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ORIGINAL PAPER

Developing technology for autism: an interdisciplinary approach

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Abstract We present an interdisciplinary methodology for designing interactive multi-modal technology for young children with autism spectrum disorders (ASDs). In line with many other researchers in the field, we believe that the key to developing technology in this context is to embrace perspectives from diverse disciplines to arrive at a methodology that delivers satisfactory outcomes for all stakeholders. The ECHOES project provided us with the opportunity to develop a technology-enhanced learning (TEL) environment that facilitates acquisition and exploration of social skills by typically developing (TD) children and children with autism spectrum disorders (ASDs). ECHOES' methodology and the learning environment rely crucially on multi-disciplinary expertise including developmental psychology, visual arts, human–computer interaction, artificial intelligence, education, and several other cognate disciplines. In this article, we reflect on the methods needed to develop a TEL environment for young users with ASDs by identifying key features, benefits, and challenges of this approach.

Keywords Autism · Technology-enhanced intervention · Interdisciplinary research · Social interactions · Social signal processing · Autonomous agents

1 Introduction

Developing technology for autism intervention is a relatively new but fast emerging field, motivated by the ubiquitousness and increased power of different interactive technologies, enabling the development of complex environments that can be manipulated through different modalities such as touch, voice, text, and motion tracking. Increased interest in the potential of technology for users with autism is further motivated by (a) the recognition that such users may have an affinity with computers [8] and (b) by the rapidly growing need for providing interventions. The latter is supported by recent reports of dramatic increase in diagnoses: Currently, over 600,000 children in the US are diagnosed with ASDs [26].

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There exists a multitude of technologies for training individuals with ASDs in specific skills that different neuro-psychological theories promote, including tutoring packages that target face recognition [19], emotion recognition [22] and understanding the mental states of others [25, 40]. Most of these encourage active, user-driven, learning and run on any home computer (e.g. [22]). Many approaches to technology-enhanced intervention rely on educational methods shown to result in good outcomes and can be used to specify design principles needed for engineering successful technology-enhanced intervention tools (e.g. [47]). However, to date, the success of technology-enhanced interventions that are already implemented and used has been mixed, with some studies reporting that improvements within the computer tutors fail to generalise to 'real-world' environments (e.g. [22, 36, 45]).

Other technologies include robots that imitate human movements, in order to provide 'robot friends' for children with severe, low-functioning autism (LFA), who often shun human-to-human contact entirely: Small-scale studies [6, 18] have shown that some children with LFA engage in shared attention and turn-taking with a robot more willingly than with a human. Digital play environments have been used to provide affect-free, audio-visually stimulating digital play environments, which are extremely popular with children with ASDs [30]. Recent developments in electro-dermal activity sensors [37, 38] and wearable cameras featuring automated facial affect recognition [29] are developed as 'emotional hearing aids' that can be used both by people with ASDs and their caregivers. Virtual reality (VR) has been used to provide training in social situations that many with ASDs find overwhelming, such as finding a place to sit in a crowded canteen [34] and going shopping [32].

Whilst existing TEL can be technologically exciting, delivering effective socio-cognitive intervention by means of technology presents significant methodological challenges. Interdisciplinarity is at the core of developing technology-enhanced intervention for users with ASDs. It crucially relies on the existing theories and practice both in clinical and education settings. It also requires advanced technological expertise to take advantage of and to progress the state-of-the art in system design, human–computer interaction (HCI) and, if the technologies are to be sensitive and adaptive to their users, artificial intelligence (AI). We argue that one of the biggest methodological challenges for developing technology for people with ASDs is to manage the diverse and at times divergent perspectives of all the disciplines and stakeholders involved. Theories, practices, methods, scientific traditions in psychology, HCI, education, social-signal processing and AI, and the different interpretations and perceptions of what constitutes good, fun or effective technology, differ significantly, but are equally important in the process. Establishing common ground and drawing on the strengths of each of those fields and views is fundamental to enabling successful development of technology that is truly able to support users with ASDs.

This paper presents an application of an interdisciplinary research methodology in the context of the ECHOES project. Whilst the individual methods discussed are not necessarily new in themselves, the novelty of our approach lies in the way in which the different methods and techniques are combined and applied in the context of technology such as ECHOES. We discuss the numerous challenges that a large interdisciplinary team, such as ECHOES, faces and how our methodological approach led us to the specific design decisions and evaluation plans. The paper is structured as follows: Sect. 2 introduces the ECHOES project and technology. Section 3 presents the ECHOES' design methodology and discusses how it draws on methods from AI in education and participatory design. Section 4 discusses measures of success and evaluation frameworks in this interdisciplinary context. In Sect. 5, we summarise our main arguments and provide a list of recommendations as a contribution to a generic methodology to the field of Autism and Technology.

2 The ECHOES project

ECHOES is an interdisciplinary, multi-partner project whose goal is to develop a TEL environment to support young typically developing (TD) children and children with ASDs aged between 5 and 7, in exploring and acquiring social interaction skills. The aim of the project is also to develop tools for research in this area. The age-range selected represents the main target population, but it is not exclusive of other ages. Furthermore, although the 5–7 age-range may seem relatively narrow, it is characterised by significant differences in children's emotional regulation as well as emotion recognition and categorisation abilities [42], thematic interests, communication and literacy skills. Taking account of all of these differences presents a significant challenge for the design of technology for this age group.

In ECHOES, children interact with intelligent, semi-autonomous virtual characters (embodied *agents*) in socially realistic situations. The agents inhabit a *sensory garden* (Fig. 1)—a multi-modal 3D environment filled with interactive objects that can become the focus of (joint) attention between them and the child. Children can manipulate the environment through touch, via a large (42″) multi-touch LCD display (see Fig. 2). ECHOES' *computer vision* is responsible for detecting where the child

Fig. 1 The sensory garden, with Andy, a semi-autonomous virtual character. Some of the objects are interactive. When touched, they become the focus of joint attention between the child and Andy

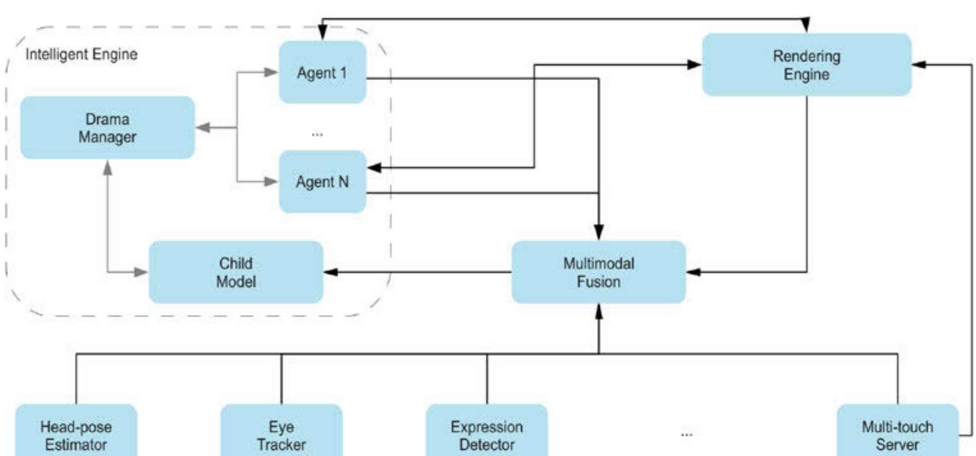
Fig. 2 A child interacting with the ECHOES environment through touch. Three cameras are positioned on the sides and top of the screen, enabling real-time head position and eye gaze detection

is looking at any given point. The interaction between the child and the agents is facilitated by a combination of *learning activities* that are designed around specific learning goals that relate to different forms of joint attention (see Sect. 3) and free exploration of the environment.

The model of each agent is fully implemented in ECHOES and is characterised by a set of internal goals, a set of strategies to achieve these goals and an affective system regulating the agent's emotional tendencies. The architecture of the ECHOES' agents is based on the FAtiMA planning system [16]. The system behaviours requested by FAtiMA, together with updates to the state of the environment, are sent to a *rendering engine* (see ECHOES' system architecture in Fig. 3), which combines three-dimensional graphics with sound. Input from touch and computer vision is combined into composite multi-modal events (*fusion component*), then sent to an *intelligent engine* that monitors and reasons about the child's behaviour through its *user model* of the child (the *child model*). The child model assesses, in real-time, the goals and cognitive and affective states experienced by the child during interaction, using a combination of supervised and unsupervised learning techniques. This assessment is based on static information about the child, including age, gender, preferences and information about previous interactions. Our initial tests of affect estimation based on unsampled data from six children interacting with ECHOES (in total, 2,422 training instances) suggest 68% accuracy for a baseline classifier (i.e. one that always chooses the most frequent class) for an overall F-measure of 0.078, using tenfold cross-validation and an improved cross-validation performance of 72.3% accuracy, using SVM classifier for an overall F-measure of 0.302. We are currently collecting and further annotating child–ECHOES interaction data in order to fine-tune and improve ECHOES' affect estimation capabilities.

The vision component detects eye gaze direction, and the head and gaze direction provides 2D screen coordinates of the child's attention. This is used to update the child model and to allow the *drama manager* to choose the

Fig. 3 ECHOES' system architecture



behaviour for the system to adopt, ensuring that the interaction adheres to the learning goals and that the ensuing interaction forms a coherent narrative. The computer vision component models and tracks the child's face and head pose automatically [15] and uses the facial features to detect the child's smile [11]. Information about child's facial expressions is used to estimate the child's emotional state and focus of attention. For eye gaze, our initial laboratory-based tests suggest accuracy of 85% based on 100 trials with different users. For face detection, the current overall rate is 95%, whilst for smile detection, it is 92%. We are in the process of fine-tuning and further testing this component with children.

3 ECHOES' design methodology

Our design methodology derives from a combination of Action Research (AR—from Education), participatory design (PD—from HCI) and Applied AI. We emphasise the need to move the locus of design and development closer to the user's community of practice, viewing design as a dynamic, incremental process that both changes and is changed by the context of practice. To improve practice, close collaboration between researchers and practitioners is vital: An iterative, practice-driven approach increases the chances that systems and practices that emerge have a real chance of taking root within the culture of schools.

Action research seeks to combine the activities of observation, interpretation, planning change and implementing change within a single framework, and both stimulates and is stimulated by the growth of theory. Typical action research [13] involves small-scale interventions in ecologically valid educational contexts, and a close examination of the effects of such interventions [21] repeatedly demonstrates that when innovation is attempted without the active participation of the community that is expected to practise the change, its success is extremely limited. The origin of this approach, which [43] has applied to other professions in his highly influential account of the 'reflective practitioner', is commonly attributed to [44].

Participatory design approaches are grounded in the perspectives, practices and needs of the target user group. Participatory design (PD) was born out of a political context in Scandinavia and sought to democratise working environments by involving workers as stakeholders in the decision-making (e.g. [7]). This was motivated mainly by an ethical argument that promotes empowerment and inclusion. It is strongly related to human–computer interaction (HCI) approaches such as user-centred design (e.g. [31]). PD has been adopted by the field of HCI as a method of achieving end-user involvement in the design of interactive artefacts (e.g. [35]). Thus, PD is about giving users a voice in the design of technology that they will use, designing *with* them rather than *for* them.

If the design aspect of interactive environments plays a crucial role for the engagement of users in general, this is even more true for users who are on the autistic spectrum: The aesthetics, the look-and-feel and the flow of the interaction can determine whether technology can engage a user. Furthermore, if, as is the case with ECHOES, the users are children, their perspective on the world around them differs significantly from an adult designer-researchers' view. As Good [23] put it: 'what children want and expect is likely to be different from what adults think children want and expect'.

In the following sections, we describe the methodology adopted in ECHOES. Our design decisions, the challenges associated with the methods that we chose in ECHOES and the resulting methodological guidelines are based on a multitude of design workshops, formative evaluation and research studies with children both TD and with ASDs (aged between 4–14 years), and with young adults with ASDs. To date, we have conducted fourteen design workshops with children (87 TD; 53 with ASDs), four formative evaluation studies (46 children with ASDs) and three research studies (75 TD children; 34 children with ASDs; 11 young TD adults; and 11 young adults with Asperger's Syndrome).[1] The purpose of ECHOES' design workshops is to inform the design of the *look-and-feel* of the environment including the functionality and interactive properties of objects, the appearance of the ECHOES' agents and other aesthetic decisions (see, e.g. [20]). The purpose of the formative evaluation studies is to evaluate the design decisions and the robustness of the individual components of the system and the overall system usability. Research studies serve to further inform the design of the system—typically the architecture and functionality of the underlying components such as the user model of the child, the drama manager and the computer vision, and to test the specific research questions, for example the extent to which children's perception of causality and animacy is affected by their preferences for specific objects (e.g. see [51]) or children's recognition of the ECHOES' virtual characters as agents and the ensuing impact on children's ability to engage in different forms of joint attention with the agents (e.g. see [1]).

In addition to the workshops with children and young adults, we also conducted two knowledge elicitation workshops and several consultations with expert practitioners (total $N = 30$) and older (11–18 years old) high functioning children and teenagers with ASDs who acted as

[1] The numbers of participants represent the total number of ASDs children and young adults, both with and without ASDs who took part in the respective workshops and studies.

consultants ($N = 3$). The workshops and studies have been conducted by the different ECHOES sub-teams in different schools across the United Kingdom. Due to space constraints, the details of the specific workshops and studies are beyond the scope of this manuscript and are described elsewhere (e.g. [2, 3, 20, 49, 51]).

3.1 Artificial intelligence in education (AI)

AI methods are tacitly interdisciplinary. [9] describes AI research as being of three different kinds: (1) *applied AI*, which aims to build products; (2) *cognitive science*, which aims to model human or animal intelligence and (3) *basic AI*, which seeks to explore techniques for simulating intelligent behaviour. The ECHOES technology is developed with similarly related objectives: (1) we aim to build intelligent technology that provides a TEL for young TD children and children with ASDs; (2) ECHOES' computational tools can be used to explore both theoretical research questions of importance to the understanding of autism (in particular in relation to joint attention) and the effects of TEL interventions; and (3) ECHOES facilitates technology-mediated interaction between its young users and semi-autonomous agents through multi-modal technology.

ECHOES adopts the Persistent Collaboration Methodology (PCM—[14]) to achieve its goals. Drawing from AR, PCM advocates active and continuing (persistent) collaboration between researchers, practitioners and technology experts in both the design and evaluation of TEL. It involves phases of four (unordered) cycles: *observation*, *reflection*, *design* and *action*. There may be a number of iterations of such cycles, which may stop and start anywhere within the process. In reality, the division between them is fuzzy. Each of the collaborators contributes distinctive knowledge and skills to the process, and can influence, and be influenced by other stakeholders. In addition to these four activities, PCM advocates that any technology should have theoretical underpinnings and that as well as fulfilling a primary goal, for example, to provide tutoring support to users in a specific domain, it should also function as a research tool capable of contributing back to the theory and practice.

3.1.1 Drawing from theory and practice

The theoretical foundations of ECHOES are built on major theories of child development, in particular developmental psychopathology, which views atypical development as a lens through which the norm can be better understood [12]. Viewed broadly, development involves the transition from understanding physical causality (physics of interacting with objects) to psychological causality (understanding that people have minds). The ability to reason about one's own and others' mental states (known broadly as 'theory of mind') is fundamental to many social, cognitive and linguistic skills. The constellation of persistent socio-cognitive difficulties experienced by individuals with ASDs is thought to stem from the inability to impute others' mental states [4].

Closely related to theory of mind is the group of skills and behaviours of *joint attention*. Frequently conceptualised as a triadic social coordination between two persons and an object or event in the environment, it requires the monitoring of another person's attention in relation to one's own [10], often through attending to another's gaze. Joint attention is considered a key developmental building block, or even a necessary precursor [48], for theory of mind. It also constitutes the main focus of the learning activities within ECHOES.

Joint attention has a strong visual component. The ability to follow and monitor others' eye gaze is the key to many types of social interactions. We posit that technology that facilitates joint attention also needs to possess the ability to detect and monitor the attention of its user. Within ECHOES, agents have the ability to emulate human gaze patterns in order to allow them to both initiate and respond to bids for joint attention. The emphasis on joint attention and the associated behaviours illustrates one way in which existing theories can influence the design decisions of technology.

A similarly close relationship exists between ECHOES and clinical and educational practice. The Social Communication, Emotional Regulation and Transactional Support (SCERTS) framework [39] provides the basis for the ECHOES' learning activities. It is founded on research and evidence-based practice, combining many major theories with well-established intervention practices including contemporary ABA (e.g. Pivotal Response Treatment, LEAP). SCERTS can be used *in tandem* with other established interventions, providing extensive guidelines in relation to the assessment of individual children by trained practitioners and to selecting and organising intervention activities. SCERTS provides a fertile ground for activities that target specific developmental precursors such as the ability of a child to imitate others, to understand the properties of objects as well as more advanced social skills related to turn-taking, initiating interactions and recognition of intentionality (agency).

3.1.2 Design of ECHOES' learning activities and the related challenges

ECHOES' learning activities correspond directly to the intervention goals specified in the SCERTS framework: They are organised around the environment's different elements. For example, flowers can become objects of interest, desire or admiration and can serve as triggers for the joint attention between the child and the agent. In order to support coherence, activities are linked through narratives that motivate the existence of the agent in the environment and its specific actions. For example, the agent may justify its desire for a flower by saying that it is collecting flowers for its mum, or it may initiate an object-sorting activity with the child by asking the child to help it tidy the ECHOES' garden shed. The different scenarios contribute to the story that unfolds in real-time, based on what the child does and the different possible behaviours of the objects and agents. The scenarios provide the child with opportunities for exploration and can be linked to form larger narratives.

Although SCERTS forms the practical basis for learning activities, it was developed for *human–human* intervention context, in which the practitioners use their long-term experience in assessing children's needs and in deciding what activities may be best. This presents ECHOES with a number of challenges of how to adapt this framework to *human–computer* interaction.

One challenge is how technology designers can access practitioners' knowledge. Practitioner's understanding of the possible behaviours that may suggest a child's affective states (e.g. boredom, joy, frustration), cognitive states (e.g. focus of attention, curiosity, understanding) and the level of goals' achievement are crucial to delivering intervention that works for that child. Such knowledge is not easily accessible, and its formalisation within a computer system is not trivial. Even if the practitioners' knowledge could be represented explicitly, current technology limits what user information a TEL environment can capture in real-time. AI techniques such as user modelling, planning and reasoning do equip ECHOES with an ability to detect, to reason about and to act on the child's actions, but such technology is not always robust and this is why the design of learning activities in ECHOES involves reliance on different modalities to support the interaction.

Another challenge relates to whether the child perceives the agent as an intentional being or merely an inanimate object. Interacting with the agent as an intentional being is crucial to ECHOES facilitating believable social interactions with the child. Reciprocity of agent behaviour and proximity of the behaviour to the type of behaviour exhibited by children has been suggested by [46] as one requirement. Another suggestion relates to the need of virtual agents to act as virtual peers as this may impact positively the effectiveness of interventions and interactions between them and children with ASDs [33]. A further test-bed for the children's perception of agent's intentionality is 'mutuality', i.e. the degree to which the child views the agent's communicative acts and intentions as being relevant to them [5]. The employment of small design and evaluation cycles, first involving mock-ups and then simple implemented prototypes allows us to address this challenge. An important design consideration is that the affordances of digital environments are different to those of human–human contexts. Digital environments permit the creation of magical worlds, where children can play with the different objects in a way that the real world does not afford. The challenge lies in embellishing the digital world with magic without losing the possibility of the experiences and skills acquired within it being transferrable to the real world. A magical world and the various transformations must also be plausible to the children. In Sect. 3.2, we discuss our application of the participatory design methods as our approach to reaching the desired outcome.

3.2 Design, reflection and action: participatory design (PD)

PD has been adopted by HCI to achieve end-user involvement in the design of interactive artefacts (e.g. [35]). PD is not just about acquiring requirements for system developers and matching the *look and feel* with users' preferences, but, crucially, it presents an ethical argument for giving users a voice in technology design. Children, users with ASDs, their carers and teachers are often marginalised in the design process. PD promotes mutually respectful relationships with stakeholders. This leads to an immersion of the designer in the users' world and allows for a more empathetic and mindful interpretation of their contributions.

The ECHOES' PD process involves a series of workshops with primary schools and specialised units working with ASDs children, through which sensory exploration and idea generation for the design of the environment and its elements is facilitated [20]. Knowledge elicitation workshops with practitioners inform the design of the learning activities and the implementation of ECHOES' intelligence, including its user model and pedagogic component (incorporated in the drama manager). In the context of PD, we encountered several challenges that we will now discuss.

3.2.1 Balancing responsibility

When designing with children, the level of their involvement can vary from ideas testing to children being equal design partners [17]. Whilst aiming for maximum involvement, our experiences have shown that too high expectations can result in disengagement: Children can become overburdened with creative responsibility [27], and this can be amplified in participants with ASDs. In ECHOES, therefore, children play the role of informants rather than fully-fledged design partners.

In contrast, practitioners are both willing and able to engage as equal design partners: Their involvement and commitment is essential both for knowledge elicitation and evaluation. Practitioners' knowledge is often implicit, but our job as system designers is to access it and to formalise it. Such knowledge includes the ability to gauge the individual child's needs in general and moment-by-moment, and the knowledge of and ability to apply the transactional support strategies that will help the given child in a specific situation. This provides the basis for designing the intelligence of our system, through the user model, the drama manager, as well as the behaviour and emotional make-up of the agents.

One tension that occurred early in the project involved our need for clearly specified practitioner knowledge and the lack of a system that would serve as the trigger for eliciting it. Practitioners need clear props (e.g. mock-ups or early prototypes) to help them reflect on their expertise and to verbalise it. Without such props, bottlenecks in the development of the technology may occur. In ECHOES, one successful solution was to employ storyboarding and to engage the practitioners in role-playing activities (see Fig. 4). 'Typical' child profiles were created by the practitioners and storyboards developed for each of these. Such tools played a crucial role in situating the activities within the experience of the practitioners and triggered a flow of information and ideas from them.

3.2.2 Mindful interpretation

The PD activities with children produced a wealth of ideas for the ECHOES system design. However, the way in which children, particularly those with ASDs, expressed their ideas was difficult to translate into actual design: They often became absorbed in details and were driven by their recent experiences. To deal with this issue, we used an approach informed by phenomenology that took us beyond the literal meaning, using the expressed experiences as the starting point for our interpretation [20]. For example, when we explored possible magical transformations of objects, a child showed us how a playground slide turned into a boomerang that had the same shape. Looking at the phenomenological qualities of the experiences described by the child, we derived a generic design concept: By using similar shapes for objects with very different functionality, we used scaling to transform one object into the other, e.g. an arch over the gate to a sensory garden can be scaled by the child and turned into a rainbow. This approach involves *mindfulness*, is non-judgmental and relates to the nature of experience that unfolds in the *here and now* [28].

3.2.3 Engagement and learning

Where aspects of the system and the interaction have been predetermined (narrowing the scope of PD activities), a tension emerged. Whilst the SCERTS framework provides guidelines as to the goals of the learning activities, PD activities focus on what constitutes an enjoyable experience within ECHOES. In the context of Autism, PD runs the risk of reinforcing existing traits of a child: An exaggerated focus on detail might be the most engaging feature for a child with ASD. However, overemphasising the need for children to complete a learning task may disengage them from the experience: Whilst learning goals might be achieved, the associated skills may not be retained. PD activities are conducted within a school environment in order to maintain ecological validity and to optimise the opportunities for contextual design. Issues that impact the development and deployment of ECHOES (e.g. the curriculum, class dynamics and technical support) must be considered from the outset.

3.2.4 Practicalities

Strong and sustained collaboration requires significant time, commitment and resources. One of the main difficulties is ongoing and timely access to participants, practitioners and parents. In ECHOES, schools are the primary point of access to our participants. Activities are developed with the aim of schools benefitting from our visits and with

Fig. 4 Knowledge elicitation and storyboarding activities with the expert practitioners

least disruption possible for teachers, parents and children. This often takes the form of providing additional motivation for children, ensuring that activities fit into the current curriculum, sharing the outcomes with the school for inclusion in the schools' record and providing information on the research undertaken as part of staff's continuing professional development activities (CPD). It is important to recognise that schools normally gain very little else by engaging with research projects, so these incentives help to balance the relationships. When approached in this way, we found that schools were very willing to collaborate with us, but intrinsically, work in schools is unpredictable and flexibility on researchers' part is required. It is also important to keep parents fully informed and make the process as transparent as possible, in order for them to give consent for their children's participation. Whilst parents of children with ASDs are generally keen to participate in research that may bring them long-term benefit, access to parents of TD children and therefore to TD children themselves is often more challenging. We addressed these difficulties by developing a wide and committed network of different stakeholders, willing to act as informants and as advocates of the research. We discuss this further in the next section.

3.3 The role of stakeholders

In addition to the children themselves and the research team, other stakeholders in the project included (1) those working in the schools; (2) parents; (3) other expert practitioners; and (4) those academics doing related research. Each of these groups was involved to a greater or lesser extent in the ECHOES project.

Prior to conducting design workshops and other school-based studies, schools were contacted, and teachers and other school-based practitioners asked for their feedback and input, as well as their willingness to collaborate in the research. The starting point for this was usually an individual contact in a specific school, followed by a meeting with the school management team, who then discussed our proposals with staff. In some cases, members of the research team also met with parents at parent evenings, or with staff teams. Once it was agreed that we would work in a school, input was requested from teachers on which children to involve in particular studies, how to communicate best with each child and the appropriateness of the materials and study plans for the children participating. Teacher input included: suggestions of how best to phrase information going to parents, both to make it more accessible to them and to increase the likelihood of their child participating; specific phrasing to use that fitted with what was used in classrooms, e.g. 'good listening', and information about tools such as picture symbol systems that the children were familiar with and how we might use them.

In order to obtain input from a variety of expert practitioners, individual contacts of project partners were used to identify a number of experienced professionals working with children with ASDs, including speech and language therapists, teachers, outreach workers, psychologists and other stakeholders. These contacts were invited to be part of a Specialist Advisory Group for ECHOES (SAGE). In turn, they suggested other practitioners who might be interested in being involved. Other contacts included those active in parent groups. Several meetings were held with the SAGE group, the style of these meetings being similar to design and knowledge elicitation workshops, as discussed above. An example of their contribution includes designing a set of personas and scenarios, based on children they were familiar with, to better inform the design process. The group were also asked for their input on our evaluation plans and made suggestions of schools that might be interested in being involved, and providing a first point of contact. In addition to practitioners, one parent and several adolescents with ASDs were part of this group.

An academic advisory group was also established, comprising six established academics working in related research areas across a number of related disciplines. They were asked to provide feedback on project plans and progress and in several cases gave specific advice on a variety of project issues.

Advantages of the approach of involving stakeholders in these ways include: contribution to CPD of researchers and practitioners; an approach that emphasises ecological validity and provides a developing model for working in classrooms; increased opportunities to shape evidence-based practice; and increased likelihood of greater impact and future uptake.

4 Evaluation

4.1 Internal testing and formative evaluation

Internal evaluation requires testing of the various system components within the implementation cycles of the respective technologies. In ECHOES, this includes testing the accuracy of the child model, assessing the suitability of the actions selected for each child and confirming the appropriateness of interactions and validation of the gaze detection.

Broader formative aspects of evaluation related to the development process include testing of the learning activities; usability of the environment in the various stages of development; and fine-tuning of the environment to the target populations. These are addressed through task-based, exploratory, formative evaluation studies with small groups of children with and without ASDs (of the target age and above), and with input from expert practitioners. Such studies provide both feedback at each stage of ECHOES' development and inform the design of the next stage, but input is required from all stakeholders. For example, one study ran in a specialist school for children with ASDs ($N = 32$: 29 men, 3 women, aged 5 to 14 years) enabled preliminary testing of the interaction with the ECHOES environment and resulted in adjustment of response timings and activity duration. It provided strong preliminary evidence of the children's engagement with the agent and suggested the possibility for joint attention between the child, the agent and ECHOES' objects [2].

4.2 Assessing the impact of ECHOES' intervention

Generalisation of learning to everyday functioning (the 'Holy Grail' of any ASDs intervention) has proved very hard to achieve even for large scale, resource intensive studies with very specified outcomes (e.g. [24]). [41] suggest that before expensive large-scale randomised controls (which measure effectiveness) are rolled out, the *efficacy* of an intervention must be established first, e.g. through more single-case and open trial designs (e.g. [50]). ECHOES focuses on efficacy: Exploratory small-group case-based research studies are undertaken, using a single participant, multiple baseline design across participants, staggered over time, across multiple sites.

Within ECHOES, individual level performance can be evaluated by looking at change in performance over time (e.g. improvement across trials) within a particular learning activity. A key indicator of *proximal* change (any within environment change—[24]) would be to show that children could transfer or apply their learning to a novel, hitherto previously unfamiliar, 'test' environment. A stronger case for proximal learning could be made if the child has the experience of one type of joint attention (e.g. following the agent's gaze) and is then put in a test environment in which they use another type of joint attention, following the conventions of ECHOES (e.g. directing the agent's attention).

We plan to use the SCERTS assessment system as a tool for analysing short video clips of children interacting both within the ECHOES environment, in classroom contexts and in carrying out task-based activities. Further *distal* effects (any improvement in a child's everyday socio-cognitive understanding) can be evaluated by asking children, teachers and parents about their perception of any difference ECHOES has made. If it could be shown that children's experiences of ECHOES had influenced the child's behaviour outside the ECHOES environment, then this would constitute a high level of success. However, for some children, simply interacting and engaging with the environment could be seen as a success. It seems likely that success will depend largely on the individual child's starting point and expected capability. One of ECHOES' strengths is its lack of prior assumptions about the child: Success can be deemed on a case-by-case basis.

4.3 Interdisciplinary, participatory evaluation of ECHOES

The ECHOES' PD approach further extends to the evaluation of its impact. The research design proposed involves experienced practitioners, from a range of backgrounds, from the outset. Evaluation is to be undertaken in partnership with both mainstream primary and special schools, grounding it in, and clarifying its contribution to, practice. Training is to be offered to the participating schools. Advantages of this approach include enhanced ecological validity and a basis for models of working with and in schools. It will provide increased opportunities to shape evidence-based practice, and to support practitioners in developing the skills needed to implement this, contributing to multi-professional practice, CPD and promoting interdisciplinarity. Through research and practice partnerships, we aim to extend the impact of the research beyond the project's life.

5 Conclusions

We presented the ECHOES project as an exemplar of an interdisciplinary approach to designing technology for users with ASDs. We aim to show that if technology design is viewed through the prism of interdisciplinary research, not only it can serve as a means of delivering intervention in situ but it can also provide an extension to human–human intervention that is adaptive, intelligent and engaging. Conducting interdisciplinary research presents challenges for the individual stakeholders involved. The ECHOES project serves here as a case study for the research methodology proposed: The ECHOES' team brings a number of different perspectives, scientific traditions and personal presumptions. We have described how we approached the challenge of developing technology for young children with ASDs and what we have learnt in the process. We will now distil from these experiences specific conclusions that may contribute to the practice, theory and culture of research in this field.

It is important to explore where different disciplines overlap, in principle and intent, and to examine ways in which the most pertinent aspects of each can be combined within a single methodological framework, such as the one applied in ECHOES. Developing a coherent research framework that supports different stakeholders in understanding, appreciating and achieving the goals of the research is daunting. It is also time-consuming and may be dismissed by some as time inefficient and unnecessary. However, it is fundamental to the success of developing technology that works in the real world.

The pronounced diversity in behaviours, preferences and traits amongst people with ASDs means that any technology should support personalisation: We chose to do this through embellishing our technology with intelligence (in the AI sense). Where the goal is to support exploration and acquisition of social skills by young children with ASDs, it is crucial that TEL should be able to emulate at least some human behaviours in order to support naturalistic interaction. It is important to adapt the environment to the individual child, whilst avoiding over-specialisation of the interaction to what may be the narrow interest of the specific child. Furthermore, although AI techniques equip us with a starting point in affect and cognition modelling, they have been applied and tested predominantly in the context of older TD users, and within well-defined interaction domains such as teaching mathematics. The differences in the domain of application and the special needs of young users with ASDs present new and exciting challenges and an opportunity to further test and extend the existing methods and techniques.

In designing technology for people with ASDs, their perspective may differ from the assumptions of TD individuals. An inclusive dialogue can lead to the emergence of technology that works. In ECHOES, such dialogue with the different stakeholders within formative cycles of observation, reflection, design and action has led to the appreciation that the primary evaluation focus of ECHOES' intervention should not be on the effectiveness of the ECHOES intervention (i.e. large-scale randomised control studies), but, in the first instance, on its efficacy: if any generalisation of learning is to be demonstrated, it is vital to define and evaluate both proximal and distal indicators of change.

The ECHOES project is currently embarking on its summative evaluation effort. This effort is aided by the close partnerships developed throughout the project with the schools, practitioners and children and their parents. Such partnerships are crucial to the success of any technology that is intended for real-world use and ensure that the ECHOES' success (and shortcomings) can be assessed in real contexts. We will be reporting on the specific methods, procedures, related challenges and, above all, the results in the very near future.

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