scassellati *et al.* (2018) that demonstrates improved collaboration among children with ASD after playing with a robot and without the presence of the robot. An important question for research is whether such positive effects are robust and enduring: do they remain stable in other contexts and in the long-term?

Many robots have been created to develop skills in children with and without ASD (Scassellati *et al*., 2012; Peca *et al*., 2014). Studies suggest that what is best depends on many factors, including appearance and functionality, child characteristics (e.g., age), goal of the intervention (e.g., learning social skills versus coding or programming skills or mechatronics skills), context (e.g., clinical or school context), and practical considerations (e.g., costs) (Galvez-Trigo *et al*., 2019; Ricks & Colton, 2010; Peca *et al*., 2014; Scassellati *et al*., 2012; Robins *et al*., 2007). For children with ASD, factors such as language ability, severity of symptoms, and social functioning should be considered when choosing a robot (Schadenberg *et al*., 2020).

Recommendations differ regarding the best choice for typically developing children and children with ASD. For instance, humanlike robots stimulate engagement in typically developing children (Van Straten *et al*., 2019), but Ricks and Colton (2010) found that humanoid robots with many human details are the least engaging to children with ASD and suggest avoiding these. This has the same background as the disorder itself: robots with much detail and features such as eyes that blink may provoke overstimulation from which children disengage. However, robots that are somewhat humanlike, such as NAO, are successfully used in clinical intervention programs for children with ASD to elicit and improve social-communicative behaviours, such as joint attention or imitation (Diehl *et al*., 2012; Pennisi *et al.*, 2016).

We conclude there is a potential problem: although some studies suggest that humanoid robots have the greatest potential for generalization of social-communicative skills from the interaction with the robot to interaction with other humans, this is (a) not proven, and (b) may not hold for all individuals with ASD. While many clinical studies suggest using humanoid robots, especially for teaching social-communicative skills (Diehl *et al*., 2012), other studies find that non-humanoid robots may be more suitable for stimulating social interaction between children instead of just stimulating robot-child interaction (Ricks & Colton, 2010). Research in special education and with children with ASD demonstrates that the non-humanoid Lego Mindstorms robots has positive effects on collaborative and social behaviour, such as initiating joint attention (Kärna-Lin *et al.,* 2006; Wainer *et al.,* 2010). Similarly, a small-scale study by Aslam *et al.* (2016) with children with intellectual disabilities found that non-humanoid robots were more engaging than humanoid robots. Thus, there is no consistent evidence that investing in humanoid features with their inherent complexity pays off. For example, Sphero, a spherical robot that can be programmed to navigate and produce sounds, benefits development comparable to more humanoid and expensive robots like NAO (Golestan *et al.,* 2017; Kärna-Lin *et al*., 2006; Kozima *et al.,* 2005; Marti & Giusti, 2010).

Several studies conclude that combining humanoid and mechanical elements is best for children with ASD (Cabibihan *et al.,* 2013; Ricks & Colton, 2010). Such robots may not look like humans, which children may find threatening, but have other anthropomorphic characteristics, such as the apparent ability to move around at free will.

Pennisi *et al.* (2016) stress to determine the choice of the robot *in relation to* a specific ability or skill. Each robot affords different actions. Making a robot travel a certain distance and avoid collisions differs from making it laugh when happy. Both tasks stimulate technological skills such as programming or constructing but they may have different effects on social behaviour and the development of social and communicative skills.

Children with ASD appreciate predictability and control. The behaviour of the robot should be predictable and dependent on the child's actions (Robins *et al.,* 2007). Predictability should be reconciled with variation and evolution, to sustain attention and stimulate development. Some robots, such as Pleio, offer consistent, predictable behaviour but also afford the child to teach the robot new behaviour (Ricks & Colton, 2010).

Lastly, there are practical considerations related to the circumstances in which the robot is used (Galvez-Trigo *et al.,* 2019). Robots in classrooms must be resilient towards knocks, bumps, and drops (Scassellati *et al.,* 2012), since children with ASD often have problems with emotion regulation. However, many robots, especially advanced ones such as NAO, are susceptible to destruction. Building sturdy, mobile, flexible robots that afford interaction in naturalistic settings such as classrooms, is a challenge (Scassellati *et al*., 2012).

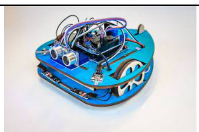
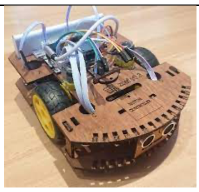
Another practical consideration concerns costs (Galvez-Trigo *et al*., 2019). School budgets typically do not allow purchase and repetitive replacement of robots, certainly not the expensive versions used in therapeutic settings (Galvez-Trigo *et al*., 2019). To stimulate more regular use, some robots with low manufacturing costs such as PABI (Penguin for Autism Behavioural Intervention; Dickstein-Fischer *et al*., 2011) have been developed.

Children with ASD vary widely (Peca *et al*., 2014). Just like ASD, robots form a spectrum, with different opportunities for interaction and levels of stimulation. Whether children with ASD react with oversensitivity or with curiosity to a certain robot, will differ from individual to individual.

Choice of robotic systems

During experimental piloting, we saw that children interacted easily with non-humanoid robotic systems like Beebot, Ozobot and Lego Mindstorms. We also concluded that designing and building a robot was beyond the practical possibilities and the constraints of time and resources. Consequently, with respect to developing technological skills, we restricted the study to computational thinking and programming a robot, which was more than enough of a challenge. Also important was our observation that children do not need a social or humanoid robot (like NAO) to develop social skills. The children even did not need to interact socially with the robot. Instead, the robot is a mediator. The activities to be performed with the robots caused the children to interact and collaborate with each other, which is actually much better since this circumvents the problem of transferring social skills developed while interacting with a robot, to interacting with other humans. Although we piloted some other systems (Pleo; Meccanoid; Leaphy) we decided to develop the robotic activities and the lesson plan with Beebot as a starter, then Ozobot and finally Lego Mindstorms. We were not entirely happy with Lego Mindstorms because it does not allow for much design and construction and is rather expensive for schools, but it is very robust and worked well enough. We hesitated with Leaphy: this system allows design and construction but proved somewhat vulnerable (children with ASD throw with things when overstimuted) and not all schools had tinkering facilities.

Table 1: Robotic systems

Robot		***Pro's***	***Con's***
Beebot		Affordable; robust; suitable for young children and for starting the development of computational thinking	No sensors; cannot be programmed to react on a condition;
Ozobot		Affordable; robust; easy programming language (Blockly); easily mediates cooperation	Limited possibilities for sensing and acting ('seeing' + moving around)
Pleo		Learns new behavior (AI); social interaction without overstimulation; many sensors and actuators	Expensive; cannot be programmed
Meccanoid		Enables design and constructing; many options (sensors; actuators).	Too difficult according to teachers; too vulnerable; pieces go missing
NAO		Allows complex social interaction without overstimulation; can be used as an avatar	Unaffordable for schools; very vulnerable; meant for interaction rather than for programming
Lego Mindstorms		Robust; easy to build with many standard options for sensing and acting; easy to learn to program (Scratch)	Not cheap; learning Scratch takes some time; in 2023 out of production
Leaphy		Affordable; easy programming language (Easybloqs); sensors and actuators; allows tinkering (design and construction)	Somewhat vulnerable; compared to Mindstorms: assembling and expanding requires time and constructing facilities
Mirte		Affordable; robust; three programming languages (Blockly; Python; ROS); allows expanding with sensors and actuators through design and construction	Compared to Mindstorms: assembling and expanding requires time and constructing facilities

We observed that, as expected, children used anthropomorphic language throughout when working with Ozobot and Mindstorms ("he wants to ….") although these robots are not social robots and never usher intentions. Table 1 summarizes the considerations on choosing a robotic system. In the table we also include a robot ('Mirte') that came on the market after our data collection but which, with hindsight, could have been our choice over Lego Mindstorms.

Educational activities and ecological validity

The literature study revealed that most clinical studies involving robots and children with ASD are one-to-one: a single child interacts with a single robot. These studies have fewer confounding variables (such as behaviour of other children) and it is easier to control the interactions. However, since the end-goal is improving the interaction of children with ASD with other humans and developing skills for collaboration is important, many studies conclude that a one-to-more situation, in which a single robot interacts with more children, may be more effective. This is important for education, since one-to-one interaction lasting longer than a short time is difficult to organise in classrooms, even in special education.

In clinical settings, development of social skills may be the sole objective. In schools, the curriculum is more comprehensive. Development of social skills is seldom the determining factor. Subjects like reading and writing, mathematics, arts, and science, are dominant and the development of 21st century and other generic skills typically is achieved within these subjects.

Although children are highly engaged during robot-assisted learning, just presenting the technology to the children is not enough to induce development of generic kills (Tapus *et al*., 2012; Kim *et al*., 2013; Pop *et al*., 2014; Simut *et al*., 2016; Desideri *et al.*, 2018). A curriculum or lesson plan should guide this (Alimisis, 2012). Consequently, aligning activities with robots with regular activities, such as design projects in technology or art class or working with maps in geography, is important. Robotics is versatile enough to fit multiple objectives. Multiple objectives can be achieved with the same integrated activity, for instance a robotics lesson in which children need to collaborate may develop both programming and social skills.

Alignment and structure are also provided through the pedagogy and the interventions by adults. Unguided exploration can be effective for some children and may be a starting point for some robot-assisted programs (Lindh & Holgersson, 2007; Williams *et al*., 2007), but other studies indicate that appropriate instruction and scaffolding by more experienced others (e.g., teachers) is more effective and efficient (Kirschner, Sweller, & Clark, 2006). This is especially important for children with ASD who often require a highly structured learning environment without ambivalences what to expect and how to react. Rules and expectations should be clear and consistent (Iovannone *et al*., 2003).

When we started piloting and developing activities, we absolutely wanted to maintain a high level of ecological validity. The activities should be doable under classroom conditions that apply to the average Dutch (special) primary school. This implies that these 'average conditions' become part of the method. But of course, these conditions are not specified or known in advance. Evidence-based or evidence-informed approaches exist against a background that is not articulated. Educational practice is an amalgam of educational system, culture, and many contingent factors. "This is how we do it". We needed to know not what is possible according to evidence-based practices reported in the literature (which may be only a fraction of the relevant educational practices in the world), or conceivable under optimal conditions (with the best available robots; teachers that are experts in all respect; plenty of time for preparation and administration; individual instead of whole class teaching; et cetera). Instead, we needed to know what is simple or complex or (im)practical for our teachers in their normal day to day practice. Our teachers, and not teachers as such, should be able to instruct and scaffold the robotic activities and do the real time assessment of technological and social skills development. Teachers and schools, however average they may be when we zoom out, are also unique. These contingencies made the piloting phase a very interesting but also time-consuming challenge. In terms of Vygotsky, we had to figure out what was within the zone of proximal development of the constellation of a teacher and her/his class. In order to improve uniformity, we iterated every activity in the three schools. Circumstances were comparable yet different, and by constantly comparing we were able to develop a lesson series that induced sufficiently comparable instructional behaviour of the teachers and comparable responses of the children in each school and with each teacher. That was why we wanted to pilot first and then execute, with the same teachers under more or less the same conditions, a lesson plan that suited our ecological niche. Covid and the resulting chaos complicated this because we repeatedly had to start all over with a new teacher and a new class. We lost the perspective of longitudinal development. However, we found that the new and inexperienced teacher nevertheless were quite positive and able to play their role. With respect to the last research question, on implementation in new schools on a wider scale, we therefore can be more confident than we would have been under planned conditions.

The lesson series

The lesson plan is an important part of the planned output. It is described in detail in an appendix and is available as a product from the website of the project, hosted by our partner TechYourFuture in Deventer:
(https://www.techyourfuture.nl/uploads/moxiemanager/Lessenserie_Robowijs_-_samen_leren_programmeren_compressed-2.pdf).

The lesson unit typically is 30 minutes, which suited the schools, and the total number of lessons (or activities) is 18, spread out in 6 themes. Some activities take more time; in these cases, lessons are combined to a multiple of 30 minutes, with the possibility of having a break. All schools and teachers could deal with this arrangement.

All themes and lessons work towards the ultimate goal: simulating shopping with a robot in a supermarket.

The *first* theme is on introducing the children to collaboration and programming. Children make a mind map on collaboration, and they draw the map of a supermarket. Most schools combined this with an excursion to a real supermarket. Programming was introduced 'unplugged': how to instruct your teacher to prepare a sandwich with butter and 'hagelslag'.

Figure 2 Ozobot track

In the *second* theme the children get to know the Beebot and the Ozobot robots. They apply computational thinking and program the Ozobot to follow a track and perform an action at a predefined place in the track.

The *third* theme is on making the actions of Ozobot meaningful in the context of shopping at a supermarket. The track now has to be the ground floor of a supermarket, and the actions of Ozobot have to stand for realistic situations, like noticing that there is no milk and moving to a supermarket employee.

In the *fourth* theme, the children are invited to imagine challenging supermarket situations themselves, discuss their challenge with other children, and program Ozobot in such a way that the challenge can be met.

Figure 3 Example of the themes in the lesson series

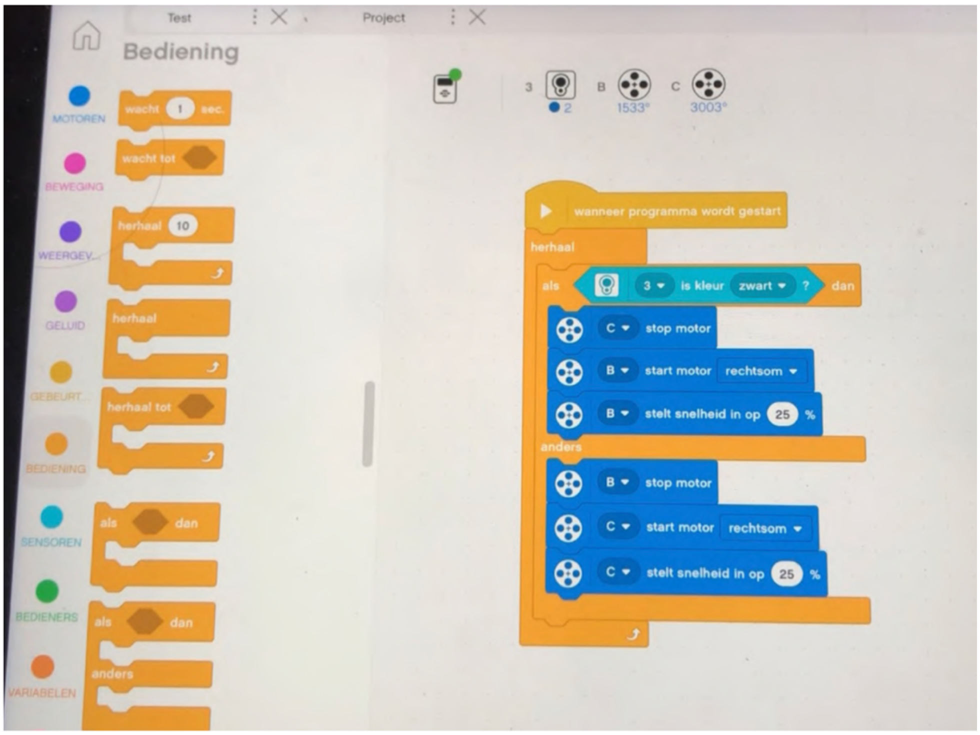
Overzicht thema's lessenserie:

Thema	Korte omschrijving	Opdrachten	Voorbereiding
Thema 1: Wat is samenwerken en programmeren?	Leerlingen leren wat samenwerken en programmeren is. Dit wordt geïntroduceerd in het overkoepelende thema: de supermarkt. Stel dat je een robot boodschappen wilt laten doen in een supermarkt, wat moet hij dan allemaal kunnen?	- Opdracht 1: mindmap maken samenwerking en een supermarktplattegrond maken - Opdracht 2: mindmap maken programmeren en opdracht 'levend programmeren'	**Tijd:** Opdracht 1: 30 minuten Opdracht 2: 30 minuten **Nodig:** - Leerlingkaart 1: afdelingen van de supermarkt - Digibord - Papier
Thema 2: Kennismaken met robots	Leerlingen maken kennis met robots: de Beebot en/of de Ozobot. Ze leren dat de Beebot reageert als je op zijn knoppen drukt en dat de Ozobot lijnen kan volgen en trucjes doet als je kleurcodes in de lijnen verwerkt.	- Opdracht 1: de robot een supermarktparcours laten afleggen - Opdracht 2: een stapje ingewikkelder (obstakels, naar de kassa, etc.)	**Tijd:** Opdracht 1: 30 minuten Opdracht 2: 30 minuten **Nodig:** - Leerlingkaarten Thema 2 - Ozobot of Beebot (1 per tweetal) - Ozobot-viltstiften - Tekenpapier - Supermarktplattegrond (gemaakt door de leerlingen in de vorige les)
Thema 3: Uitdagingen voor de Ozobot	Leerlingen leren de Ozobot zo te programmeren dat hij kan reageren op allerlei verschillende situaties in de supermarkt, zoals naar een medewerker gaan als een product op is.	Een serie kleine opdrachten die leerlingen in tweetallen kunnen uitwerken	**Tijd:** 60 minuten **Nodig:** - Leerlingkaarten Thema 3 - Ozobot (1 per tweetal) - Supermarktplattegrond - Ozobot-viltstiften - Tekenpapier
Thema 4: Zelf uitdagingen verzinnen	Leerlingen bedenken aan de hand van voorbeelden zelf situaties waarvoor de Ozobot geprogrammeerd moet worden en leggen deze aan elkaar voor.	- Opdracht 1: leerlingen bedenken in tweetallen scenario's die ze aan andere tweetallen voorleggen - Opdracht 2: de overstap naar 3D. Leerlingen kunnen een parcours uitzetten met blokken en daarop de opdrachtkaarten uitvoeren.	**Tijd:** Opdracht 1: 30 minuten Opdracht 2: 30 minuten **Nodig:** - Leerlingkaarten Thema 4 - Digibord - Ozobot (1 per tweetal) - Supermarktplattegrond - Ozobot-viltstiften - Tekenpapier - Blokken

In the *fifth* theme, Lego Mindstorms is introduced, including an introduction in programming in Scratch. They receive a pre-assembled Lego Mindstorms robot that is able to do the same things as Ozobot (for example, it has a colour sensor that can be programmed to react to changes in the observed colour). The children learn to program the robot in Scratch (see

Figure 1) to run the track and also to react to obstacles. This requires 'if … then …' reasoning and applying this thinking skill to use sensor input as a condition for actuator output.

Figure 4 Programming the robot to follow a black line



In the *sixth* theme, the children learn to program the robot to cope with various challenging situations, such as searching for an employee, finding a certain product, avoiding other customers (other robots) in the lane.

Figure 5 Lego Mindstorms robot

To provide additional structure for the children, we created task cards that the children could consult at will. This is an approach that was used already in the special education school for children with ASD. An example is provided in Figure 6.

Figure 6 Task card

Leerlingkaart - Thema 4: Zelf challenges verzinnen - Opdrachtkaart 1

Opdracht

In deze opdracht gaan jullie net als vorige keer de robot door de supermarkt sturen om alle boodschappen van het lijstje te vinden. De vorige keer kwam de robot in allerlei lastige situaties terecht, zoals dat er obstakels op het parcours waren of dat producten op waren. Nu mogen jullie zelf challenges bedenken! Bedenk samen 3 challenges voor een ander tweetal. Voer daarna de challenges uit die een ander tweetal voor jullie heeft bedacht.

Nodig:

- Ozobot (1 per tweetal)
- Ozobot-viltstiften
- Tekenpapier
- Potlood

Hebben jullie er moeite mee om nieuwe uitdagingen te verzinnen? Bekijk dan nog eens de challenges die jullie tijdens thema 3 kregen. Ze staan hieronder. Misschien komen jullie dan op ideeën!

Challenges uit thema 3

- Ojee, de stapel wc-papier is omgevallen! Laat de Ozobot omdraaien en een nieuwe route vinden.
- De cola is verplaatst en staat op een andere plek. Verplaats het cola-plaatje en maak een nieuwe route.
- Je staat in de rij voor de kassa, maar de kassa gaat sluiten. Ga naar een nieuwe kassa.
- De bananen zijn op. Ga op zoek naar de winkelmedewerker om te vragen of er nog meer bananen zijn.
- De supermarkt gaat bijna sluiten! Ga extra snel richting de kassa.
- De vloer van de zuivelafdeling is gedweild en je kunt er niet overheen lopen. Vind een nieuwe route.
- Een winkelwagentje blokkeert het pad dat jij wilt nemen. Vind een nieuwe route.

After several covid-related interruptions, we were finally able to execute the lesson series in all three schools and collect observational data.

Determining the development of robotics skills

The lesson series form a context to answer the third and fourth research questions:

> How, and with which instruments, and with which accuracy can the development of technological and social skills be determined?

> Which factors (such as characteristics of the teacher, characteristics of the children, characteristics of teacher-student interaction, characteristics of cooperation with other children; frequency of activities) influence learning outcomes with respect to social and technological skills?

In our original plan, we thought it would be possible to measure the development of technological skills.

However, we were not quite able to achieve this goal, for three reasons. Firstly, we realized that we were far more interested in the possible development of the social skills. The goal of our study was not that children are enabled to solve any robotic problem, but to acknowledge and use their talents in this area.

Second, in the Dutch primary curriculum, technological skill is not defined in a measurable way. The important core objective (‘Kerndoel 45’) is that “Pupils learn to design, carry out and evaluate solutions for technological problems”. This is a beautiful objective, but without specifying the characteristics of the problems and the solutions it is not possible to evaluate the skills of pupils. Since most primary schools do not assess core objective 45, and many schools still have not implemented teaching technology, there is no agreed upon approach to compare the development of robotic skills in our project to some standard. We discussed some approaches, such as using the Skills Rubric Inquiry and Design (Van Keulen & Slot, 2014), but this required a professional development effort beyond the possibilities of this project. The same holds for the CT Skills model of Amatzidou & Demitriadis (2016), which looked at the outset a promising tool to assess the coding or programming skills of the children.

In line with observations from Techniekpact (2021), we conclude that in primary schools, technology is taught (if at all) in the form of stand-alone activities without clear goals or learning progressions, and this implies that teachers have no repertoire and no experience with assessing technological skills. We could not find the time in this project to develop the technological knowledge and skills of the teachers to the level needed to assess their children’s development.

Third, we had overestimated the possibilities to integrate designing and constructing the robot in the tasks and the activities. We piloted one robotic system (Mechanoid) that includes construction options, but it proved too complicated for both children and teachers.

Lego Mindstorms has some construction options, such as choosing and positioning sensors, and in the pilot phase we noticed that several children tinkered successfully with that. The lesson series therefore included tasks to think of challenging situations while shopping in the supermarket and build and program the robot accordingly to face these challenges.

These final Lego Mindstorm tasks were challenging, and too difficult for many children within the time frame of the lesson plan. Since task formulation ('build a robot for your challenge') is very open, ideas and approaches were quite different and difficult to compare or assess in terms of technological competency.

We contented ourselves that in our situation, although many children and most teachers were new to robotics and programming, they seemed to pick up the necessary skills to execute the tasks. Since they devoted several hours to this subject, it is not surprising that their skills improved. All children could handle and programme the Ozobot without problems. Lego Mindstorms was more challenging, but typically the children picked up programming in Scratch quite easily. Programming a 'sense-reason-act' sequence, in which a sensor picks up a signal ('red spot sighted'), which is compared in the computer to a predefined goal condition ('turn right at red spot', resulting in a command for the actuator ('turn left wheel only for 1 second'), was a task that suited many children, although of course not always with perfect results.

Moreover, almost all children enjoyed the activities, and they were far more motivated than usual, as reported by the teachers. One parent, for example, declared that her son normally never wanted to go to school, but when robotics was on the schedule, he insisted to go, even when he was ill (not covid).

We could see a relation between involvement in robotics and collaboration and we concentrated on that, leaving aside the assessment of the development of the skills for robotics. We used task name and task complexity (simple – medium – complex) as the parameters to be scored and correlated with collaboration.

Collaboration

In our set up, the lesson series was executed at three different locations, with different teachers and children. In most tasks there was considerable variation in what the children actually did, making quantification and statistical handling difficult. Conclusions are therefore typically drawn from observations and teacher reports. In an important result is that all teachers were pertinent that children show more collaborative behaviour during robotics, especially when the robotic tasks become challenging.

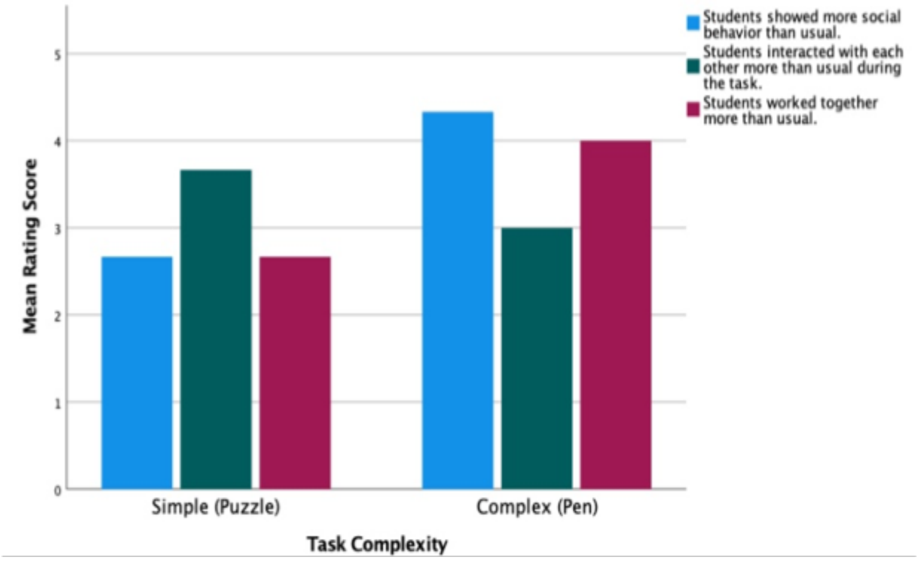
To illustrate this point, in one lesson, 'creating a track for Ozobot', we had teachers compare the interaction in a simple introductory task (using patterned cardboard puzzle pieces to make a map) and the complex task (using Ozobot pens to draw a track for Ozobot to follow).

We analysed the scores of the teachers on the questionnaire, and the results confirm the qualitative observations and statements in logbooks (Figure 7).

Item 1 (Students showed more social behavior than usual) and item 3 (Students worked together more than usual) is scored higher within the complex task, whereas more interaction between participants is perceived during the simple task (Item 2).

This illustrates how the robot functions as a mediator for interaction and social behaviour. The robot draws direct attention away from the peer to the robot, while stimulating joint attention to the task and functional collaboration without enhanced risk of overstimulation.

Figure 7: social behaviour in relation to robotic task complexity



The influence of robotic taks complexity

The data on this sample are not suitable for drawing inferences, such as concluding that complex robotic tasks as such initiate more collaboration among children with ASD. To study the influence of task complexity on collaborative behaviour of children with ASD with more methodological rigour, we singled out one task that was executed in a comparable way, was easy to define in terms of perceived difficulty, and was well within the 'zone of proximal development' of the children, preventing disengagement and guaranteeing task completion. The task selected was therefore one of the first tasks of the lesson series: 'creating a track for the Beebot'. This task was specified in three activities or challenges, with different levels of complexity.

A teacher at each school instructed and supervised the task. Three or four different groups per school with two to three different children each engaged in the task. We used video material of four groups with a total of n=11 students, ranging from age 8 to 13 (*M*=10.64, *SD*=1.36, 7 boys and 4 girls).

All videos were shortened to a uniform length of eight minutes by removing the teachers' initial instructions and sampling the next eight minutes. The observations were coded with MAXQDA (VERBI Software, 2019).

During the simple challenge (Task 1) children were instructed to create a path for the robot to follow using cards displaying arrows pointing in varying directions. Thereafter, the robot had to be programmed in such a way, that it would follow the previously assembled path. See Figure 8 for a screenshot of this challenge.

Figure 8 Screenshot of video recording from challenge 1

In the challenge of medium difficulty (Task 2) the track was to be assembled using coloured papers. These were to be placed on the floor, creating a pathway for the robot to follow after correct programming (Figure 9).

Ultimately, the complex challenge (Task 3) asked the children to create their track with the help of long wooden blocks ('Kapla'). Children had to build the frame of their track with the blocks, respecting the movement distance of 15 cm typical of Beebot for forward commands. To do this, they made use of rulers and measured the 15 cm distances in their track beforehand, to prevent the robot from moving out of bounds (Figure 10). The teacher clarified each of these tasks before the groups began.

Figure 9 Screenshot of video recording from challenge 2

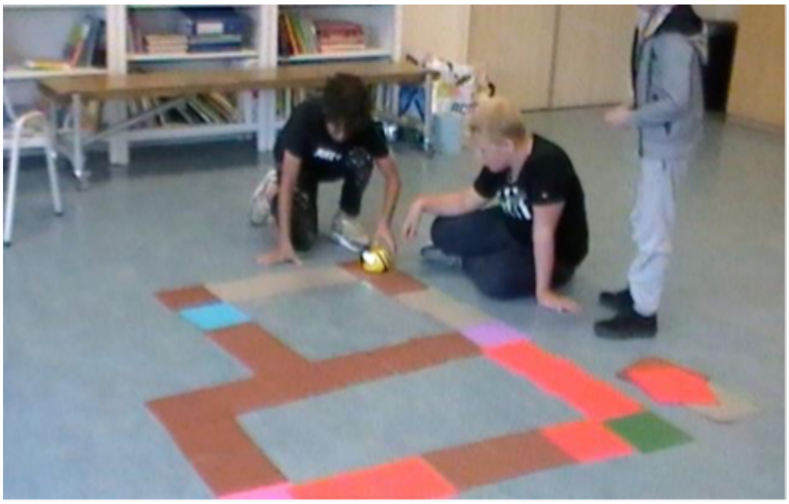
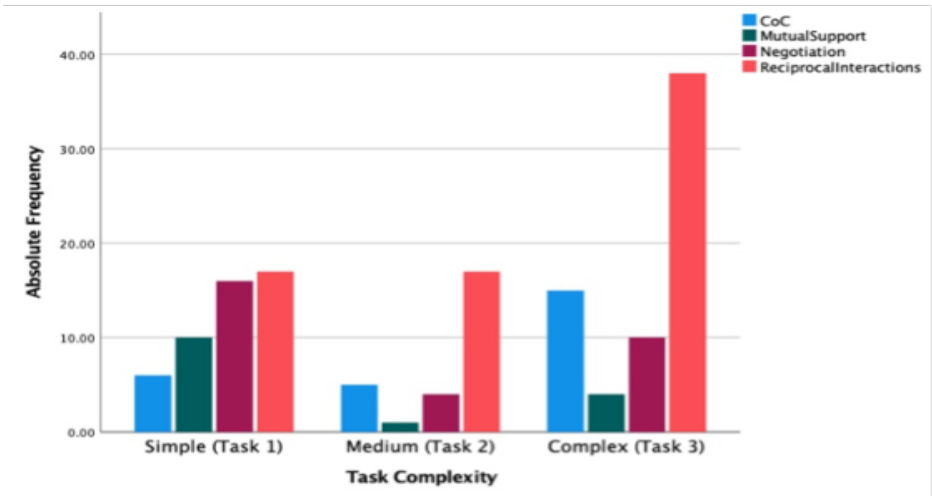


Figure 10 Screenshot of video recording from challenge 3

Within each challenge, the number of circles of communication was counted and the indicators 'mutual support', 'negotiation' and 'reciprocal interactions' were scored. We averaged the frequencies of collaborative behaviours for each challenge. The results are shown in Figure 11.

Figure 11 Frequency of collaborative behaviour in relation to task complexity



As can be seen, the number of circles of communication is highest in the complex challenge. Verbal negotiation is higher in the simple challenge; when things get more complicated children shift their attention to the robot, but the attempts to interact (the number of verbal and non-verbal actions that are reciprocal (nodding; performing the action the other child suggests) rises, correlating with the rising number of the circles of communication. Children cooperate without looking at each other and remain in joined attention to the challenge for a considerable time.

Due to the small sample size and each task being conducted only once, the collected data is not very suitable to carry out statistical testing. Our most convincing evidence is what the participating teachers remarked in logbooks, professional learning communities and interviews. We include several quotes in Figure 12.

Figure 12 Quotes of teachers

Role of the teacher

In our literature study we found studies stressing the role of teachers' support for initiating and implementing robots in the school's program (e.g., Karim *et al*., 2015). It is important that the technology fulfills both teachers' and students' needs. Teachers need a rationale for teaching robotics. Without connections to specific learning objectives teachers likely see robotics as an extracurricular activity, without obligations and a sense of direction (Kopcha *et al*., 2017). Teachers' pedagogic repertoire to scaffold students' explorations is important for successful implementation of robotics in the curriculum (Slangen, 2016). Teachers appreciate guidance when integrating robotics education into the curriculum and are more engaged when they are involved in designing the intervention to teacher-perceived student needs (Anwar *et al*., 2019). Although the role of the teacher is imperative, the characteristics of the school, such as engagement of principals and facilities, are also predictive of successful integration of robots in schools (Davies, 2010).
Research shows that developing skills in children with ASD through participation in activities with robots and more complex activities, such as programming, substantially depends on encouragement and a step-by-step instruction and guidance by a teacher throughout robot-assisted activities (Knight *et al*., 2019; Robins *et al*., 2004; Chambers *et al*., 2008). Some studies warn that without guidance of an adult, students with ASD run the risk that their skills may in fact deteriorate, especially among those with greater difficulties to interact with peers and with problems in emotion regulation (Desideri *et al*., 2018).

We observed teachers during the lessons when instructing and when interacting with the children, discussed observations and experiences, gathered learner reports, wrote minutes of the meetings of the professional learning communities, and analyzed these data to answer the research questions (5 and 6) on teachers and schools:

> 5. What do primary special education teachers need to become competent with respect to teaching robotics, especially to children with ASD, such as support with content knowledge, self- efficacy, educational design skills, inquiry and design-based teaching skills, observation, and interaction skills?
>
> 6. How can educational activities with robotics be aligned and implemented in the regular curriculum of special and regular primary education, so as to contribute to a learning progression for technological and social skills?

Our empirical findings confirm the literature and our expectations. Teachers play a decisive role and through participating in the piloting and discussing observations and experiences did they developed ownership and self-efficacy. We were fortunate that all participating teachers were positive and often enthusiastic about robotics and were eager to explore the possibilities for enhancing social skills. Developing social skills is a key attainment target in special education for children with ASD, so this partly explains their initial commitment.

Because of Covid, we had several setbacks which hampered the analysis of the role of the teacher. As we had planned, we gathered general information on the teachers. At the beginning, we assessed the teachers' attitudes towards technology with a translated version of the STEBI-B questionnaire and the DAS (the Dimensions of Attitudes towards Science questionnaire, Van Aalderen-Smeets et al., 2013), as we had planned to do. However, not one of the teachers we started with was still part of the project when we finished, so the development of their attitudes and skills in relation to other characteristics could not be investigated as we had planned to do. What teachers stated that they needed most was on the one hand emotional and practical support from the side of the management of their organization, which they received. On the other hand, they appreciated expert suggestions and ideas on robotic activities, such as the suggestion to frame the lesson series on simulating shopping at a supermarket and programming tracks and challenges on a 2D map and elaborating the map with 3D props. They needed help with programming in Scratch for Lego Mindstorms, but Ozobot was never a problem.

With respect to research question 6, on broader implementation, we are quite optimistic of the possibilities. As planned, we produced the lesson series 'Samen leren programmeren' (Figure 13) and presented the project in a closing symposium, in September 2022. This symposium drew participants from primary and secondary education, and from special and regular education, who shared our view.

Figure 13 Lessen series 'Samen leren programmeren'

In regular education, developing social skills is not a 'subject', and must therefore be integrated. Learning outcomes often remain implicit and unknown. The concept of the circle of communication was greeted with enthusiasm. Participants from special education welcomed the approach in which the talents (for robotics) of children with ASD are central, and not their problems. After the symposium, participants received the latest product of the project, a practical booklet (Figure 14) in magazine and pdf format, 'RoboWijs en sociaal vaardig worden, hoe doe je dat? – Praktijkboek voor de basisschoolleerkracht' (Van Keulen et al., 2022). All products are now available at the website of the project: https://www.techyourfuture.nl/kennis-uit-onderzoek-robowijs.

Figure 14 'Praktijkboek voor de basisschoolleerkracht

Discussion

The goal of this project was to find out whether children with ASD can benefit from robotics, for the development of their skills for technology, and for development of their social skills. We wanted to investigate this question in a regular classroom setting and not under circumstances that are applied in therapeutic settings. In this way, we elaborated on the talents that children with ASD reportedly have, namely that they are good in computational thinking, programming, and working with computers and robots.

The project was explorative in nature. We needed to try out many things and observe the children in their classrooms. This can only be done on a relatively small scale. We found ecological validity (regular classroom conditions and teachers as co-creators) of more importance than strictly controlling all variables that may influence processes and outcomes. This study therefore is not an 'intervention' investigated for its effectiveness, but rather a 'proof of concept' study.

We think that we shown that the concept (enhancing social skills through robotics) works for children with ASD. Results show that the tasks of this study elicit collaboration between children. We saw, and teachers confirmed this observation, that children collaborate during robotic activities, and, according to the teachers, the children do this more often, more sustained, and with more children, than usual. We draw the conclusion that robotic tasks positively affect collaborative behavior of children with ASD.

Our study highlights the importance of creating tasks that afford collaborative behavior by stimulating joint attention to material at hand that pose problems that children can solve. The robot works as a mediator: it draws sustained attention and possibly prevents overstimulation. Children focus on the behaviour of robot on the track and they can communicate on this without needing to look at each other.

It can also be inferred that a good task structure itself predestines a certain degree of collaboration, since if children only have one robot at hand they are required to interact and negotiate to complete their task. According to the teachers, several children were able to collaborate with more children (two or three, instead of working individually or in pairs) than usual during the robotic tasks. They might have preferred working individually with the robot, but we infer that their motivation for the robot helped them overcome this tendency to avoid social interaction. Future research could investigate the association between group size and collaborative behavior of children with ASD.

With this, we recommend that collaborative tasks are structured with limited options for individual work, to avoid situations where children will complete tasks individually. This might be done by reducing the number of materials children are supplied with, and by scaffolding the children towards joint execution. The task cards we provided might be of help, since reading the card and reflecting on what to do allows children to disengage for a moment from social interaction and resume with new ideas.

The overall robot acceptance and motivation during the tasks in this study are consistent with the theory of systemization, which explains the preference and talent towards robots in terms of their repeatability and predictability (Baron Cohen 2009).

The counting of circles of communication is already a good and established approach, however the specification of the variables and indicators that together create complex and concepts such as 'collaboration' should receive more attention since these constructs are fuzzy and overlapping and are dififcult to score unambiguously. It is especially challenging to interpret non-verbal signals as reciprocal interaction and as acknowleding.

We observed that the complexity of the robotic task influences that number of circles of communication. Complexity, however, is not an objective characteristic of a task, but is confounded by experience, and pre-knowledge within the child, and by instructional activities from the teacher. Through intensive piloting, we were able to design a lesson series that suited the 'zones of proximal development' of both the children and the teachers. We think this explains the success to a good deal, but this also means that lesson series cannot be 'thrown over the hedge' without a good deal of professional development and information about the school context. The teacher is important, the teacher support structure is important, and educational outcomes are relative to this context and vary with the parameters that define this context. We have as yet no idea between which bounds outcomes will vary, or should be allowed to vary. This would be an interesting theme for further investigations.

In the time we did the project (2019-2022), more robotic systems have been designed, such as the 'Mirte' robot from the Robotics Department of the Faculty of Mechanical, Maritime and Materials Engineering of Delft University of Technology. We would have loved using this robot instead of Lego Mindstorms, because it also robust, but it is cheaper, affords adding sensors and actuators more easily, and can be programmed both with an easy icon language (Blockly, which is comparable to Scratch) and with Python, which is more advanced, allowing children to take up a next level challenge and building a pathway to programming tasks in secondary education. As reported, we did not push on investigating the development of skills for technology and robotics, partly because the robotic system affordable to schools do not afford much design and constructing, and a benchmark for these skills is absent. It is no surprise that children improved their skills for computational thinking and programming: this is mainly an effect of time on task. So here is another question for future research: what can we expect from children when it comes to designing, building, and programming robots, and which attainment targets and core objectives with respect to digital literacy and computer skills should become a mandatory part of the national curriculum?

Due to the lack of continuity caused by the Covid pandemic, the small number of participants, and the absence of a control or retrial group, this study has limitation with respect to drawing conclusions on the effectiveness of robotic tasks for stimulating the development of social skills in children with ASD, or in children in general. We draw our conclusions from observations of situations that are ecologically valid but difficult to control and reproduce, and on the reports and reflections of teachers that are representative but also unique. We think there is 'descriptive evidence' for this approach, which remains to be confirmed through controlled interventions with a larger number of participants. We were unable to reach this stage in our project. A controlled intervention could compare collaboration in terms of the number of communication circles between various conditions, such as a robotic collaboration task followed by another social collaboration task, compared to a control group that was not previously exposed to the robotic task.

We would like to end this reflection by thanking all participants (children, teachers, school principals and support staff), TechYourFuture for its support, and the staff at NRO for showing consideration with our Covid-related problems and allowing us more time to finish the project. We hope that we have contributed to the long-term goals of Dutch educational research.

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