# State-of-the-art in TEL to support social communication skill development in children with autism: A multi-disciplinary review

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**Abstract:** The paper reviews state-of-the-art in TEL to support social communication skill development in children with autism. We identify the driving research directions, and their associated challenges, from three broad perspectives that shape TEL: pedagogical foundations, technology, and learner involvement in the design process. We further explore these challenges through the discussion of ECHOES, an example state-of-the-art system. The review assists researchers working in multi-disciplinary teams to identify the new directions that are shaping state-of-the-art in order to drive successful future research projects in this area.

Keywords: technology enhanced learning, social communication, multi-disciplinary, children, autism, ASC, virtual agent, virtual environment, multi-touch, affective computing, user modelling, participatory design

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## 1. Introduction

Technology enhanced learning (TEL) to support the development of social communication skills in children with autism is a fast growing area of research. The overarching aim of any TEL system is pedagogical. However, the design space is vast and the development of TEL experiences is a multi-disciplinary process, involving, for example, psychology, design, and computer science. State-of-the-art in TEL is shaped by new directions from each discipline.

In this paper we review state-of-the-art TEL research to support social communication skills in children with autism from the three broad disciplinary perspectives that currently shape it: 1. pedagogical foundations (including psychology and educational research), 2. technology (including input processing, embodied agents, and user modelling), and 3. learner involvement in the design process (including participatory interaction design and visual arts). The aim is not to give an exhaustive review or to discuss the evaluation of these systems, as this has been done elsewhere (for example, Wainer and Ingersoll, 2011), but to identify the current disciplinary research directions that are shaping state-of-the-art research in this area and the challenges that emerge from them. The review assists researchers working in multi-disciplinary teams to identify the new directions that are shaping state-of-the-art in order to drive future research projects.

In section 2 we identify current disciplinary research directions that are driving the design of TEL to support development of social communication skills in children with autism. In section 3 we discuss the challenges that emerge from these new directions. In section 4 we further explore these challenges through the discussion of our work in this area: the development of ECHOES, an example state-of-the-art TEL system.

## 2. TEL for social communication development in autism

The term autism is used in this paper to mean Autism Spectrum Condition (ASC). Autism is a lifelong neuro-developmental condition with conservative estimates of its prevalence at 60/10,000 (Medical Research Council, 2001). According to the Diagnostic and Statistical Manual (4$^{th}$ edition, American Psychiatric Association, 1999), autistic individuals may experience difficulties with social and emotional understanding and interaction, use and understanding of communication and language as well as flexibility of thinking and behaviour. Sensory perception and processing difficulties can also be present. Social communication difficulties are considered a core feature in autism (Volkmar et al., 2004) and they tend to be universal in individuals across ages and language abilities (Tager-Flusberg, Joseph and Folstein, 2001). Difficulties in social communication entail emotional reciprocity, verbal and nonverbal communication, and developing and maintaining relationships. The paramount significance of educating people to be able communicators is stated in the European Convention on Human Rights (Article 10, online) and the UN Convention on the rights of the Child (Article 13, online). Supporting social communication should be a priority for all intervention programmes for children with autism (Sigafoos and Littlewood, 1999; Prizant et al., 2006). A variety of approaches have been used to this end. Two main approaches are behavioural/

naturalistic (for example, Applied Behavior Analysis-ABA, Picture Exchange Communication System-PECS) and developmental/relationship-based (for example, Social Communication Emotional Regulation Transactional Support-SCERTS, Intensive Interaction). Behavioural/naturalistic approaches take place in highly structured environments in which adults use reinforcement, prompts, modelling and predictability. In developmental/relationship-based approaches adults build strong relationships with the child through mutual enjoyment of their interaction.

Recently, technology has been widely used to support the development of social communication skills in children with autism as they show affinity to technology (Hardy et al., 2002). Technology has provided a means to both engage children and to manipulate the social interaction in order to simplify it, make it more predictable, and make important information salient to the learner. Thus TEL experiences are well placed to support the development of social communication skills. This section reviews the research directions that have shaped state-of-the-art research in this area from the three broad perspectives that currently shape TEL for autism: 1. pedagogical foundations, 2. technology, and 3. learner involvement in the design process.

### *2. 1. Pedagogical foundations*

We can categorise TEL systems based on four pedagogical approaches. The first involves *training component skills of social communication (a)*, such as facial expression recognition, in isolation of the everyday context in which they are used (for example, Golan et al., 2010). In contrast, the second approach adopts a contextualised framework for understanding children's behaviour that aims to deliver intervention through *structured activities in the context of interaction with others (b)* (for example, COSPATIAL, online). A third, less structured, approach uses technology to *immerse the child in creative play (c)* (for example, Keay-Bright, 2007). In this case the technology is the prompt for social interaction and the scaffolding of social communication skills relies on the expertise of the human social partner. A fourth category are *tools for visual communication (d)*, which indirectly support development of social communication skills by facilitating communication (for example, Madsen et al., 2008).

a) *Training component skills of social communication:* Explicit targeting of social communication skills has largely focussed on facial expression recognition. For example, Golan et al. (2010) report on a study that used a 3D animated series called 'The Transporters' to train recognition of facial expressions. The series features animated vehicles with human faces that display a range of emotions. The animation is designed to draw attention to facial expressions by minimising the detail in the rest of the scene.

In the category of training component skills we also include virtual environments that help support learning about relevant social cues and appropriate response behaviours. For example, some virtual environments support learning about specific social contexts such as cafes (Parsons and Cobbs, 2011). Other software can be used to engage the child's explicit understanding of past or future social events from the child's life (for example, iCommunicate, online).

b) *Structured activities in context of interaction with others:* The TEL systems in this category range from technologies to support structured collaborative activities with adults or peers, to more technologically sophisticated systems that take on the role of the social partner (robots or virtual agents). Though the technology may be different, what all these TEL projects have in common from a pedagogical perspective is that the technology is designed to structure the interaction and scaffold particular responses from the learner during the course of the interaction. The nature of the interaction, therefore, needs to be specified, as do the behaviours or prompts that will elicit communicative responses and initiations from the child. For example, the SIDES project (Piper et al., 2006) developed a cooperative game on a multi-touch tabletop that scaffolds turn-taking and forces players to wait for their partners' turn. The COSPATIAL project (2012) explored the design of collaborative games in a virtual environment. Tangible technologies also show potential to support collaborative play (Farr, Yuill and Raffle, 2010). Virtual agents (for example, Tartaro and Cassell, 2008; ECHOES, online) and robots of various designs (for example, AuRoRa, online) have been used to explore scaffolding of social communication, both with the robot as a medium for collaboration with a human partner, and as an artificial social partner that engages the child in joint attention and turn-taking.

c) *Immersing the child in creative play:* A few TEL systems have been developed as simple applications that support explorative play. The interaction with the technology in these applications is unstructured and the enjoyment and engagement with the technology acts as a prompt for the child to interact with others around them. For example, the ReacTickles software (Keay-Bright, 2007) is an application that creates flowing patterns of abstract shapes in response to the user's actions. Other examples of such systems are MEDIATE (Pares et al., 2005), and the robot Keepon (Kozima, Michalowski and Nakagawa, 2009).

d) *Tools for visual communication:* Visual supports have long been used to assist communication (Savner and Smith-Miles, 2000). Software applications that run on mobile touch-screen devices have provided easily customisable visual language tools through which children with autism can express themselves non-verbally (for example, iCommunicate, online). Other approaches have involved development of supports that help autistic individuals interpret facial expressions in real time (Madsen et al., 2008). These technologies do not aim to directly scaffold the development of social communication skills. It is through facilitation of communication that they provide support, allowing children to develop their skills through increased participation in social interaction with others.

The four approaches use technology in different ways to achieve the same goal of supporting social communication. The skills targeted in the first approach may support the child interpret social interactions and, therefore, help them to participate in social events. The second approach scaffolds social interactions with a human or artificial partner, in order to support the child gradually increase their understanding of social interactions and their ability to engage in them. The third approach also scaffolds social interactions, but here the scaffolds are provided by the (human) social partner, not the technology. In this approach, the technology acts purely as a medium to engage the child. The fourth approach provides assistance to the child to facilitate their participation in social interaction. However, the technology here is not explicitly designed to scaffold the development of skills that will eventually replace the need for assistive tools.

## 2.2. Technology

The technological requirements of TEL interventions vary. Some have relatively simple requirements, for example, the implementation of ReacTickles (Keay-Bright, 2007). In contrast, others rely more heavily on recent advances in computer science, for example the implementation of adaptive virtual agents (ECHOES, online). In this section we concentrate on the technological building blocks that can be used to develop TEL systems. We begin by discussing advanced low-level interaction technology: speech recognition and synthesis, head and body tracking, and (multi-) touch input devices. We then discuss ways that embodied agents have been used in this area of TEL. Finally, we outline the intelligent technologies that can be used to select the behaviour of TEL systems: user modelling and affective computing.

*Speech recognition and synthesis:* If the goal is to enable children with autism to learn skills which will eventually transfer to real-world social scenarios, it is useful to allow them to interact in a setting as close to face-to-face conversation as possible. However, recognising the speech of even typically developing (TD) children is known to be a difficult problem (Gerosa et al., 2009). The spoken language of children with autism can often be unintelligible to humans (Koegel et al., 1998), which makes automated speech recognition even more difficult. For this reason, most interactive systems for children with autism that allow spoken input have employed a “Wizard of Oz” methodology, where a human experimenter provides input to the system (for example, Milne et al., 2010; Tartaro and Cassell, 2008). Speech synthesis is also a challenge in this area: ideally, for systems that aim to recreate social interaction, any spoken output should use a child-like voice. However, synthesising child speech presents difficulties (Watts et al., 2010). A common solution is to use pre-recorded prompts (for example, Tartaro and Cassell 2008): this produces higher-quality speech, but limits the flexibility of the system.

*Head, face, and body tracking:* In face-to-face interaction, non-verbal behaviour such as gaze, facial expressions, and body language provide a rich communicative channel. Detecting this behaviour of the user is therefore an important aspect of supporting social interaction. Computer vision is the least invasive method of tracking non-verbal behaviour. Software such as FaceAPI (Seeing Machines, 2012) and the Computer Expression Recognition Toolkit (Littlewort et al., 2011) can provide robust head-pose estimation, expression recognition and gaze tracking, while products such as the Microsoft Kinect (Microsoft Corporation, online) are able to do body tracking.

*(Multi-)touch input devices:* Touch screens and other touch input devices allow the users to interact directly with the system. In recent years touch interfaces have become mainstream, ubiquitous, and therefore both cheaper and less potentially stigmatising. Multi-touch devices, which respond to several simultaneous touches, have further expanded the interactive possibilities of touch screens. Touch hardware may be small and portable (Apple Inc., online), or take the form of a large screen (PQLabs, Inc., online). The directness of the interaction makes touch devices potentially useful for autism (for example, Hewlett-Packard, online; Hourcade, Bullock-Rest and Hansen, 2012).

*Embodied Agents (EA):* An EA is a computer interface that is represented as a human body. It can exhibit facial expressions and body language either with the goal of encouraging the child to engage in interaction or to give the child practice in identifying signals such as facial expressions. The main benefit of an EA is that it allows users to interact with a computer in face-to-face conversation. Reeves and Nass (1996) and others have shown that, when artificial systems produce social cues, users will respond socially.

Examples of virtual agents that have been used with children with autism include the life-sized virtual peer developed by Tartaro and Cassell (2008), which was able to participate in collaborative narrative with children with autism. Milne et al. (2010) created a virtual tutor that instructs children with autism on social skills including detecting and responding appropriately to facial expressions and dealing with bullying.

A number of studies (for example, Bainbridge et al., 2010) have shown that physical embodiment promotes higher social engagement and attribution than virtual embodiment, as well as greater enjoyment, believability and trustfulness, especially with regard to cooperative tasks. Examples of social robots that have been used with children with autism include Keepon (Kozima, Michalowski and Nakagawa, 2009), a small silicone-made robot. Different robotic platforms have been used in the context of the AuRoRa project (online), from simple mobile robots to more anthropomorphic creatures.

*User modelling:* The behaviour of embodied agents in the context of assistive technology for children is generally remotely controlled. Recent research, however, has explored the development of autonomous agents, which will be able to act on the basis of a real-time assessment of the child's behaviour (and cognitive and affective states) using modelling techniques. For example, Feil-Seifer and Matarić (2011) introduce a technique to automatically distinguish positive vs. negative reactions of children on the basis of the physical distances between the child, the robot and the parent. Within the AuRoRa project, a technique has been developed for automatically recognizing the style of play of a child ("gentle" vs. "strong") (Francois, Polani and Dautenhahn, 2007).

*Affective Computing:* A full range of wearable technological artefacts and new machine learning techniques have been developed to allow detection of affective states (El Kaliouby et al., 2006). These portable sensors, which can be embedded in jewellery or woven into clothing, are able to capture one or more channels of affective information, such as facial expressions, gaze, tone of voice, gestures, and physiology. Software techniques interpret the affective cues and infer states such as frustration, stress, and confusion. The detection of these states is key to enhancing communication by and towards people with autism. A machine (robot or virtual agent) can receive information about his/her affective state in real time and be able to adapt by exhibiting an affectively appropriate behaviour. Inferred affective states can also be communicated to users in order to allow self-awareness and self-regulation (for example, Teeters et al. 2006).

The technological advances reviewed in this section are enabling the development of increasingly sophisticated technologies that can provide naturalistic communication channels and can adapt to the individual child in real-time. However, none of these technologies will deliver effective interventions if the experience is not engaging to the child. In the following section we discuss the approaches taken to understanding the user experience from the child's perspective.

### *2.3. Learner involvement in the design process*

The design of TEL systems to support development of social communication skills in children with autism has predominantly been shaped by pedagogical foundations and the development of new technologies. Individuals with autism have had less of a role in shaping the design. However, research in the field of Human Computer Interaction (HCI) is moving towards design approaches that go beyond eliciting feedback from end users at various stages of the design process but try to actively involve them as co-designers (Harrison, Tatar and Sengers, 2007). Participatory Design (PD) goes beyond making informed decisions and evaluating them, but recognises the ethical and social responsibility of including people who are affected by technology in its design (Ehn, 1989).

This inclusion of end-users in the design process makes them active stakeholders. Such empowerment of user groups is particularly important when their life experiences are radically different from those who design technology for them, and if they are exposed to unequal power relationships. People with special needs live in such relationships and participatory approaches can help them gain control and help researchers to understand their lives.

This section takes a closer look at the roles of children with autism in the process of creating TEL systems, and which approaches and methods have been used to involve them in designing the user experience. By user experience we mean communicative and interactional qualities as well as contextual relevance, motivational aspects, emotions and engagement. We categorise work by the level of involvement of autistic people in the design of TEL systems, applying a simplified adaptation of the ladder of participation by Arnstein (1969) and the participatory roles as defined by Druin (2002) as a framework.

*Non-participatory approaches:* The design of many TEL systems derives primarily from an analysis of the pedagogic requirements of the learner experience, and a broad understanding of what experience learners will find motivating to engage with based on previous work. A typical example is ‘The Transporters’ (Golan et al., 2010), which was designed without direct user involvement. It originated from experience of children’s attraction to patterns and rule-based movement, and their love for vehicles.

*Passive involvement and proxies:* The methods to inform the design of TEL systems in this category are restricted to the observation of children or engaging proxies such as teachers, parents or domain experts. As such, the input collected is mediated either by the interpretation of the researchers or the people who have first-hand experiences of the children or greater domain-specific knowledge of their needs. Zancanaro et al. (2010), for example, involved teachers and Cognitive Behavioural Therapy experts in a user-centred design process.

*Participatory design:* The most demanding form of involvement undoubtedly is direct participation in the design process. The features of autism such as social skills difficulties, reduced language and behavioural problems make this particularly challenging (see Millen, Cobb and Patel, 2010). Benton et al., (2011) developed IDEAS (Interface Design Experience for the Autistic Spectrum), a participatory design process that addresses some of the issues children with autism experience during design activities. Support is provided, for example, by using drawing templates to scaffold the children's input or by using a visual timeline for sessions. Similarly, Millen, Cobb and Patel (2010) investigated how a participatory design approach for TD children could be adapted to fit the needs of children with autism in the COSPATIAL project. This included the use of scheduling, visual representations and the provision of context for users through structured representations of design work such as drawings. Keay-Bright (2007) describes a range of low-fi participatory activities with children with autism to elicit creative triggers for developing ReacTickles, a system focused on providing stimulating sensory experiences. The LINKX project involved low functioning children with autism in the design of a language learning game and demonstrated the difficulties of providing appropriate means for participation when basic communicative skills are impaired (Rijn and Stappers, 2008). It is important to note that this direct participation of children does not replace the need for engagement with other stakeholders such as teachers and parents.

## 3. Research challenges that emerge from state-of-the-art

State-of-the-art research gives rise to challenges in the design, implementation and evaluation of TEL experiences. In this section we discuss the challenges that emerge from the three perspectives of psychological foundations, technology, and learner involvement in the design process.

### *3.1. Challenges emerging from pedagogical foundations*

Generalising skills remains a major challenge for all interventions. The more motivating and predictable context of TEL may support the child to engage in social interaction, however, children with autism have great difficulties in generalising skills (National Research Council, 2001).

When evaluating the effectiveness of TEL systems it is important to understand where the learning (if any) can be attributed. Particularly for a system that is used in naturalistic settings, the contextual factors influencing the use of the technology make it difficult to conduct an evaluation that can identify the features of the technology and/or the context of use that led to learning. It is necessary to understand what worked and why to improve future designs. Equally important is the need to justify the cost necessary to buy or build TEL systems by demonstrating the role of the technology in learning.

The more structured the support from the technology, the more it becomes necessary to pre-define the space of possible interactions, in order to build the necessary knowledge and flexibility into the system. However, it is difficult to predict the ways in which children will interact with technology, particularly given individual differences and when designing for multiple contexts. It is also a challenge to identify pedagogic knowledge at the necessary level of specification. Practitioners are able to draw on their experience and familiarity with specific children to adapt principles for supporting social communication to different contexts. However, they cannot easily define how they interpret a child's needs or how they decide on an appropriate response. Pedagogical frameworks specify general guidelines for scaffolding social communication skills and provide example scenarios, but do not prescribe activities and behaviours in specific contexts. The specifics of how to respond to a child's behaviour are open to interpretation and rely on the social partners' experience. Even if these decisions are left to the practitioner, a range of possible system behaviours must be implemented for the practitioner to select from.

### *3.2. Challenges emerging from technology*

A general problem with many technological devices, as noted previously, is that they are designed for use with neurotypical individuals, most often adults. When technologies such as speech recognition and synthesis and head/body tracking are used by children with autism, the performance is often significantly lower in practice, which makes it challenging to build a successful interactive system. Another important consideration when using advanced technology in the context of TEL—particularly with special-needs children—is its physical robustness. Given that many children with autism find it difficult to cope with unpredictable events (Hatton and Boughton, 2011), such as unplanned changes in activities, they are likely to experience emotional dysregulation in cases of technical problems.

Integrating intelligent embodied agents and technology such as user modelling and affective computing into a system affords natural, 'face'-to-face interaction. However, using these technologies raises the additional, significant challenge of interpreting the child's state accurately. It also requires specifying and implementing intelligent, adaptive, and socially appropriate behaviour: an 'intelligent' agent that does not always respond appropriately could result in a lower quality experience.

### *3.3. Challenges emerging from learner involvement in the design process*

The specific context in which a TEL system is developed impacts on the level of involvement that is possible. For example, if the target user group are children with no language then less involvement is feasible than otherwise. New methods need to be developed that facilitate inclusion of children with autism.

Eliciting the support for participatory design both by researchers from other fields and from schools is another challenge. While HCI has a long tradition in human-centred design methods, psychology or more technical disciplines do not typically yield control to users. One of the challenges of increasing participation of users is, therefore, communicating its importance to researchers from other fields and finding ways in which pedagogical foundations and user involvement complement each other in shaping the design.

The social support network of children also plays a significant role: open-minded institutions or schools with available time resources are essential to support involvement and provide opportunities for empowering the end user group. However, it is potentially challenging to gain support for new TEL systems whose effectiveness is unknown. Communication of the aim of a TEL system, particularly where the technology is unfamiliar to teachers and is in the process of being developed (and thus cannot be demonstrated) is a real challenge.

## 4. ECHOES: an example state-of-the-art TEL intervention

In this section we discuss the key challenges that emerged in developing an example state-of-the-art TEL system. The ECHOES project was a multi-disciplinary effort that involved collaboration from psychology, education, artificial intelligence, computer vision, and design. It aimed to support development of social communication skills in children with autism as well as typically developing children (aged 5-7 years). The child plays in a virtual 'magic' garden and completes activities in collaboration with a virtual agent. The pedagogical foundation was derived from the SCERTS framework (Prizant et al., 2006).

Foster et al. (2010) give a description of the technology integrated into the system. In summary, ECHOES was developed to monitor the child's actions using two main input channels: computer vision (head-pose estimation and facial expression detection) and multi-touch gestures on a large screen. The system output combines behaviours of an animated character in a virtual world, along with changes to the objects in the world. The autonomous system behaviour was supplemented by a control panel, which allowed the researchers to direct the course of the interaction.

### *4.1. Challenges in ECHOES*

*Pedagogical foundations:* We were faced with many questions in the design of the activities and the agent's behaviour. For example, designing appropriate activities to support a specific skill, and identifying appropriate responses to the child's behaviour. We worked with practitioners to better understand these design issues. Such collaboration is not straightforward. ECHOES was developed to automate the agent's behaviour as guided by automatic detection of the child's cognitive and affective states. It was a challenge both to explain to practitioners how this could be achieved, but also the necessity of it given the possibility of using 'Wizard of Oz' techniques. Consequently, it was challenging for them to work within the design space we had specified.

In evaluating the system, it proved difficult to isolate the effectiveness of the technological design. Even though ECHOES was designed to support structured activities between the child and a virtual agent, in practice there was variation in the way the researchers interacted with the child (for example, in the amount of prompting).

*Technology:* ECHOES involved the development of a state-of-the-art vision system that would track head pose and recognise facial expressions. The system worked reasonably well under optimal conditions (Chen and Lemon, 2009), but in practice it was unable to track gaze or expressions reliably. This was largely because of the naturalistic context in which ECHOES was used: with the child standing and free to move around, it was difficult to aim the cameras to be able to see their face reliably. Without reliable information from the vision system, in practice the pedagogic decisions in ECHOES—for example, deciding when the agent should make a bid for interaction to the child—were made by the practitioner.

*Learner involvement in the design process:* In ECHOES, we conducted a wide range of activities to engage children actively in the design process (Frauenberger, Good and Keay-Bright, 2011). These included sensory workshops to explore affordances, the use of comic strips to develop narratives and the employment of initial digital prototypes. While the input from these activities was rich, we also became increasingly aware of the gap between the children's contributions and the design decisions required to implement a TEL system (see Frauenberger et al., 2012).

## 5. Concluding comments

In this paper we reviewed technology enhanced learning (TEL) to support the development of social communication skills in children with autism. Our aim was to identify the diverse research directions that are driving state-of-the-art and the challenges these directions give rise to. The overarching aim of any TEL system is pedagogical. However, as we've discussed, the design space is also shaped by other disciplines. It is through an increased understanding of the new directions and challenges that we can better map the research space to drive successful future TEL interventions.

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## References

American Psychiatric Association (1999) *Diagnostic and Statistical Manual of Mental Disorders 4th edition (DSM-IV),* American Psychiatric Association, Washington, DC.

Apple Inc, iPad2. [online] Available at http://www.apple.com/ipad/ (Accessed 28 February 2012)

Arnstein, S. R. (1969) A Ladder Of Citizen Participation, *Journal of the American Institute of Planners*, Vol. 35 No. 4, pp.216 – 224.

AuRoRa project. [online] Available at http://www.aurora-project.com/ (Accessed 28 February 2012)

Bainbridge, W.A., Hart, J.W., Kim, E.S. and Scassellati, B. (2010) The benefits of interactions with physically present robots over video-displayed agents, *International Journal of Social Robotics*, Vol. 3, pp. 41 – 52.

Benton, L., Johnson, H., Brosnan, M., Ashwin, E. and Grawemeyer, B. (2011) 'IDEAS: an interface design experience for the autistic spectrum' in *CHI 2011: Proceedings of the annual conference extended abstracts on Human factors in computing systems*, ACM, New York, NY, USA, pp.1759 – 1764.

Chen, J. and Lemon, O. (2009) 'Robust facial feature detection and tracking for head pose estimation in a novel multimodal interface for social skills learning' in *Advances in Visual Computing*, volume 5876 of *Lecture Notes in Computer Science*, Springer, Berlin / Heidelberg, pp. 588 – 597.

COSPATIAL project. [online] Available at http://cospatial.fbk.eu (Accessed 28 February 2012)

Druin, A. (2002) The Role of Children in the Design of New Technology, *Behaviour and Information Technology*, Vol. 21 No.1, pp.1 – 25.

ECHOES. [online] Available at http://www.echoes2.org/ (Accessed 28 February 2012)

Ehn, P. (1989) *Work-oriented design of computer artifacts,* 2nd ed., Arbetslivscentrum, Stockholm.

El Kaliouby, R., Picard, R.W. and Baron-Cohen, S. (2006) Affective Computing and Autism. *Progress in Convergence.* Eds. W. S. Bainbridge and M. C. Roco, *Annals of the New York Academy of Sciences* 1093, pp. 228 - 248.

European Convention on Human Rights [online] Available at http://www.hri.org/docs/ECHR50.html#C.Art10 (Accessed 15 March 2012)

Farr, W., Yuill, N. and Raffle, H. (2010) Social benefits of a tangible user interface for children with Autistic Spectrum Conditions, *Autism*, Vol. 14, pp. 237-252.

Feil-Seifer, D.J. and Matarić, M. J. (2011) 'Automated Detection and Classification of Positive vs. Negative Robot Interactions With Children With Autism Using Distance-Based Features' in *HRI 2011: Proceedings of the International Conference on Human-Robot Interaction*, Lausanne, Switzerland, pp. 323 – 330.

Foster, M.E., Avramides, K., Bernardini, S., Chen, J., Frauenberger, C., Lemon, O. and Porayska-Pomsta, K. (2010) 'Supporting children's social communication skills through interactive narratives with virtual characters' in *Proceedings of ACM Multimedia*, ACM, Florence, pp. 1111 – 1114.

Francois, D., Polani, D. and Dautenhahn, K. (2007) 'On-line behaviour classification and adaptation to human-robot interaction styles' in *Proceedings of the ACM/IEEE International Conference on Human-Robot Interaction*, ACM, Washington DC, pp. 295 – 302.

Frauenberger, C., Good, J. and Keay-Bright, W. E. (2011) Designing Technology for Children with Special Needs - Bridging Perspectives through Participatory Design. *CoDesign: International Journal of CoCreation in Design and the Arts*, Vol. 7 No. 1, pp. 1 – 28.

Frauenberger, C., Good, J., Keay-Bright, W. E. and Pain, H. (2012) 'Interpreting Input from Children: a Designerly Approach' in *CHI 2012: Proceedings of the annual conference on Human factors in computing systems*, ACM, New York, NY, USA.

Gerosa, M., Giuliani, D., Narayanan, S. and Potamianos, A. (2009) 'A review of ASR technologies for children's speech' in *Proceedings of the 2nd Workshop on Child, Computer and Interaction*, Cambridge, Massachusetts, pp. 71 – 78.

Golan, O., Ashwin, E., Granader, Y., McClintock, S., Day, K., Leggett, V. and Baron-Cohen, S. (2010) Enhancing emotion recognition in children with autism spectrum conditions: an intervention using animated vehicles with real emotional faces, *Journal of autism and developmental disorders*, Vol. 40 No. 3, pp. 269 – 279.

Hardy, C., Ogden, J., Newman, J. and Cooper, S. (2002) *Autism and ICT: A Guide for Teachers and Parents,* David Fulton Publishers, London.

Harrison, S., Tatar, D. and Sengers, P. (2007) 'The Three Paradigms of HCI' in *CHI 2007: Proceedings of the annual conference on Human factors in computing systems*, ACM, San Jose, CA.

Hatton, S. and Boughton, T. (2011) An Introduction to Supporting People with Autistic Spectrum Conditions. Talk given at *What Are Our Goals and What Counts as Success?* CPD Conference by British Institute of Learning Disabilities, 4th November 2011.

Hewlett-Packard. Hacking Autism, 2012. [online] Available at http://www.hackingautism.org/ (Accessed 28 February 2012)

Hourcade, J.P., Bullock-Rest, N.E. and Hansen, T.E. (2012) Multitouch tablet applications and activities to enhance the social skills of children with autism spectrum disorders, *Personal and Ubiquitous Computing*, Vol. 16, pp. 157-168.

iCommunicate. [online] Available at http://itunes.apple.com/au/app/icommunicate/ (Accessed 28 February 2012)

Keay-Bright, W. (2007) The Reactive Colours Project: Demonstrating Participatory and Collaborative Design Methods for the Creation of Software for Children with autism, *Design Principles & Practices: An International Journal*, Vol. 1 No. 2, pp. 7 – 15.

Koegel, R.L., Camarata, S., Koegel, L.K., Ben-Tall, A. and Smith, A.E. (1998) Increasing speech intelligibility in children with autism, *Journal of Autism and Developmental Disorders*, Vol. 28 No. 3, pp. 241 – 251.

Kozima, H., Michalowski, M.P. and Nakagawa, C. (2009) Keepon: A playful robot for research, therapy, and entertainment, *International Journal of Social Robotics*, Vol. 1 No. 1, pp. 3 – 18

Littlewort G, Whitehill J, Wu T, Fasel I, Frank M, Movellan J. and Bartlett M (2011) 'The Computer Expression Recognition Toolbox (CERT) ' in *Proceedings of IEEE International Conference on Automatic Face and Gesture Recognition*, Santa Barbara, CA, p. 298-305.

Madsen M., el Kaliouby R., Goodwin M. and Picard R. (2008) 'Technology for just-in-time in situ learning of facial affect for persons diagnosed with an autism spectrum disorder' in *ASSETS 2008: Proceedings of the 10$^{th}$ international ACM SIGACCESS conference on Computers and accessibility*, ACM, Nova Scotia, Canada, pp. 19 – 26.

Medical Research Council (2001) *Review of Autism Research Epidemiology and Causes*, Medical Research Council, London.

Microsoft Corporation, Kinect for XBox 360, 2012 [online] Available at http://www.xbox.com/en-GB/kinect (Accessed 28 February 2012)

Millen, L., Cobb, S. and Patel, H., (2011) Participatory design approach with children with autism, *International Journal on Disability and Human Development.* 10(4), 289-294.

Milne, M., Luerssen, M., Lewis, T., Leibbrandt, R. and Powers, D. (2010) 'Development of a virtual agent based social tutor for children with autism spectrum disorders' in *IJCNN 2010: Proceedings of the 2010 International Joint Conference on Neural Networks*, pp. 1 – 9.

National Research Council, Division of Behavioral and Social Sciences and Education, Committee on Educational Interventions for Children with Autism-NRC (2001) *Educating Children with Autism*, National Academies Press, Washington, DC.

Parsons, S. and Cobb, S. (2011) State-of-the-art of virtual reality technologies for children on the autism spectrum, *European Journal of Special Needs Education*, Vol. 26, pp. 355 – 366.

Pares, N., Carreras, A., Durany, J., Ferrer, J., Freixa, P., Gomez, D., Kruglanski, O., Pares, R., Ribas, J.I., Soler, M. and Sanjurjo, A. (2005) 'Promotion of creative activity in children with severe autism through visuals in an interactive multisensory environment' in *IDC 2005: Proceedings of the 4th International Conference on Interaction design and children*, ACM, Boulder, CO, pp 110 – 116.

Piper, A.M., O'Brien, E., Morris, M.R. and Winograd, T. (2006) 'SIDES: a cooperative tabletop computer game for social skills development' in *Proceedings of the 2006 20th anniversary conference on Computer Supported Cooperative Work*, New York, NY, pp. 1 – 10.

Prizant, B., Wetherby, A., Rubin, E., Laurent, A. and Rydell, P. (2006) *The SCERTS Model: A Comprehensive Educational Approach for Children with Autism Spectrum Disorders: Volumes I and II*, Paul H. Brookes Publishing, Baltimore, Maryland.

PQ Labs, Multi-Touch screen for LCD large screen, plasma TV display - Touch Screen Overlay, 2012 [online] Available at http://multi-touch-screen.com (Accessed 28 February 2012)

Reeves, B. and Nass, C. (1996) *The Media Equation: How People Treat Computers, Television, and New Media Like Real People and Places*. Cambridge University Press, Cambridge.

van Rijn, H. and Stappers, P. J. (2008) The Puzzling Life of Autistic Toddlers: Design Guidelines from the LINKX Project. *Advances in Human-Computer Interaction*, 2008.

Savner, J.L. and Smith-Miles, B. (2000) *Making Visual Supports Work in the Home and Community: Strategies for Individuals with Autism and Asperger Syndrome.* Autism Asperger Publishing Co, Shawnee Mission, Kansas.

Seeing Machines, faceAPI 2010 [online] Available at http://www.seeingmachines.com/product/faceapi/ (Accessed 28 February 2012)

Sigafoos, J. and Littlewood, R. (1999) Communication intervention on the playground: a case study on teaching requesting to a young child with autism, *International Journal of Disability, Development and Education,* 46(3):421-429.

Tager-Flusberg, H., Joseph, R. and Folstein, S. (2001) Current directions in research on autism, *Mental Retardation and Developmental Disabilities Research Reviews,* 7:21-29.

Tartaro, A. and Cassell, J. (2008) ‘Playing with Virtual Peers: Bootstrapping Contingent Discourse in Children with Autism’ in ICLS: *Proceedings of International Conference of the Learning Sciences*, ACM Press, Utrecht, Netherlands, pp. 382-389.

Teeters, A., el Kaliouby, R. and Picard, R.W. (2006) ‘Self-Cam: feedback from what would be your social partner’ in *SIGGRAPH 2006: Proceedings of the 33rd International Conference on Computer Graphics and Interactive Techniques,* Boston, MA, p.138.

UN Convention on Children [online] Available at www.unicef.org/crc (Accessed 15 March 2012)

Volkmar, F., Lord, C., Bailey, A., Schultz, R. and Klin, A. (2004) Autism and pervasive developmental disorders, *Journal of Child Psychology and Psychiatry, 45*, 135-170.

Wainer, A.L. and Ingersoll, B.R. (2011). The use of innovative computer technology for teaching social communication to individuals with autism spectrum disorders, *Research in Autism Spectrum Disorders,* Vol. 5 No. 1, pp. 96 – 107.

Watts, O., Yamagishi, J., King, S. and Berkling, K. (2010) Synthesis of Child Speech With HMM Adaptation and Voice Conversion, *IEEE Transactions on Audio, Speech, and Language Processing*, Vol.18 No.5, pp.1005 – 1016.

Zancanaro, M., Gal, E., Parsons, S., Weiss, T., Bauminger, N. and Cobb, S. (2010) ‘Teaching social competence: in search of design patterns’ in *Proceedings of the 9th International Conference on Interaction Design and Children*, ACM, New York, USA, pp. 270 – 273.