

Research Article

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Kaspar in the wild: Experiences from deploying a small humanoid robot in a nursery school for children with autism

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Abstract: This article describes a long-term study evaluating the use of the humanoid robot Kaspar in a specialist nursery for children with autism. The robot was used as a tool in the hands of teachers or volunteers, in the absence of the research team on-site. On average each child spent 16.53 months in the study. Staff and volunteers at the nursery were trained in using Kaspar and were using it in their day-to-day activities in the nursery. Our study combines an “in the wild” approach with a rigorous approach of collecting and including users’ feedback during an iterative evaluation and design cycle of the robot. This article focuses on the design of the study and the results from several interviews with the robot’s users. We also show results from the children’s developmental assessments by the teachers prior to and after the study. Results suggest a marked beneficial effect for the children from interacting with Kaspar. We highlight the challenges of transferring experimental technologies like Kaspar from a research setting into everyday practice in general and making it part of the day-to-day running of a nursery school in particular. Feedback from users led subsequently to many changes being made to Kaspar’s hardware and software. This type of invaluable feedback can only be gained in such long-term field studies.

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1 Introduction

For someone involved in the meticulous process of designing, building, implementing and testing a set of complex technologies, like those involved in developing a humanoid robot, the thought of “releasing it into the wild” can be a challenging one on many different levels. Away from the safe confines of the controlled environment of its laboratory, the robot may face situations that its creators could never have anticipated. This could possibly lead to breakdowns, which could cost hours and days of work for lengthy repairs and rebuilds. Without the watchful eye of someone who has in-depth knowledge of its capabilities, it might end up scaring or (in extreme cases) hurting someone. Finally, it might not be able to do what it was designed to do and might end up on the scrapheap of good ideas that ultimately were not feasible in practice.

Despite this, the release of a robot into the environment that it, or its technological “descendants”, will eventually be expected to operate is a crucial stage in creating an application. After all, how else can it become useful to real users in the real settings? It also allows researchers to verify whether the system works and to see how it can be improved. Throughout the process, from the initial preparations to the final summative evaluations, the experiences of the researchers, the technologies and the end users are a rich source of insight that can be used to improve the system being developed as well as its application.

This article describes the process, challenges and findings from embedding the humanoid robot Kaspar in a nursery specialising in autism and related conditions. Kaspar is a mature research platform specifically developed for interaction studies for children with *autism spectrum conditions* (ASCs).¹

¹ Note that we are using the increasingly prevalent term of ASC rather than ASD (autism spectrum disorder) in this article in order to be inclusive and avoid stigmatisation [1,2].

Baron-Cohen *et al.* [3] estimate that around 1–2% of primary schoolchildren in the UK might be diagnosed with ASC. They note that the number of diagnoses has increased dramatically in the last 30 years, and this has led to a strong interest in these conditions and how they can be addressed across different disciplines. Following this line of research, the work described in this article is part of an ongoing effort to investigate the use of robots for children with ASC.

This article is structured as follows. The remainder of Section 1 discusses the background to this research. Section 2 discusses the difficulties one faces when measuring technology acceptance in the wild, followed by our approach to addressing these. Section 3 presents our research questions, followed by our study methodology in Section 4. Results are presented in Section 5, including interviews with staff (users) and data collected on the children's developmental journey. We discuss the results in Section 6 and highlight challenges, limitations of the study and future work in Section 7. Section 8 provides the overall conclusion.

1.1 Autism

ASCs are a set of diverse and heterogeneous lifelong developmental conditions which according to the international statistical classification of diseases and related health problems, 10th revision (ICD-10) and diagnostic and statistical manual of mental disorders (DSM-5) are characterised by *the presence of social and communication difficulties, as well as strong and narrow interests and/or repetitive and stereotypical behaviour* [4,5]. These characteristics may be caused by what is often described by scholars in the field as the triad of impairments: impaired social interaction, social communication and social imagination [6].

A child growing up with autism may experience greater difficulties in interpreting intentions, facial expressions and emotional responses than their peers of the same age. Likewise, children with autism often find verbal and non-verbal communication, including eye contact, more difficult [7]. It is also common for children with autism to have difficulties with language.

These difficulties will in turn impair their ability to interact with and maintain social relationships with their peers [8] as well as reduce their enjoyment of social and collaborative play. This means that this group of children is more likely to engage in solitary play [9]. While solitary play has many merits [10], the lack of social and collaborative play may to some extent rob

these children of the rich experiences and enjoyment other children gain from social play. This may further impair the development of social skills and abilities that they will need in the future interactions. About 20 years ago, it was proposed to use robots for the possible therapy and education of children with ASC, in order to facilitate social and collaborative play and communication with, and among children with ASC [11]. Since then, we have seen extensive research efforts in the international research community studying robot-assisted play for children with autism.

1.2 Using robots for children with autism

The use of robots for therapeutic interactions to address ASC issues has been a rich field of inquiry since the late 1990s, with many research platforms being developed and tested [12–14]. Researchers have examined the efficacy of using robots as socially assistive aides [15], facilitating interactions between children with ASC and teachers, therapists, parents and other carers.

Many different types of robots have been used by various research groups to engage autistic children in playful interactions, e.g. creature-like or cartoon-like robots such as Keepon and Probo, artificial pets such as the pet dinosaur Pleo or mobile robots such as IROMEC or Labo-1 (cf. [16] for a mapping of different robots to therapy and educational objectives for children with autism). Specifically relevant to our work is research using humanoid robots such as Nao [17,18], Zeno [19,20], the robotic doll Robota [21], the robot Charlie [22] and the child-like robot Kaspar [23].

Those robots were designed to engage people in social interactions stimulated by the physical, emotional and behavioural affordances of the robot. International collaboration in many projects were funded by the European Union (EU) as well as by the national authorities (e.g. socially competent robots (SoCoRo), De-Enigma, development of robot-enhanced therapy for children with autism spectrum disorders (DREAM) or Babyrobot) to further develop the technology and investigate the possible use of robots as therapeutic or educational tools for autism interventions. The SoCoRo project, funded by Engineering and Physical Sciences Research Council, UK, aimed to develop a robot with socially expressive behaviour that can function as a training device for high-functioning adults with autism and help them improve their ability to recognise social signals [24]. Using the Zeno robot, the project De-Enigma developed a robot-based system that is context sensitive with

naturalistic human-robot interaction (HRI) aimed at enhancing the social imagination skills of children with autism [25]. The DREAM project, using the NAO and PROBO robots, aimed at developing clinical interactive capacities for supervised autonomy therapeutic robots. These robots can operate autonomously for limited periods under the supervision of a therapist [26]. In the H2020 BabyRobot project, researchers used the Zeno, Kaspar and Moogi robots to develop special interventions to improve various key aspects of social communication and social interactions of children with ASC [27]. These robots have been used in research with children with ASC to help develop skills to assist in communication and social interaction, e.g. joint attention, imitation, tactile interaction, emotion recognition, visual perspective taking, etc., and to help and mediate interactions with other people (peers and adults) [28–33].

Despite this intensive research over the past 20 years, a review conducted by Diehl et al. [34] suggests that research in this field is still in its infancy. They argue that while this research field is promising, more research is required, and they also suggest several avenues of research to be pursued. One of these is more careful attention to the *therapeutic* context and protocol. They highlight that the “state-of-the-art” context of use, where a robotics expert is controlling and maintaining the robot *in situ* while an educationalist/therapist is conducting the session, is not viable.

The work described in this article is an attempt to address part of this need by moving an experimental research prototype into an established educational setting. Adapting the robot itself for use by carers, and therapists, as well as examining how the insertion of this technology into such settings can be achieved, is an important cornerstone. This work aims to broaden the research into the clinical and educational use of robots for children by examining how a research platform can be adapted for and deployed into these settings.



Figure 1: The Kaspar robot.

1.3 Kaspar

Kaspar has been used in many HRI studies with children with autism and with encouraging results (Figures 1, 2). Results have shown how the robot can be used to elicit body awareness and appropriate physical interaction in children with autism [35]. Sets of play scenarios for robot-assisted play for children with autism have been developed as a guide for teachers and other users of Kaspar [36–38], which are mapped against specific therapeutic and educational objectives.

Prior research has shown that Kaspar can facilitate collaborative play in children with autism [39], including a long-term study involving pairs of children with autism [40]. Interactions with children with autism have led to rich data that have been analysed from a conversation-analytic perspective [41]. An independent research team

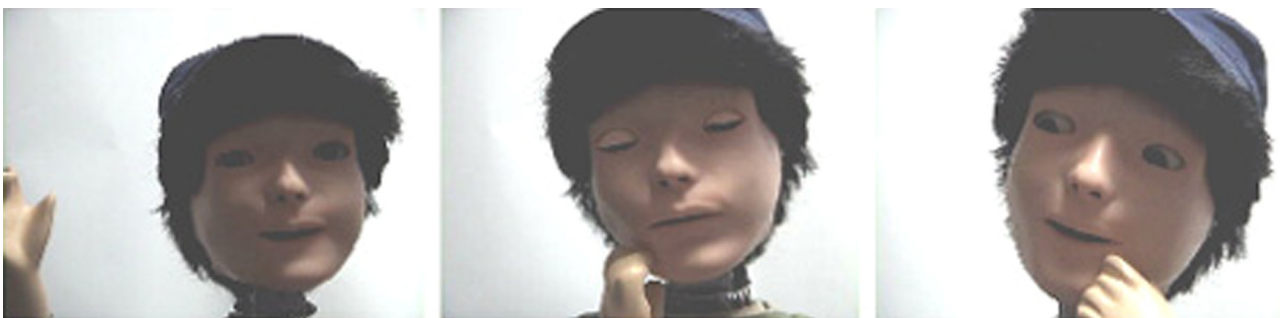


Figure 2: Some of Kaspar’s expressions.

interviewed 54 ASC practitioners and found that they are convinced that Kaspar can be useful in interventions for a broad range of therapeutic and educational goals. Specifically, they expect Kaspar to contribute to ASC objectives such as “communication”, “social/interpersonal interaction and relations”, “play”, “emotional well-being” and “preschool skills” [42].

Apart from studies on robot-assisted therapy for children with autism, Kaspar has also been used in scenarios of robot-mediated interviews with children, where it served as a mediator between the child to be interviewed and the human interviewer [43]. Kaspar has been shown to be a useful tool in these studies, which encourages us to take the next step and move it into the “wild”.

2 In the wild

Although studying robots in the wild is challenging, it is essential to the research of HRI. Sabanovic *et al.* demonstrate how robot design features that were appropriate for specific laboratory-based studies are not always transferable to a real-world setting [44]. For example, when detecting the arrival of a human in its environment, turning towards the human and initiating an interaction makes perfect sense in a laboratory study, but if the same behaviour is introduced in a busy reception it will lead to the humans working in or visiting the site needlessly, getting hassled by the robot.

Salter *et al.* [45] also found that testing their prototype in the wild was a source of insight, highlighting the spontaneous nature of such interactions when they occur in environments that are less constrained. Another insight gained is that of a heightened understanding of situational context. Even when the actual interaction is close to the interaction one would have in a lab, not adapting appropriately to the constraints in the setting itself may cause additional problems.

Prior work describes some of the challenges facing HRI researchers when attempting to use a humanoid robot to interact with children with diabetes in order to encourage healthy behaviours in a hospital setting [44]. The researchers found that even though the interaction situation itself may be controlled, the wider organisational context with its schedules and demands would often make it difficult to fit the interaction into the existing treatment schedules of the child.

These findings support the notion put forward by Sabanovic *et al.*: Prototyping in HRI need to “*address the emergent situated interaction dynamics between people and robots in specific contexts of use*” [47]. In order for us to achieve this with Kaspar, inserting it into the day-to-

day running in a nursery for children with ASC means that not only is the immediate use of Kaspar not mediated by members of the research team, but also it is subject to the scheduling and other time and space management decisions made by the staff at the nursery.

Note that our use of the term “in the wild” has been inspired by research in anthropology, e.g. Edwin Hutchins’s seminal book “*cognition the wild*”, which argued that cognition not only lies within the individual but is situated in the individual’s social, physical and cultural environment [48]. The study of distributed cognition thus requires to go outside the laboratory and employ methods relevant to and applicable to this context. Recently, the term “research in the wild” is used more broadly for *in situ* research in human-computer interaction and HRI, focusing on activities in real-life settings [49]. In the present work, it means to study the use of a robot in its naturalistic setting and envisaged use case (i.e. robot-assisted therapy and education for children with autism) without the presence of researchers and providing in-depth analysis of rich data derived from a small sample size. Such studies are intended to complement laboratory and researcher-led studies that are conducted under more constrained conditions and are guided by precise hypotheses.

2.1 Acceptance of Kaspar as technology

The availability of Kaspar meant that the staff themselves could choose how to incorporate the robot into the sessions they had with the children, how often they did this and how long the interaction sessions would last. While the “wildness” of these interactions may not be that easy to categorise in terms of Salter *et al.*’s [50] taxonomy, all aspects of the interactions that staff and children had with the robot were outside of the direct control of the researchers. Without the direct mediation of the research team, the use of the Kaspar robot in this setting to a large extent depended on *user acceptance* of the robot among the staff and children at the nursery.

2.2 Davis’ technology acceptance model (TAM)

While this article is not a formal application or validation of a specific TAM, the work described here draws heavily from this field of study. The classical TAM framework was advanced by Davis [51] who suggests that while the benefits of using a given technology is important, the ease of getting these benefits for the user is also an important factor. Because of this, Davis’ model sees the acceptance of technology as a function of *perceived usefulness* and *ease of use*. Later

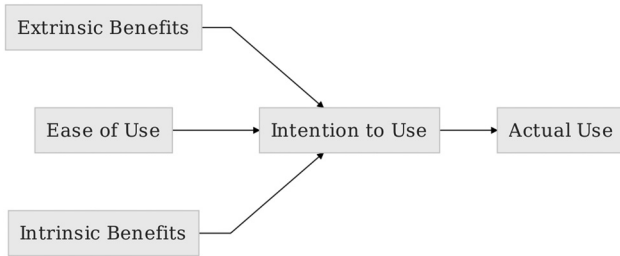


Figure 3: Technology acceptance model.

iterations of Davis’ model [52] saw the addition of motivation theory, which while considering the extrinsic motivations such as the usefulness of the system, allowed for the *intrinsic* motivations for the use of a system, such as the *enjoyment* that it gives its prospective users. This model is described graphically in Figure 3 and explained in more detail in Table 1.

Later work on technology acceptance has expanded into more complex and comprehensive models. Venkatesh et al. [53] condense these into the unified theory of acceptance and use of technology (UTAUT) model. This model incorporates demographics, such as age, gender and experience, as well as social influences and external conditions within the usage setting that may impact the use of the technologies. These models, however, are conceived and tested as complex quantitative constructs and as such need to rely on large samples. Because of this, we used the less complex model described in Figure 3 and Table 1 as our main reference for attempting to understand the acceptance of Kaspar as a technology by the individual members of the nursery.

Some work in human-centred research has critically commented on the need to investigate further which aspects of TAMs could actually predict technology accepted [54]. They argue for a shift from focusing on mere technological acceptance and usability to emphasising on how technology could enrich a user’s life. For example, De Graaf and Ben Allouch stressed that both utilitarian and hedonic factors are important in users’ acceptance of social robots [55]. However, such more complex approaches

towards assessing user experience and acceptance were not practical in the present field study.

2.3 TAM as applied to organisations

An *individual* approach, as Davis’, may serve to explain some of the reasons individual practitioners may or may not choose to use Kaspar as a technological aide. However, when trying to explore the possible adoption of this robot in similar settings, one needs also to consider the larger context of the adoption of this complex piece of robotic technology within the organisation of the nursery as a whole.

Leonard-Barton and Deschamps [56] suggest that the intention to use, as well as subsequent use, is based on the interplay of individual, managerial and organisational-cultural factors, and that the use of novel technologies should be understood as a *diffusion* of decisions made at different levels of the organisation. Only some of these decisions are strategic decisions made by management. These decisions do to some extent determine the (at least expressed) intention to use, but the actual use of a given technology is often determined by the individual members of the organisation themselves as they engage with it on a day-to-day basis.

Even if the use of a specific technological tool is mandated by the governing bodies and individuals of an organisation, it still may not be adopted in the long run [57]. Therefore, it is important for us to understand how the use of Kaspar impacted the running of the nursery as an organisation and how the greater structure of the nursery impacted the usage of the robot.

3 Research questions

To explore the above-mentioned issues, we specified the following research questions:

Table 1: Davis’ TAM

Aspect	Explanation	Examples for Kaspar
Extrinsic benefits	Benefits that exist outside the use situation itself	Therapeutic and educational outcomes
Intrinsic benefits	Benefits that exist within the use situation	Enjoyment, interaction quality
Ease of use	How much effort is needed to get the extrinsic and intrinsic benefits	Difficulty in setting up, technical challenges
Intention to use	Whether the user would choose to use the artefact if they were free to choose	Belief that the use of Kaspar is a valid use of time. Planning to use Kaspar
Actual use	Whether the artefact is used by the user in the appropriate situation	Fitting Kaspar into the day-to-day schedule of the nursery

1. Extrinsic benefits
 - (a) Do the users of the robot feel that the use of the robot is benefiting the children?
 - (b) Can such benefits be quantified?
2. Intrinsic benefits
 - (a) Do the users enjoy using Kaspar as a technology?
 - (b) Are the interactions that the users have with the children enjoyable when they are mediated by Kaspar?
3. Ease of use
 - (a) What made the robot easy to use, and what caused problems?
 - (b) How much support from the research team will non-technical² users of Kaspar need?
4. Intention to use
 - (a) Did the users want to use Kaspar?
5. Actual use
 - (a) How did the intention to use Kaspar translate into actual use?

4 Methodology

4.1 The robot

This section is intended to give the reader an introduction to the robotic platform Kaspar and its use. For a detailed description of Kaspar and the considerations in its initial design, please refer to Dautenhahn *et al.* [58] and Wood *et al.* [59].

4.1.1 Introduction to Kaspar

Kaspar is a child-sized interactive, humanoid robot (Figure 1) created to help teachers, parents and other carers support children with autism. It has realistic human-like but very much simplified features. It has an expressive face and can move its arms and head in order to make human-like gestures and signal attention. These capabilities allow it to be used as a social mediator, mediating interactions between a child with autism and another person engaged in the interaction with Kaspar in different play scenarios.

² By non-technical, we mean that this user group's main expertise does not lie in the use of complex computational artefacts such as robots.

4.1.2 Technical specifications

Kaspar can show a variety of different movements and expressions based on its 17 degrees of freedom (Table 2).

4.1.2.1 Sensors

Kaspar has two types of sensors, two cameras (mounted in each "eye") and a set of *tactile sensors*. The tactile sensors are intended to give the robot the capability of responding directly and autonomously to being touched and are attached to the robot's hands, feet, chest, arms and face.

4.1.2.2 Speech

Kaspar can produce pre-recorded speech and music (words, sentences and songs) to engage children in play and provide feedback to the children about their actions. Many of the children we have worked with as part of our research in special needs schools either are non-verbal or use speech in a very restricted manner. Thus, there were no interaction scenarios that require the robot to understand speech in this study.

4.1.2.3 Robot controls

There are several ways that Kaspar can be controlled, and this depends on the interaction scenarios that Kaspar is being used for. For instance, if the scenario is focused on exploring the robot and its expressions and behaviour, e.g. as part of an imitation game, the robot can be directly controlled by the child, or in some instances, two or more children, using a remote control or a computer. An adult can also use a remote control in order to provide specific robot behaviours to facilitate interaction or meet specific pedagogic goals. In addition, the robot can operate autonomously for specific play scenarios [38]. A hybrid mode, allowing the robot's autonomous behaviour to be interrupted by specific inputs from the remote control or computer, is also supported. This allows the users to moderate the robot's behaviour. This could be done to compensate for sensors not picking up a child's behaviour, or the adult (teacher/carer) interpreting the intention of the child in a way that would make the robot's autonomous response inappropriate.

4.2 Example play scenarios

We previously documented play scenarios that children with autism can play when they engage with Kaspar [36,37]. Examples are the games that were developed to target tactile interactions, providing autonomous robot responses via its

Table 2: Kaspar’s degrees of freedom

Body part	Degrees of freedom	Details
Arms (each)	4	Two in each shoulder Two in each elbow
Eyes	2	Pan and tilt
Eyelids	1	Ranging from fully open to fully closed. Used for various facial expressions and for blinking
Lips/mouth	2	Mouth open and close, lips up and down. Used for various expressions (e.g. happy and sad) and for “speaking”
Neck	3	Controlling head movements (pan, nod and tilt)
Torso	1	Turning from side to side (possibly to indicate that it has experienced an “unpleasant” interaction)

tactile sensors. For instance, the tactile play scenario “make it smile” is a cause and effect game [37] that involves one child and one adult (teacher, therapist, parent, etc.).

The child will be encouraged to physically explore the robot and its features (e.g. its face, feet, arms, etc.) and the robot will respond autonomously to different types of touch, e.g. raising the left arm when the left hand has been touched, responding with speech (“Ha, Ha, Ha”) when being tickled on the chest or “That’s nice, it tickles me” when tickled on its feet (Figure 4).

The adult can provide additional appropriate feedback via a remote control where different buttons elicit different body movements and/or speech of the robot. The version of Kaspar used at the school was able to distinguish between hard and soft touch (e.g. hitting vs stroking), but in cases where the robot did not respond appropriately, the appropriate feedback could be triggered by the adult (e.g. after a child hit the robot it would turn away, cover its eyes and say “Ouch that hurts”). The adult can then take the opportunity to discuss cause and effect, e.g. asking the child how the robot feels, thus encouraging the child to identify emotional expressions but also to ask the child how he or she can make the robot smile (“happy”) again.

**Figure 4:** A child with autism’s tactile exploration of Kaspar.

This is just one example that the robot can be used as a safe, enjoyable and non-judgemental tool in the hands of teachers, therapists or parents. Hitting another person cannot be tolerated, so children do not usually have the opportunity to calmly reflect on the consequences of their own actions in this situation. However, Kaspar can be used in this way, as it has been made robust enough to encourage tactile interactions with children with autism. Due to its introduction to the children deliberately as a robot and not a child, situations can be practiced that would not be possible with a person.

4.3 Setting

This study was conducted in collaboration with TRACKS autism, an early years centre located in Hertfordshire, UK, specialising in children with complex social and communication conditions, catering to ages from 2 to 6, inclusive. TRACKS supports children with all language abilities, from non-verbal to fully verbal. Children attend TRACKS 1–3 times a week. The centre has a high ratio of specialist staff that includes a specialist teacher, occupational therapist, speech and language therapist, speech therapy assistant and a music therapist. TRACKS operates in a purpose-designed setting, striving for a total communication environment (photographs and symbols are embedded in practices and are available for all activities. Sign-a-long (signing) supports all spoken communication, staff have symbols and photos to support all transitions and objects of reference and environmental cues to support those who do not yet understand visual representations). The facility has main room, specialist smaller rooms, sensory room, ball pool, access to a purpose built, partly covered outside area. The centre is organised around a set of 4-h play sessions. The centre runs five of these sessions a week and each session can accommodate up to ten children.

This nursery has previously allowed the research staff access for interaction studies with Kaspar [37]. This meant that the decision makers at the centre had a clear idea about what they could expect from the robot in terms of technical and interactional capabilities. It also gave them information on what the usage of the robot might entail in terms of resources required as well as how they could benefit from the robot. Note, neither demographic information nor details on the diagnoses of the children who participated in this study were available to the researchers.

4.4 Participants

There were two types of participants in the study:

1. Primary participants
 - Staff at the nursery, teachers and volunteers, also referred to as “users” in this article.
2. Secondary participants
 - Children attending the nursery.

There were four primary participants, three of these were staff who worked with Kaspar and the children, while the fourth primary participant was involved in a more managerial capacity. There were 19 secondary participants (i.e. children attending the nursery).

4.4.1 Recruitment, consent and training

The study was approved by the University of Hertfordshire Science and Technology Ethics Committee with Delegated Authority, under protocol numbers COM/ST/0007 and COM/PG/UH/00061.

Individual members of staff were not recruited by the researchers. Rather, an organisational decision was made by the nursery to participate in the study and use Kaspar. However, in terms of direct data collection by the research team, such as through interviews and questionnaires, it was made clear that participation was voluntary. Prior to the study, staff at the school were already generally familiar with the Kaspar robot as they had observed and sometimes participated in sessions with Kaspar in previous studies that were conducted by researchers at the school.

For this study, which was conducted by the users themselves, the user group received a thorough training on how to operate the robot. The teachers were given a two-layered training by a researcher on how to operate the robot – first a session that explained in more detail the provided user manual (and the safety instructions) accompanied by a demonstration of the robot by the researcher.

The second session was a “hands-on” session with the robot supervised by the researcher, where teachers gained experience on how to operate the robot.

In both sessions, all pre-programmed interaction scenarios were illustrated in detail. Some of these scenarios included generic robot behaviour (e.g. greetings, pre-recorded feedback/confirmation/encouragement, eye-blinking, etc.), and other scenarios were specific game scenarios (e.g. turn taking and imitation, food and eating, body awareness, etc.). Following these two training sessions, the researcher offered their support to the teachers in their first couple of familiarisation sessions with the children. We offered users support throughout the study, in the form of periodical meetings when they wanted to discuss new ideas or receive feedback on their work at the time.

Consent for participation for the individual children was given by their parents and guardians. In order to not tie interaction with Kaspar to participation in the study, there were two tiers of consent. In the first one, the parents or guardians consented to the children interacting with Kaspar, but without the interactions being recorded or any information regarding the child being shared with the research team. The second tier was a consent to participation in the study itself, with information regarding the child’s interaction with the robot being shared with the researchers.

In addition, interactions with Kaspar for the child were on an opt-in basis as part of the child-directed play and learning programme that the nursery provide for the children in their care. Interactions with the robot were one of the several activities that the child might participate in each day, and as such, interactions could not take place without the child wanting to interact with the robot.

4.5 Proposed usage of Kaspar

The robot was provided to the nursery with the intention that it would be used by the nursery as part of their programme of work. While the research team provided the nursery with example scenarios and interactions that had been developed as part of the research conducted by the team, it was made clear that the ultimate decision in how to use Kaspar within the individual interactions with the children would rest with the staff at the nursery.

4.5.1 Frequency

The initial intention was for the members of the nursery to provide the children with the opportunity to interact with the robot in as many sessions as was deemed meaningful within the day-to-day running of the nursery.

4.6 Data collection

There were two strands of data collection which we termed *staff data* and *child data* (see Table 3 for details).

4.6.1 Staff data

The primary source of data for this study is what we term the staff data. These data were collected over the course of four visits to the nursery. The four visits were scheduled, so that they would allow the researchers to meet and talk to the participants at different stages of the deployment of the robot. At each of these visits, researchers would give a questionnaire to the members of staff at the nursery which participated in the study and conduct brief individual interviews. Due to some practicalities, this schedule was not followed strictly and some visits were delayed by up to a few months.

4.6.1.1 Questionnaires

Questionnaires given to the participants consisted of open-ended questions regarding the participants' experience with Kaspar. Responses to the open-ended questions were incorporated into the visit reports.

4.6.1.2 Interviews

The members of the nursery that took part in the project were interviewed by members of the research team individually as part of the visit. The interviews were semi-structured. Each visit used a slightly different schedule. We made an effort to retain enough flexibility in the interviews to let the participants voice their concerns and discuss the aspects of their use of the robot that they felt were the most important, while at the same time let the interview cover the topics that the research team had specific interests in.

After each interview, the researchers would briefly make notes of the most salient parts of the interviews. These notes would be collated later on the same day, and a report regarding the interviews would be prepared within a week. The researchers would then discuss

and amend the notes within a week, as necessary. The discussions in this article are primarily based on the notes and reports from these visits.

The data analysis was goal directed, focusing on obtaining insights that could be used to improve the robot and make its use in the school as smooth as possible.

4.6.2 Child data

In addition to the information that we collected on the interactions, staff at the nursery would complete an assessment questionnaire twice for each child. The initial assessment was conducted as they entered the study and was followed by an assessment at the end of their study. This questionnaire assessed each child along five different domains including *sensory development*, *communication and interaction*, *cognitive development*, *social and emotional development* and *psychomotor development*, with 123 items in total. Each item was scored as N, R, O, F, A and n/a (N = never, R = rarely, O = occasionally, F = frequently, A = always and n/a = not applicable). The evaluation questionnaire was initially developed by the University of Hertfordshire team within a previous EU project, interactive robotic social mediators as companions (IROMECS),³ and it was based on the International Classification of Functioning, Disability and Health for Children and Youth published by the World Health Organization [60].

This questionnaire was further adopted to map against the guidelines published by the UK's education department in their Early Years Foundation Stage publication, which sets the standards for learning, development and care of children from birth to 5 years old. Note that due to the way that the admission of children to the nursery would work, children would enter the study at different times. These assessments were completed on each child as they entered and left the study, and the assessment data were provided to the researchers several months after the conclusion of the interviews (Table 4).

5 Results

Please note that a “*” symbol in Tables 6, 8, 9 and 10 denotes statistically significant results at the $p < 0.05$ level.

Table 3: Data

Data type	Data source
Staff data	Interview notes, questionnaires
Child data	Changes in children's scores on developmental scales

³ URL: <http://www.iromec.org>, accessed 19 February 2020.

Table 4: Original planned visit schedule

Visit	Stage
1st	Pre-deployment
2nd	1 month
3rd	6 months
4th	12 months

5.1 Child data

This analysis shows the changes in responses to the assessment questionnaires that were completed by staff from the nursery for each child in the study. The responses were condensed into five scales, one for each domain, and the analysis was conducted on these scales. Because of the heterogeneous nature of ASC, the use of very broad categories was considered appropriate. While the noise inherent in such scales might mask some of the effects from the robot, the broadness of them might still pick up on wider communalities in how the children developed over the study.

This analysis was conducted to determine the answer to the following questions:

1. Can we distinguish between individuals in the sample in terms of:
 - (a) time spent with Kaspar,
 - (b) initial scores in different scales collected by staff at the beginning of the study.

If the answer to this question is yes, then it means that it is feasible to conduct a subsequent analysis, which will ask these questions:

1. Is there a relationship between time spent with Kaspar and:
 - (a) shifts in the scores,
 - (b) initial scores.

This would allow us to examine whether there was a relationship in the amount of development a child exhibited and the time it had spent with Kaspar during the study. The analysis was conducted using R 3.2.2 [61], with the packages knitr [62], ggplot2 [63] and ppcor [64].

5.1.1 Time spent with Kaspar

See Figure 5 for the distribution of interactions with Kaspar across the sample. The mean number of interactions with the robot per child was 27.37 and the standard deviation was 18.62. The distribution did not significantly deviate from a standard distribution (Shapiro-Wilk's $W = 0.92$, $p = 0.127$).

This suggests that the sample did vary in terms of how much interaction they had with Kaspar, and that the differences in interactions with Kaspar can be used as a measure in a correlational analysis in which changes in the measures could be related to the number of sessions that the children had with the robot. However, the absolute time in which the children took part in the study also varied.

There were also differences within the sample in terms of the actual period in which they took part in the study as shown in Figure 5. The mean number of months in which the sample took part in the study was 16.53 and the standard deviation was 4.38. The distribution of

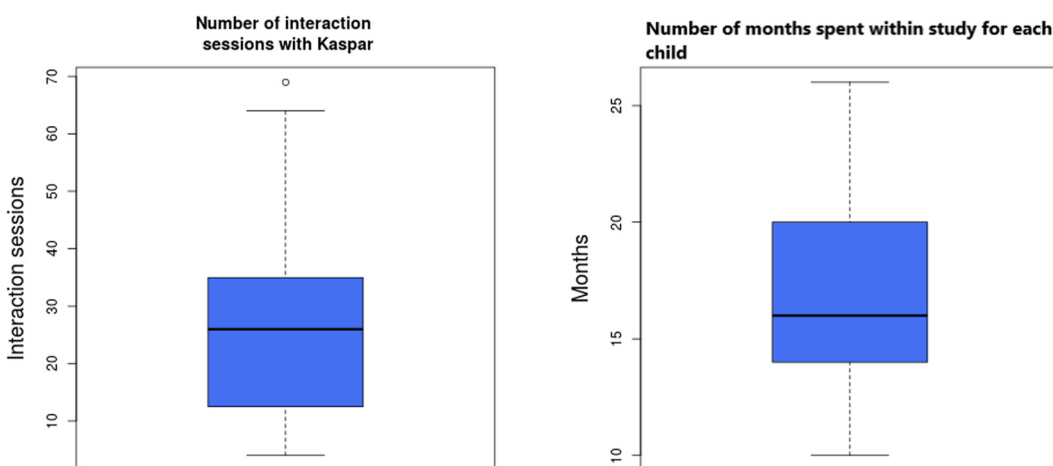


Figure 5: Box plots showing distribution of interactions with Kaspar and length of study period (middle line denotes median, shaded area shows the interquartile range [i.e. the middle 50% of results] and whiskers describe interquartile range times 1.5).

scores did not significantly deviate from the standard distribution (Shapiro-Wilk’s $W = 0.95, p = 0.44$).

There was a non-significant trend in which children who had taken part in the study over a longer period of time also had interacted with Kaspar more ($r = 0.27, p = 0.26$). While non-significant, it still meant that the subsequent analysis would have to account for whether differences in development could be attributed to interactions with the robot, or purely the fact that more time might have passed for the children who interacted with Kaspar more.

5.1.2 Initial scores

The results from Figure 6 and Table 5 suggest that there were some variations in the scores for each domain between the children. In order to examine whether there was an initial selection bias, in terms of which children would interact more with the robot based on their initial scores, a series of Spearman’s correlations were conducted. These results are shown in Table 6 and suggest that children with *lower initial scores* in the social and emotional domain would have *more interactions* with Kaspar.

5.1.3 Changes in scores for domains

There was no negative change for any of the children in the study. Table 7 and Figure 7 show that the sample varied in terms of how their scores changed over the study period. In addition, the distribution of these changes did not deviate significantly from the normal distribution.

Table 5: Initial scores of domain scales

Domain	Mean	SD	Range	Shapiro p.
Sensory	2.57	0.28	1.77–3.15	0.008
Communication	1.97	0.22	1.56–2.36	0.877
Cognitive	2.14	0.34	1.59–2.88	0.544
Social emotional	1.63	0.27	1.18–2.35	0.312
Psychomotor	1.81	0.28	1.40–2.60	0.010

Table 6: Correlations between initial scores and number of interactions with Kaspar

Domain	Spearman’s ρ	p value
Sensory	−0.15	0.542
Communication	−0.18	0.452
Cognitive	−0.10	0.690
Social emotional	−0.48	0.044*
Psychomotor	−0.31	0.204

Table 7: Changes in domain scores across the study

Domain	Mean	SD	Range	Shapiro p.
Sensory	1.36	0.49	0.57–2.21	0.573
Communication	1.09	0.59	0.04–2.46	0.623
Cognitive	1.07	0.63	0.00–2.44	0.833
Social emot.	0.78	0.42	0.00–1.47	0.570
Psychomotor	0.88	0.60	0.00–1.80	0.119

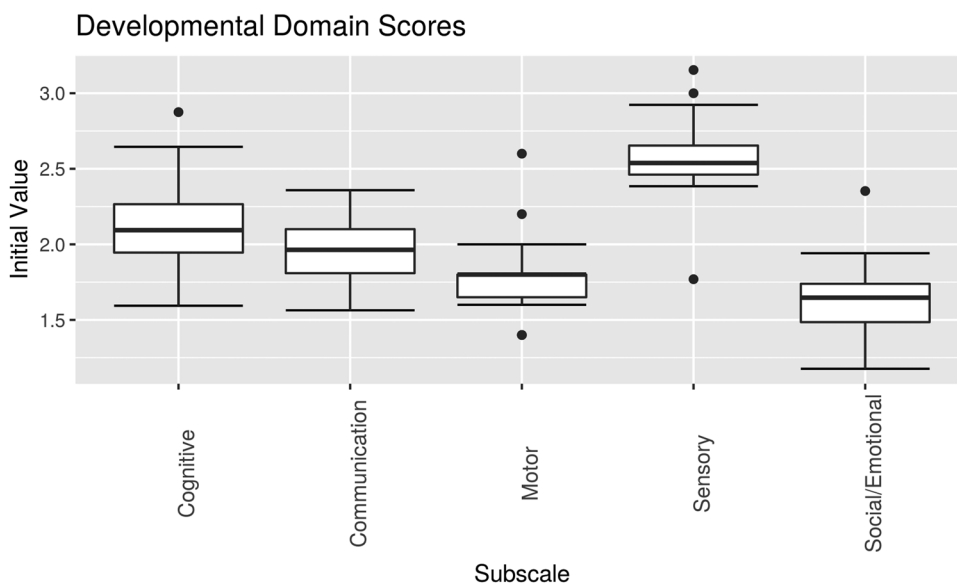


Figure 6: Box plot showing distribution of initial scores on the domain scales.

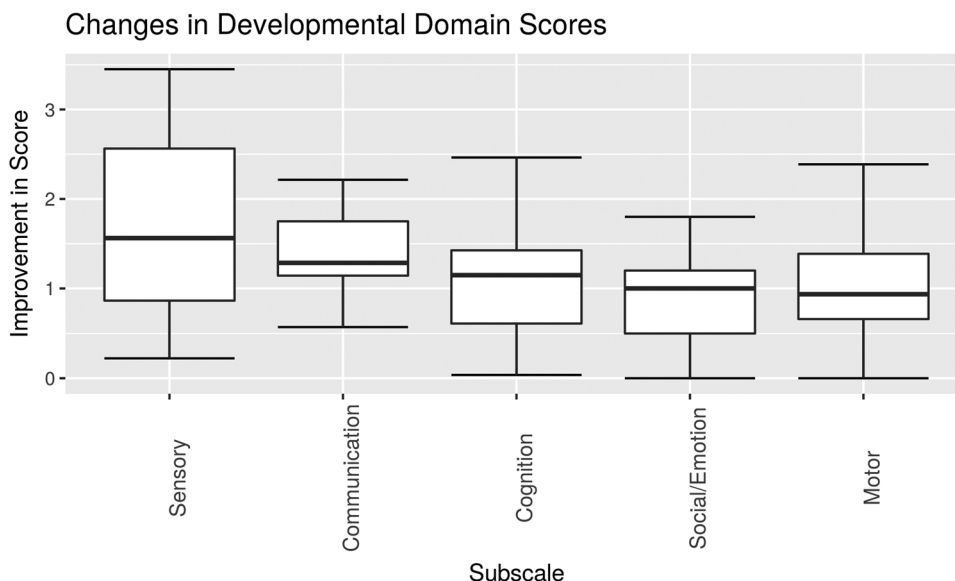


Figure 7: Box plot showing distributions of changes in scores by domain across the study.

5.1.4 Changes in scores and interactions with Kaspar

In order to examine the relationship between interactions with the robot and changes in the scores, a series of Pearson correlations were conducted. The results are presented in Table 8, which suggest that children who interacted with Kaspar more also significantly improved more in the sensory and communication domains. The results also suggest a trend⁴ towards significance in the cognition domain. However, this was not the case for the social emotional and psychomotor domains.

Table 8: Pearson correlations between the number of interactions with Kaspar and the change in domain scale scores

Domain	<i>r</i>	<i>p</i> value
Sensory	0.541	0.021*
Communication	0.476	0.046*
Cognition	0.461	0.054
Social emotional	0.262	0.294
Psychomotor	0.323	0.190

⁴ We are in this article reporting on results that approach significance, as it is done in many very recent publications, e.g. [65–67], which report on “trends” that are “not quite significant” or are “marginally significant”.

5.1.5 Changes in scores and the passage of time

As previously mentioned, there was a small (non-significant) correlation between the amount of interaction with the robot and the total period of time that the child was involved in the study. Therefore, children having interacted with Kaspar more might have been part of the study for longer, possibly making the increase in scores the result of natural development processes independent of the robot. This was investigated by first correlating the changes in scores with the total time in months. The results shown in Table 9 show (rather unsurprisingly) that the children tended to display greater improvements the more time had passed. In order to control for this potentially mediating effect, a series of partial correlations were conducted.

Table 10 suggests that there still was a positive relationship between interactions with Kaspar and changes in the measurements. This approached significance for communication and cognition and was significant for sensory. This was

Table 9: Pearson correlations between months in the study and the change in domain scale scores

Domain	<i>r</i>	<i>p</i> value
Sensory	0.381	0.119
Communication	0.518	0.028*
Cognition	0.305	0.219
Social emotional	0.259	0.299
Psychomotor	0.409	0.092

Table 10: Partial Pearson correlation between the number of interactions with Kaspar and the change in domain scale scores, controlling for the number of months in the study

Domain	r	p value
Sensory	0.499	0.026*
Communication	0.422	0.072
Cognition	0.419	0.074
Social emotional	0.212	0.401
Psychomotor	0.253	0.311

while we controlled for the overall duration of time. It is important to note, however, as this is a purely correlational analysis, it is difficult to make a clear claim in terms of causality. Despite this, these findings support the continued exploration of Kaspar as a tool to help children with ASC.

5.2 Staff data

Staff data are presented chronologically in order to show the process of adoption of the robot in the nursery. The different visits brought up different issues and motivated different approaches to resolve them.

5.2.1 First visit

This was the first visit to the nursery as part of the collection of research data regarding the use of the robot in the nursery. At this point, the members of the nursery had only seen the robot in use with, and operated by, researchers and were about to receive training in the use of the robot.

5.2.1.1 Interview topics

The interviews conducted as part of this visit were introductory in nature. They served as a means for the research team to get to know the team working with Kaspar and understand what hopes and fears they had for the use of the robot. The participants would introduce themselves and their role in the nursery in this set of interviews. We investigated the following:

- The individual participant’s view on their role within the nursery and in the use of Kaspar.
- Motivation for using the robot (hopes).
- Worries and concerns about using the robot (fears).

5.2.1.2 Hopes

In this set of interviews, the staff would refer to the previous work that the research team had done with

Kaspar and children with ASC. The staff were looking forward to be able to provide the possible benefits of using the robot for children who were under their care in the nursery. In addition, the staff also hoped that their work with Kaspar and the children in the nursery would benefit the wider research programme.

All of the staff would reference specific interaction games or technical capabilities that the research team had developed for the robot, in particular the advanced “skin-like” sensors developed through the EU Project Roboskin [68] and turn-taking games developed in previous research [33]. The staff stated how they believed these capabilities would benefit the children through specific learning/therapeutic goals, i.e. appropriate touching and interactional turn taking.

5.2.1.3 Fears

The staff’s main apprehensions were related to the functioning of the robot by itself. The staff were concerned with the complexity of controlling the robot, in particular the setting-up and putting-away phases. They were also concerned with the stability of the system, in particular the hardware breakdowns. The staff brought up concerns regarding how a hardware breakdown would impact their interaction with a child present during the breakdown. Some of the staff outlined their initial plans for how they could prevent this from impacting the “relationship” between the robot and the adversely, i.e. “*What if the child gets a bit frightened and then does not want to see Kaspar again?*”. However, they felt that the way that interactions were planned out, with two members of staff present at all times to support each other, should alleviate most of the problems.

5.2.1.4 Summary of the first visit and the relationship with the TAM

It is clear that the staff explicitly aligned their motivations with the aims of the wider research programme related to the research teams’ work with Kaspar. Their motivations for the use of the robot were based on an initial acceptance of the robot as beneficial to children with ASC. Furthermore, their two primary concerns were how they could best ensure that the robot be used in manner that would allow it to both benefit the children in the nursery and the development of the robot, and how they could avoid the robot having technical problems.

The statements by the users at this stage also clearly reflected a view in which staff described their motivation for use primarily in terms of its extrinsic benefits (i.e. the benefits that the robot would provide for the children).

In terms of fears, the staff referenced worries about technical breakdowns or difficulties in controlling the robot. This mirrored Davis' [51] view of technology acceptance as a function of perceived benefit balanced against the ease of use.

5.2.2 Second visit

5.2.2.1 Overview

This visit took place 1 month after the robot had been deployed at the nursery and was intended to get a sense of the first impressions that the staff had of the robot and how the adoption process of Kaspar was developing in the nursery. At this point, the members of nursery had been using the robot for about a month. The topics that the interviews were intended to cover were as follows:

- Using Kaspar
- How often did they manage to use Kaspar?
- What were the reasons that stopped them from using Kaspar?
- What are the perceived benefits of using Kaspar?
- What were the difficulties of using Kaspar?

5.2.2.2 Using Kaspar

In terms of using Kaspar, the results were overall encouraging. The staff at the nursery stated that they were managing to use Kaspar for semi-regular sessions. The staff all highlighted technical faults with the robot as the main reason for the robot not being in use for some sessions. This could be a fault that developed in the set-up or interaction phases in that session. It could also be an ongoing issue from a previous session that had not yet been fixed by the research team.

5.2.2.3 Perceived benefits

All of the staff talked about interactions with the children when discussing the benefits of the robot. The only difference between the different members of staff was the degree to which they used specific interactions with specific children as examples. The staff also discussed the difficulty in quantifying the actual benefit of the robot, giving examples on how different behaviours for different children could be traced to the influence of the robot's presence in the nursery.

Furthermore, the staff at the nursery introduced the notion of what they referred to as "*Wow! moments*". These were moments when a child did something that

was both surprising to the staff at the nursery and at the same time suggested that the child had developed in a positive way.⁵

While some of the examples that the staff gave referred to events that occurred outside of the interactions with Kaspar (e.g. conversations a child might have had with a parent), the majority of the moments that were described occurred within the interaction with Kaspar. The staff shared the enjoyment with the child in these moments and that this was a powerful motivator for the use of the robot. One example of such a moment was a child who had rarely displayed pleasure or joy and was difficult to motivate into any activity. This child suddenly took a strong interest in Kaspar, allowing the use of the robot to be a form of common ground between them and the adults working in the nursery.

Other wow-moments were instances when children used phrases and interactive behaviour learned during the interactions with Kaspar and apply them to situations outside of their play with Kaspar. The staff acknowledged the difficulty in quantifying these experiences but argued that these desirable outcomes for the children could not have happened without the use of the robot.

5.2.2.4 Points for improvement

The staff were, as commonly observed in the early stages of technology adoption, enthusiastic about using the technology. This enthusiasm was also evident in the staff's description of their difficulties with Kaspar and in their suggestions as to how these interactions could be improved to benefit the children in the nursery.

This was the first time Kaspar was used outside of the culture of the research group that had developed the robot. The perceptions of the users were not grounded in the decisions made by a succession of researchers in the research group over the course of the development and use of the robot. They came from a novel perspective. The combination of these two factors made for a rich

⁵ Wow-moments can be interpreted in many ways. They can be discounted as a type of "conditioned superstition" as described in Skinner [69] and in later literature as how miracles are constructed where two unrelated events are merged into a causal narrative that is difficult to replicate or find evidence for. The heterogeneity of ASC, along with the processes of childhood development, makes observations particularly vulnerable to these sorts of processes. However, this is mitigated by the fact that the staff are doing these assessments as part of their professional roles, rather than how a parent or other carer would.

discussion about issues that the staff felt made Kaspar less useful than it could be. We have categorised these issues into the following three categories:

1. Issues that caused interactions to break down or prevented interactions.
2. Possible changes that would make existing interactions easier.
3. Possible changes that would expand interactions or make them more in lines with Kaspar's perceived function.

5.2.2.5 Issues that led to a breakdown in interactions

The staff referenced situations where Kaspar stopped working or did not start working in the beginning of the session. In most cases, the staff would treat Kaspar as any other form of computing technology and “turn it off and on again”. This was, not surprisingly, effective for many of the faults. In these situations, the two main concerns of the staff were to ascertain whether the robot could be used in the session at all as well as maintaining the interaction of the child.

The most common of the hardware faults that was mentioned by the staff was overheating in the servos in the neck of the robot. The servos needed to be on for the robot's head to be upright. If the robot was left in this position for a long period, the servo would overheat, leading the robot to stop working. The staff discussed this in terms of preventing it from happening.

In the first sets of situations, the focus was on how to maintain the interactions with children when Kaspar stopped working. The staff would describe strategies for doing this, such as enlisting the aid of the child in trying to find out how to fix Kaspar or to share how they felt about Kaspar not working. For some of the children, interacting with Kaspar was intrinsically rewarding enough that they would happily go along with this. However, this would, for most children, only work for a short period of time, and if the situation was not resolved, the child could become frustrated. This made it important for the staff to know whether the given fault could quickly be remedied, in order for them to effectively manage the expectations of the child and, if necessary, end the interaction session to prevent frustration.

The second set of situations was mainly discussed in terms of how they could be avoided. The servos heating up was a known issue to the research team, and the possibility of this happening had been highlighted in the initial training that the staff had received. This particular issue did, however, highlight the differences between members of a development team using a prototype and external users. For the researchers, this issue was an obvious and intrinsic part of

the robot's design. However, for the users in the nursery it was less obvious. In particular, the humanoid shape of the robot would suggest that holding its head upright should not be a strain. In addition, when Kaspar was being used by the members of the research team, *the use of Kaspar was the primary focus of the situation*. For the staff at the nursery, however, its usage was situated in a much more complex setting, where the users of the robot had to fulfil several other functions at the same time. This meant that they might have to leave the robot at short notice, increasing the risk of overheating.

While the users did suggest that this could be mitigated by training, they also suggested that safeguards could be put in place to prevent this. One measure was for Kaspar to give a signal to the user if the head had been up for too long and the neck servo needed to rest. The other was for Kaspar to use a type of “idle” or “standby” mode in which the head would slowly nod down in case the robot was not in use for a while. Interestingly, the staff did not suggest that the neck be redesigned to eliminate the issue, rather they suggested solutions that would mitigate it in use.

The neck of Kaspar has since been redesigned by the research team based on this feedback from the users. The newest version of the robot does not overheat from having its head upright for a long period.

5.2.2.6 Possible changes to make interactions easier

The staff also noted that they felt that the way that Kaspar was set-up and controlled during interactions could be improved. The staff found that changing between different interaction games on the laptop while the robot was interacting with the child could be distracting. While changing games on the laptop was very easy (i.e. staff only had to click on a list of games to select another game), the staff's attention nevertheless briefly had to turn to the laptop. In addition, the user would still be using the keypad to interact with the robot. This would sometimes make it difficult for the participant to know what mode the robot was in, and this could lead to the robot doing something unintended.

The staff suggested that this problem could be remedied by using a touchscreen interface, as this could provide a clear indication to the user which mode Kaspar was currently in as well as provide context-dependent menus. Another suggestion was to use a larger keypad for the use of the robot. Based on this feedback, several changes have been made to Kaspar's interface. Radio frequency identification (RFID) cards held against the side of the robot can now be used to change games, so a

laptop is no longer needed when operating the robot. In addition, a set of overlay covers attached to the keypad was developed which shows the appropriate keys for each game. This allowed the researchers to address the issues raised by the staff while still retaining the use of a keypad.

The above-mentioned issue of the overheating of the neck servo highlights the challenge using a research prototype in a long-term setting.

The staff also raised an issue that became apparent through the sustained use of Kaspar during this period. It was that the robot became more rewarding the more children interacted with the robot. While this was an encouraging observation for the research team by itself, it also had some unintended consequences. When children explored the possible interactions they could have with Kaspar, many realised that Kaspar would often use more complex utterances when attempting to “discourage” inappropriate behaviour (such as hitting the robot). This often encouraged the children to perform these behaviours more with the robot. The staff would consider this the result of the novelty factor of the robot wearing off. They suggested that this could be remedied by increasing the amount of utterances that Kaspar would use when the child engaged in more appropriate behaviour.

5.2.2.7 Expanding the scope of interactions

Another issue that clearly shone through in these interviews was the desire to expand the range of interactions that the children could have with Kaspar, and the ways that the staff at the nursery could use Kaspar in different situations. In particular, the staff wanted to be able to relate the interactions that children had with the robot to the other activities that were happening in the nursery.

They reported that they found referring to the images they used to teach emotion recognition and expression in the nursery was quite effective when they were interacting with Kaspar. They suggested expanding the different behaviours of the robot in a manner by taking into account the specific learning goals and themes of the main nursery sessions. This process required iterative involvement and further technological development with the research team and increased Kaspar’s repertoire of behaviours over time. The staff in the nursery also argued that making it easier for them to “program” sequences of behaviours for Kaspar might be more effective, as this would allow even greater flexibility in terms of how the robot could be used in the future.

This feedback led to the development of a significantly increased repertoire of games and behaviours for

Kaspar, including pretend games around personal hygiene and food (supported by the robot’s new ability to hold an item of cutlery, a comb, a toothbrush, etc.) as well as new games involving singing nursery rhymes, etc. It has also led to greater efforts in streamlining the processes for incorporating new user-suggested activities into interactions with Kaspar.

5.2.2.8 Conclusions and relation to the TAM

The interviews suggest that it is difficult to disentangle extrinsic and intrinsic rewards when discussing robots like Kaspar. It is designed to not only facilitate child-robot interactions, but is also intended to facilitate interactions between children and adults, and between children, and these interactions can be rewarding, too. While the wow-moments described by the staff are clearly representative of a perceived extrinsic benefit, these moments are still experienced *within* the interactions, and so they are by their very nature rewarding the staff intrinsically. This also means that the ease of use category is difficult to consider by itself. Some aspects of the robot, for instance, the time it takes to set up, the issues with the servos overheating, etc., are neatly placed into an ease of use category which is about using the robot to obtain the extrinsic or explicit goals of using the robot. However, a lot of the issues raised by the users are about possible improvements that will streamline the interactions themselves, and as such, these two categories of reward were important for the users in how they reasoned about their intentions to use Kaspar.

5.2.3 Third visit

The focus of the interviews in this visit was primarily to follow up on the issues raised in the second visit, and the following topics were covered:

1. Frequency and context of use.
2. Positive aspects of Kaspar.
3. Points of improvement for Kaspar.

5.2.3.1 Frequency and context of use

Overall, the staff felt that the use of Kaspar had normalised over the months that were passed since the second visit. However, they also conceded that the use of Kaspar was dependent on other aspects of the day-to-day running of the nursery. In particular, the staff felt that they used Kaspar less at the end and the beginning of term. This visit took place during January, and the staff

highlighted the run-up to the Christmas holidays as a period in which the normal schedules would be changed due to seasonal activities. During these periods, interactions with Kaspar were often cancelled as the nurseries procedure for using Kaspar required two members of staff to be present for the interaction, and they found it difficult to spare two members of staff in any one session. The staff did expect the usage of Kaspar to become more frequent as the nursery fell into its term-time routine.

5.2.3.2 Positive aspects of Kaspar

The staff were asked about their views of Kaspar in two ways: their positive experiences with the robot and how they would describe the positive aspects of it to others. When replying to the first question, the staff answered with anecdotes about specific children interacting with Kaspar, describing wow-moments that they had experienced.

The staff also described their own emotional response to these wow-moments within interactions as a reason for wanting to use Kaspar. In addition, the staff often described how they enjoyed the way that the interactions with Kaspar let them interact with the children in novel and sometimes richer ways than they thought would be possible with some of the children, suggesting that as time progressed, intrinsic rewards within the interaction became more important.

Interestingly, when discussing how they would describe and justify the use of Kaspar within the nursery, staff would refer to the more extrinsic benefits of Kaspar, pointing out the improvements in the behaviour of the children along and arguing that these benefits would not be possible without the robot.

5.2.3.3 Points for improvement of Kaspar

The points for improvement that the staff referenced in the previous visit were still present to some extent. The issue of the servos overheating had been mitigated through the staff stringently observing routines, preventing it from happening. However, the most common point for improvement of the robot was still the occasional technical breakdowns, as these would either prevent or prematurely end interactions. The staff were, however, better at determining whether a given technical problem could be resolved quickly or if it meant that they would have to stop the session completely. This allowed them to better manage their time as well as the expectations of the children. This meant that the impact of technical breakdowns was smaller than it had been in the past.

The staff's earlier concerns regarding the interface were reiterated. The staff had been working with members

of the research team to make changes to the keyboard, and this work was progressing. In addition, the staff reiterated the wish for a way for them to implement new behaviours for the robot. This was felt to become more important as time progressed as the children had gotten used to the robot's repertoire of behaviours.

The point of improvement was not so much a comment on the robot itself as in the usage of Kaspar. The staff discussed the demands that using such a complex technology within the nursery had on the time and resources in the nursery. In particular, managing to cordon off the personnel and space to use Kaspar in the given setting required the staff running the session to give priority to Kaspar. This combined with the changing demands of the nursery required the staff to "negotiate" with their colleagues in order to use the robot within their session.

5.2.3.4 Comments and reflections

This particular session showed that the three predictors of use, *extrinsic* rewards, *intrinsic* rewards and *ease of use*, were all still considered in the staff's reasoning about the robot. The intrinsic rewards of the mediated interaction with the children through the robot were given more weight than in the previous interviews. However, despite the staff using references to rewards intrinsic to the interactions with Kaspar and the children, they would highlight extrinsic rewards *when discussing the use of the robot to colleagues*.

This discussion also brought up themes regarding technology acceptance which are not encompassed by Davis' 1992 model, such as social influences and facilitating conditions, that are a feature of the UTAUT approach of Venkatesh et al. [53]. In these discussions, the staff highlighted the importance of the social interplay within the nursery when determining whether Kaspar would be used within a session and also how these influences would interact with facilitating conditions like the time and space resources that needed to be allocated.

5.2.4 Fourth visit

By this visit, staff in the nursery had had time to familiarise themselves with Kaspar. Previous visits had seen the staff becoming more secure in using the robot. Staff had also been proactive in working with the research team to change Kaspar. In this session, we saw that the staff now also started to adapt the way that they use the robot and to link it more closely with the other activities that they did with the children. While this



Figure 8: Sample PECS card set.

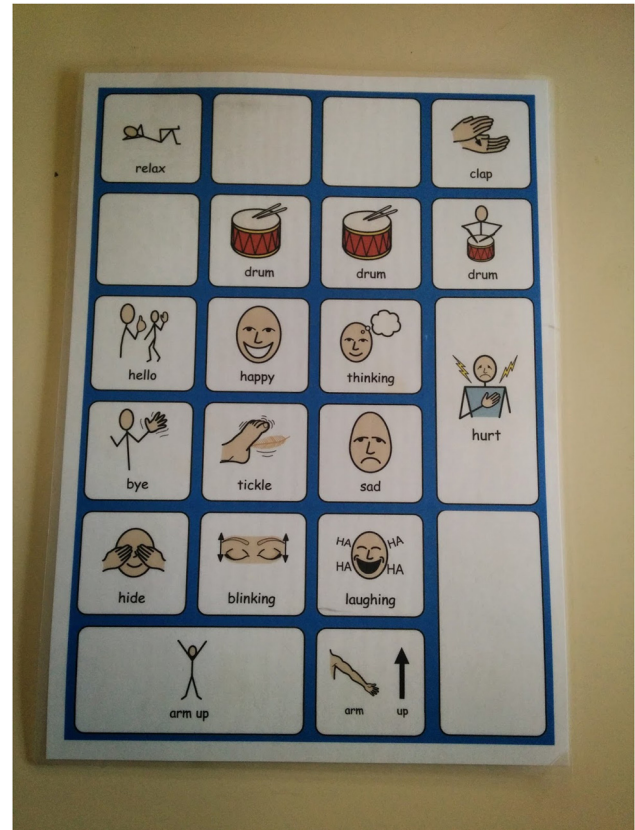


Figure 9: Reproduction of control keypad using the PECS cards.

had been a hope throughout the study, this was the first time that we observed it in a structured manner.

5.2.4.1 Greater emphasis on child-led interactions

The staff at the nursery discussed the changes that they had implemented in the interactions with Kaspar. According to some of the interviewees, in the months prior to summer, two issues had been identified as problematic:

- There were not enough opportunities for the child to direct the interaction.
- Children using the keypad would effectively “cut out” the interaction with the member of staff and engage in a purely dyadic interaction with the robot.

There was some discussion across all the interviews as to what caused this. One suggested cause lay in the limited ability of some of the children to express their wishes as to what sort of interactions they wanted to engage in with Kaspar. While allowing the child to directly control Kaspar through the keypad did alleviate this, it led to a perceived overuse of the keypad. In addition, as members of staff familiar with the robot had

greater knowledge about the capabilities of the system, they would often make suggestions as to what sorts of interactions that the child could have with Kaspar, which decreased the control the child had over the session.

This was addressed by creating specific sets of picture exchange communication system (PECS) cards [70] (Figure 8) for the interactions that the children had with Kaspar. An example set is shown in Figure 9. As the PECS cards were used to interact with children across a range of activities within the nursery, it meant that communication skills and experience learned using this system could be applied to and transferred from the interactions with Kaspar. Its use also gave children greater opportunity to master these interactions by simultaneously providing them with information regarding the capabilities of the system as well as allowing them to communicate preferences for the activities. In addition, the researchers recreated those cards on the buttons of the control keypad, allowing the children fine-grained control over the system’s behaviour without leaving the staff out of the loop.

In addition to the use of the PECS cards, several of the staff members indicated that they had also gained a better appreciation of the way that some children might want to interact with Kaspar, in particular as regarded

more “passive” interactions, where a child would just observe Kaspar’s behaviour, often from a distance. For some children, this might be part of a wider familiarisation process leading on to more involved interactions with the robot, but even if not, they found that often aspects of children’s observation of the robot would become relevant. The nursery staff were also able to more clearly distinguish different roles for Kaspar for different children, and how to best use the robot for each child from just using its basic behaviours as a motivating toy to using the more advanced interaction games.

5.2.4.2 Competence, security and flexibility

These developments occurred within a greater process of familiarisation with the technology on the part of the staff at the nursery. Members of staff reported feeling more secure with the robot in particular as regarding their approach to technical problems. While the stability of the problem was still an issue, the interviewees reported that technical problems were less problematic compared to the previous interviews for the interactions themselves. Furthermore, the staff were less distressed by the technical problems occurring within interactions and were more capable of resolving the most common causes of problems. This led to the staff feeling more secure with Kaspar as it became more predictable to them. One of the interviewees also highlighted how the greater degree of understanding of the system and its capabilities led to greater flexibility in how they used the robot as well as a higher degree of sophistication in its use as evidenced by the adoption of the PECS.

The nursery is a busy place and has many demands for both the facilities and the staff present at any given time. The three interviewees who discussed it gave two or three different conditions in which a child could interact with Kaspar. These conditions are set out in Figure 10 and will be discussed in more detail below:

- Space: The room in which Kaspar is kept is used for other activities in the day-to-day running of the nursery. This means that particular needs of a set of activities or those of a particular child in a given session may take precedent over the use of Kaspar, and so the robot cannot be set-up at all during that session. In addition, this means that the robot is always packed away in the later stages of a given session as the room will be needed for other activities.
- Staff: The nature of the work in the nursery requires all members of staff to be flexible with their tasks. In addition, only three members of the day-to-day staff are trained in the use of Kaspar, so if any of these three are not present, or they are needed to perform a different task, the robot cannot be used.

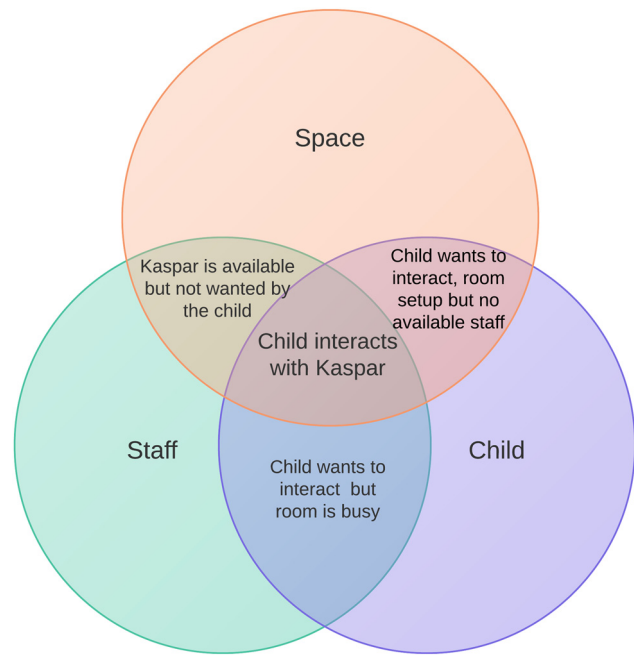


Figure 10: Venn diagram for use of Kaspar.

- Child: The nursery provides a varied set of activities and practices child-directed learning, meaning that a child may choose to not interact with Kaspar in a given session as they are engaged with another activity.

The Venn diagram in Figure 10 shows the interaction of these three conditions that need to be met. Staff felt that the situations in which the child wanted to interact with the robot, but the room or staff were otherwise occupied, were the lost opportunities for valuable interactions. However, if the room has been set-up and Kaspar is not being used due to demands on staff or lack of interest from children, this is in essence a waste of both the space (which is at a premium) and the time it took the staff to set-up the robot. Likewise, if members of staff have been trained to use Kaspar but do not use this training, it is also not ideal, as their time could have been spent differently.

While it is clear that continuous use of the robot is impossible (and not necessarily desirable), there did seem to be a consensus in the interviewees that they would like to be able to have Kaspar available to the children throughout the sessions.

5.2.4.3 Resolution

The staff had already begun addressing the above-mentioned issues. The following paragraphs are a summary of how the nursery will resolve these issues.

- Space: At the time of the last interview, the nursery was preparing to move to a new location that would enable them to dedicate a specific space to Kaspar. This would not only eliminate situations where interactions with the robot cannot occur due to the room not being available, as presented in Figure 10, but also make demands on staff less strenuous as a dedicated space would decrease the time required to set-up the robot before the session, and it would not require them to put Kaspar away during the session. This would significantly decrease the impact of the robot on the day-to-day running of the nursery apart from when it is in use.
- Staff: In addition to the improvements made by dedicating a space to Kaspar, the members of the nursery were also in the process of training the other members of staff in the use of Kaspar, so that more members of staff would be able to make the robot available to children within each session. This means that the demands of the robot can be spread out on a wider range of the staff, decreasing the number of situations in which the robot is not available due to one or more trained members of staff not being able to utilise it.
- Child: Children may not always want to interact with the robot at any given time, some children may find other activities more inherently interesting and rewarding than interacting with the robot. However, in the set-up taking place during the course of the study, only one activity (free play) ran parallel with the opportunity to interact with Kaspar. With a dedicated space for Kaspar and more staff available, children can compare Kaspar with a wider range of activities, which can mean that some children in the course of this study who currently would not choose to interact with Kaspar may choose to do so when comparing it to activities they have less interest in.

5.2.4.4 Reflections on the visit

Overall, the staff members in the nursery felt that they had learned both as individuals and as an organisation to use Kaspar more efficiently and in a more rewarding manner over the long-term period that the system had been in use there. The staff at the nursery were also actively looking for ways to continue to improve their use of the robot. The move from their current space to a new building has also been considered in terms of how it will affect their work with Kaspar. The greater availability of space may be a very positive factor in the use of Kaspar, and this also represents a move to including the robot as an integrated part of the nursery.

The prolonged use of Kaspar has provided us and the nursery with greater insight into how to use the robot. The nursery has been able to address many of the challenges that come with taking a research platform like Kaspar and finding a place for it within an established practice of child care. The researchers working with Kaspar in similar settings can examine how some of these challenges can be addressed prior to deployment. One example is to use the PECS card sets from the start of the deployment. Furthermore, almost equally important is looking for ways to minimise the impact that the usage of the robot has on other aspects of the running of the setting that it is deployed in.

6 Discussion

6.1 Extrinsic benefits

Overall, the staff were convinced that the use of the robot benefited the children. When asked to illustrate how this had manifested, the staff would most commonly respond with specific examples regarding how different children had developed. While it is difficult to quantify the content of these stories, the heterogeneous way in which ASCs express themselves along with how children in nursery ages develop is in keeping with the diversity of these anecdotes. Because of this, the professional opinion of those working with the children was supplemented using a questionnaire which was used by the staff at the nursery to rate a child prior to taking part in the study and then towards the end of the study.

The analysis of the changes in ratings on these scales shows that there were observed relationships between the degree of development along the sensory, communication and cognition domain scale scores, and the amount of interaction children had with Kaspar. When the amount of time in the study was added into the analysis as a control, the degree of development along the sensory domain remained significant, while the communication and cognition subscale scores approached significance ($p < 0.10$). While this is an encouraging result that supports the assertion of the staff that the robot was beneficial to the children, it is difficult to make a strong causal claim based on a correlational result like this.

6.2 Intrinsic rewards

Based on our observations, intrinsic rewards were strongly present in this study. While the developmental

benefits of interacting with the robot for children could be thought of as an extrinsic benefit, the way that they impacted and rewarded the participant within the interaction itself was clearly a powerful motivator for the use of Kaspar. The staff referenced the extrinsic benefits in discussions in the early stages of using the robot as well as when discussing how they would argue for its adoption in the nursery and in other settings. However, when discussing their own use in the later stages in the study, they relied on intrinsic rewards to describe their experiences of the interactions. This suggests that there is a strong longitudinal element in the relationship between extrinsic and intrinsic rewards. In addition, it suggests that staff in this study actively used the different types of rewards in different ways. They would use the intrinsic rewards to make sense of their own experience, while using the extrinsic rewards to justify the use of the robot by non-researchers. Another factor may be that the extrinsic rewards were easier to communicate to people outside of the study.

6.3 Ease of use

The staff actively shared their experience regarding the robot's ease of use. Throughout the study, the staff would examine how the robot's interface and technical issues impacted their use of the robot. The most pressing issue for the staff were the technical issues inherent in the research prototype and the interface issues. They also found some of the constraints of the robot in terms of space requirements and set-up time challenging.

The staff worked together with the research team to remedy the issues of breakdowns and interface and developed strategies for overcoming the constraints of the robot and the environment in order to get the most out of the robot. While the staff working directly with the robot immediately suggested a touchscreen for remedying the issues with the interface, this solution was not adopted by the research team. The use of a touchscreen, while addressing many of the issues the staff raised, would require the interaction with the robot to be mediated through a controller that was more fragile than the keypad and would lack the tactile feedback that the use of the keypad offered. Therefore, the use of a customisable keyboard overlay was considered more appropriate. The later adoption of RFID cards for changing games not only allowed for quick changing of modes but also the use of the physical cards allowed further interaction between the child and the adult. Thus, the research team was able not only to respond to

the suggestion of the users but to build on them to develop novel solutions to the issues that came up.

6.4 Intention to use

Intention to use was to a large extent determined by the extrinsic and intrinsic rewards of interaction with the robot. However, the way this intention was communicated and experienced changed over the course of the study. Furthermore, intention to use was not necessarily translated into actual use, which could be due to both technical issues from the robot and the constraints of the nursery setting preventing it from being realised. Despite this, the intention to use remained an important factor in how the staff set-up both individual sessions and the overall structure of their work in the nursery.

6.5 Actual use

In terms of the actual use, factors from later TAMs like the UTAUT become more important. While Davis' model account well for the individual (and within-group) experience of the robot and its use, the actual adoption of the robot in an organisation like the nursery required a more complex interaction between the different decisions that lead to the allocations of resources that allowed the robot to be used in a given session. Unlike a classical UTAUT approach, the participants' individual experiences with the robot formed a basis for their intentions. This in turn interacted with the different formal and informal social structures in the nursery, which potentially led to the decision to the use of the robot.

6.6 Overview

Overall, the results were very encouraging. Kaspar was used effectively, and on a regular basis by a team of users that were not part of the research group and were not trained engineers or computer scientists. Also, it was perceived to be of benefit to the children that the participants worked with. A set of ratings along five different domain scales supported this view, although as noted previously it is difficult to make a strong causal claim.

The r coefficients shown in section 5 were large, suggesting a strong effect size, and it is doubtful that such an effect can be traced *only* to the robot strongly

benefiting the child. Instead, there could be several effects coinciding to create this large correlation, and we can refer to them as *selection bias*, *expression channel* and *actual effect*.

6.6.1 Actual effects

For the purposes of this discussion, the actual effect is one in which Kaspar directly impacts the development of the child. As discussed earlier, the use of the robot as a safe human-like object allows for the teaching and practice of many social behaviours.

6.6.2 Selection bias

Drawing on the interviews with the staff, we know that the intrinsic benefits, in particular the *wow-moments* often occurred within interactions and that the staff assigned quite a lot of value to them. This might have caused an unconscious selection bias which led children who exhibited a greater change in development to interact with Kaspar more often. Likewise, children who most profoundly experienced the empowering effects of Kaspar might have expressed a desire to interact with Kaspar more often.

6.6.3 Lower baseline

There were negative correlations between baseline, initial scores along the different dimensions and the amount of interaction a child had with Kaspar. This means that these children would have more scope for development throughout the study. This is unlikely to account for the effect seen in section 5. If this was the case, the domains with the largest negative correlations between baseline scores and the amount of interaction with Kaspar should have shown the greatest increase. However, the domains with the largest correlations for the relationship between interactions with Kaspar and positive change (i.e. sensory, communication and cognition) were also the domains with the smallest negative relationship between baseline scores and the amount of interaction with Kaspar. This is the opposite of what one would have expected if the lower baseline was responsible for the effect.

6.6.4 Expression channel

By expression channel, we mean that due to the novelty and range of interactions that Kaspar provided, it allowed for a greater range of situations and behaviours through which a child could express their development. In particular, the role of the robot as a compelling object for

shared attention, as reported in Robins *et al.* [71], would allow for such an increase in the range of interaction. This increase might have allowed the person rating the child to see behaviours and abilities that would not have been displayed without the interactions that the robot provided.

Finally, the above-mentioned effects could also interact with each other. For instance, the wow-moments that used Kaspar as an expression channel could reward the staff, which could lead to a selection bias allowing the child more time with the robot and more time to express the underlying development. It is not inconceivable that this in itself would also benefit the child's development and in turn maximise the actual effect of the robot. This could explain the relatively large effect sizes in the correlations between robot usage and observed development. The dynamic manner in which these effects might interact also highlight the importance of situating children's interactions with Kaspar in an established program of teaching and care. This may at times come into conflict with the conditions assumed by randomised controlled trials that by their very nature may fail to account for the complex web of interactions that are impacted by the use of a novel technology in a setting like this.

7 Challenges, limitations and future work

7.1 Challenges of field studies

While quantitative data collection in such field studies is typically limited, we nevertheless tried to follow a rigorous approach of including users' feedback during an iterative evaluation and design cycle of Kaspar. We argue that this is necessary in order to achieve the envisaged benefits and societal relevance of robots in society in general and particularly in our specific context of a nursing school for children with autism.

We had to demonstrate whether and how the "robot would work" as part of the staff's daily work. Such fieldwork is highly complex and challenging, it is very time-consuming and research intensive. It also poses particular challenges for designing and conducting the study, data collection and data analysis, compared to traditional laboratory studies or researcher-run studies outside the laboratory. Importantly, it also requires to have a research prototype available that is usable and robust enough to be deployed in a naturalistic setting without requiring constant monitoring and maintenance by the research team.

The recruitment of schools, staff, children and, separate from the actual formal process of recruitment, “getting the staff on board”, i.e. ensuring their commitment to use the robot, adds additional complexity. The authors were able to conduct this study as part of a multi-disciplinary team, with complementary competence and skills of the research team in order to address the variety of these challenges.

7.2 Limitations

This was the first study of a humanoid robot used in robot-assisted play for children with autism in a naturalistic setting in a long-term study where on average each child spent 16.53 months in the study. Researchers were not involved in the study at the school. Instead, their role was to conduct interviews and collect other data that the staff were able to provide. Given the small number of staff and their busy schedules, there were severe limitations on how much data could realistically be collected. As such, the sample size was small, and also no precise data were available on the diagnoses of the children.

Given the nature of this work, we had to consider the trade-off of data collection on the one hand and creating a naturalistic environment for children in a special needs school on the other hand. We chose the latter which is the novelty of this study, and our findings highlight how a robot could be used in a truly naturalistic setting, rather than in highly controlled laboratory experiments or constrained researcher-run studies.

Future work could take a more detailed user-centred approach, e.g. going beyond the TAM to investigate more detailed user experiences and alternative models of user acceptance. As explained above, in this study we used TAM as the first step towards gaining feedback from users. Future studies can take inspiration from other related work (e.g. [72,73]). As with most studies in the wild, results typically raise a large number of further questions, so we hope that researchers in the field can use some of the lessons that we learned during this project to inform their own future work.

7.3 Continuation of the work

Since completing the study reported in this article, the Kaspar robot is still being used in the special needs nursery school by teachers, although we are not collecting any more data (in total the robot has now been used in the nursery school for 7 years).

A number of focus groups with professionals and practitioners in the field of autism have been conducted

by Huijnen et al. in the Netherlands [74] as well as a co-creation study with Kaspar, involving people with autism, parents and professionals [75]. While those studies with Kaspar were conducted independently of our research team at the University of Hertfordshire, our team has also conducted a number of other more controlled studies in schools. This includes a study using the robot in a different cultural context, namely, in a Greek school [76] as well as studies investigating how Kaspar can teach children with autism about visual perspective taking, for examples see [29], and how the robot can learn from interactions with children with autism [77]. Moreover, Kaspar was used independently by a clinician in the University Children’s Hospital-Skopje, Macedonia, and case studies with children with severe autism are provided in [78]. In addition, a feasibility study of a randomised controlled trial to investigate the effectiveness of Kaspar has been completed (see the protocol in [79]) funded by the National Institute for Health Research (UK). Regarding technical developments, the hardware and software of the robot have been developed further to facilitate semi-autonomous behaviour and make it more user-friendly for non-technical users [80,81].

8 Conclusions

The prolonged use of Kaspar has provided the research team and the nursery with greater insights into how to use the robot. The nursery has been able to address many of the challenges that comes with taking a research platform like Kaspar and finding a place for it within an established practice of child care. The challenge for the researchers working with deploying the robot in similar settings is to examine how some of these challenges can be addressed prior to deployment. One example is to use the PECS card sets from the start of the deployment but almost equally important are looking for ways to minimise the impact that the usage of Kaspar has on other aspects of running the setting that it is deployed in. While the strong effect size in the relationship between the amount of interactions with the robot, and the children’s development is encouraging, it is still difficult to make a clear causal claim. The results do suggest, however, that holistic interventions using broad overall measures of functioning might be a good approach to investigate the use of robots such as Kaspar for these types of field studies in the real-world environments.

The authors firmly believe that in order to ensure progress in the field of robot-assisted therapy and education for children with autism, the robot research prototypes developed in the laboratory need to “leave the lab” but also need to be “freed” from research staff being nearby to

operate and/or monitor or maintain the robot. If research in this domain wants to achieve a lasting effect on society, then the robots need to be situated in and become part of people's daily lives by doing field studies in practice.

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