Design issues on interactive environments for children with autism

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ABSTRACT

This article addresses design issues that are relevant in the AURORA project which aims at developing an autonomous, mobile robot as a therapeutic tool for children with autism. Cognitive theories of mind-reading are discussed and related to the AURORA project. This approach is put in the broader context of interactive environments, which autonomous mobile robots are a special case of. Implications of this research for interactive environments in general, and virtual environments in particular are discussed.

1. INTRODUCTION

This article discusses the use of interactive environments (software or robotic) as learning and teaching tools for the rehabilitation of children with autism. The discussions draw upon experience gained in the AURORA project, which develops an autonomous, mobile robot as a therapeutic tool for children with autism (Dautenhahn, 1999; Werry and Dautenhahn, 1999; Dautenhahn and Werry, 2000). Conceptually, this approach is strongly related to Seymour Papert's *constructionist* approach towards learning (Papert, 1980). Such an approach focuses on active exploration of the environment, namely improvisational, self-directed, 'playful' activities in appropriate learning environments ('contexts') which can be used as 'personal media'. In the mid-1960ies Papert and his colleagues at the MIT AI LAB developed the programming language LOGO which has been widely used in teaching children. A remote controlled device (a 'turtle' robot) was developed which is moving according to a set of LOGO instructions, cf. the LEGO/LOGO Artificial Life Toolkit for children (Resnick, 1989). In 1976 Sylvia Weir and Ricky Emanuel (Weir and Emanuel, 1976) published research which used such a LOGO learning environment to catalyse communication in an autistic child. They report on their experience with a seven-year-old autistic boy and the positive effects of his explorations in controlling a LOGO turtle on his behaviour. Important differences between this project and the AURORA project are: a) the robot did not act autonomously, the child remotely operated the robot via a 'button box', b) the child did not directly (physically) interact with the robot, c) the publication gives little information on the performance of the child before start of the sessions, d) only one child was tested. Although the mobile robot was remotely controlled, this is to our knowledge the first study which uses a mobile robot as a remedial device for children with autism.

A more recent approach using more interactive rather than remote-controlled technology for rehabilitation of autistic children is taken in the Affective Social Quotient (ASQ) project, (Blocher, 1999). Here, embedded technology is used to support autistic children in learning about social-emotional cues. Short 'emotionally charged' video clips are used together with a set of physical stuffed 'dolls' (embodying one emotional expression) through which the child can interact with the movies. By touching the doll the child can match a doll with a video clip. A child can explore emotional situations by picking up dolls with certain emotions, or the system can prompt the child to pick up dolls that go with certain clips. A therapist is able to control and monitor the interactions. The system shows that human-intensive, repetitive aspects of existing behavioural therapy techniques can potentially be automated.

2. THE AURORA PROJECT

2.1 Autism

People with autism are a very heterogeneous group and it is difficult to list defining symptoms. Although we use the term autism throughout this paper it is more appropriate to use the term *autistic spectrum disorders* (ASD) which acknowledges the fact that autism occurs in differing degrees and in a variety of forms.

The National Autistic Society (NAS, 2000) lists the following triad of impairments:

1. Social interaction (difficulty with social relationships, for example appearing aloof and indifferent to other people, inappropriate social interactions, inability to relate to others in a meaningful way, impaired capacity to understand other's feelings or mental states).
2. Social communication (difficulty with verbal and non-verbal communication, for example not really understanding the meaning of gestures, facial expressions or tone of voice).
3. Imagination (difficulty in the development of play and imagination, for example having a limited range of imaginative activities, possibly copied and pursued rigidly and repetitively).

In addition to this triad, repetitive behaviour patterns and a resistance to change in routine can generally be observed, associated with a significantly reduced repertoire of activities and interests, stereotypical behaviour, and a tendency of fixation to stable environments.

Depending on what is included in 'autism', rates of occurrence are given which range between 5-15 in 10000. Instead of a physical handicap which prevents people from physically interacting with the environment, people with autism have great difficulty in making sense of the world, in particular the social world. Autism can but need not be accompanied by learning disabilities. At the higher functioning end of the autistic spectrum we find people with Asperger Syndrome. Some of them manage to live independently as adults and to succeed in their profession, but only by learning and applying explicit rules in order to overcome the 'social barrier' (Grandin, 1995; Grandin and Scariano, 1996; Schäfer, 1997). Instead of picking up and interpreting social cues 'naturally' they can learn and memorise rules about what kind of behaviour is socially appropriate during interaction with non-autistic people. Autism is not, as has long been assumed in public, a voluntary decision to retract from the world: people with autism do not have the choice to live socially or not, the decision has been made for them.

Two different viewpoints exist on how to connect the autistic with the non-autistic world: either efforts are undertaken to teach people with autism the skills they need to survive in the world of 'normal' people, or it is suggested that they might be happier living separately in a world specifically designed for them. From all what we know about the way individuals with autism feel (see books written by Temple Grandin and others), they are painfully aware of their 'being different' from other people, and express the wish to be part of the 'world outside'. Accepting the differences, empowering people with autism, and linking their world with the world that non-autistic people are living in poses many challenges. In order to understand people with autism we have to understand better the causes of autism, and can find ways to empower them, including computer and robotic technology, so that they have the choice of whether and to what extend they want to connect to the world of non-autistic people.

2.2 Socially Intelligent Agents

Recently *Socially Intelligent Agents* research has resulted in a variety of different software and robotic systems which can successfully interact with humans and show aspects of human-style social intelligence (for an overview see Dautenhahn and Numaoka 1998; Dautenhahn and Numaoka, 1999; Dautenhahn 2000; SIA, 2000). Interesting interactive robotic systems are the KISMET platform (Breazeal and Scassellati, 1999) and the ROBOTA dolls (Billard et al, 1998; Billard, 2000). KISMET is a humanoid face that can generate expressive social interactions with human 'caretakers'. Such 'meaningful' interactions can be regarded as a stepping-stone for the development of social relationships between a robot and a human. The ROBOTA dolls are humanoid robots developed as interactive toys for children and are used as research platforms in order to study how a human can teach a robot, using imitation, speech and gestures. Increasingly, robotic platforms are developed as interactive playmates for children (e.g. Montemayor et al, 2000; Canamero and Fredslund, 2000). Besides commercial purposes (see Sony's Aibo robot), such interactive robotic systems can potentially be utilised as learning environments and in rehabilitation applications, as studied in the AURORA project.

Figure 1. *The two photos on the left show two children with autism interacting with the Labo-1 robot. The left photo demonstrates what we mean by 'eye-contact' in the case of human-robot interaction. The middle photo shows a child who played with the robot for an extended period of time until he needed to go back to class. Most of the time the child was lying on the floor and playing 'interaction games' with the robot, i.e. reaching out and touching the robot which then caused the robot to approach/avoid the child. The photo on the right shows Labo-1 in more detail. The basic sensor configuration consists of active infrared sensors for obstacle avoidance and pyro-electric sensors which allow detection and following of humans. The robot weighs about 6.5 kg. Due to a 4 wheel differential drive it can turn very smoothly. The robot can manage a few kilograms of additional weight, e.g. when children are pushing the robot or (partially) stepping on it. Words and simple phrases are produced by the robot in certain situations, by means of a voice production device (not shown). In the trials the robot moves very slowly, so that even when it bumps into a child (what rarely happens since the children are very attentive to the robot's movements) no harm is done. The robot is robust enough to cope with being extensively pushed around during the trials.*

2.3 Brief Project Description

Since end of 1998 the project AURORA (AUtonomous RObotic platform as a Remedial tool for children with Autism) investigates how an autonomous mobile robot can be developed into a remedial tool in order to encourage children to become engaged in a variety of different interactions that possess features which are important elements of human social behaviour (eye-contact, joint-attention, approach, avoidance, following, imitation games etc.). Figure 1 shows the robot that is used in the AURORA project. The children who are interacting with the robot are between 8-12 years of age, including children who are non-verbal, i.e. they cannot use language or usually do not use language.

In the rehabilitation of children with autism therapeutic issues (e.g. eye contact, joint attention, turn taking, reading mental states and emotions) are usually addressed in constrained teaching sessions (Howlin et al, 1999). In contrast, robot-human interactions in the AURORA project are unconstrained and unstructured, the children are allowed to interact with the robot in whatever position they prefer (e.g. lying on the floor, crawling, standing, cf. Figure 1), they are also free to chose how they interact with the robot (touching, approaching, watching from a distance, picking it up etc.). Interference is only necessary if the child is about to damage the robot or if the child (by pressing buttons) switches off the robot so that it needs to be restarted. Such conditions are much different from other projects on robot-human interaction (e.g. KISMET, or the ROBOTA dolls) where the human is expected to interact with the robot while adopting a particular position and orientation towards the robot (e.g. sitting face-to-face in close distance to an interactive robot that is not moving in space). The particular challenges faced in the AURORA project, in the broader context of rehabilitation, together with a more detailed discussion of therapeutical issues involved, is given in (Werry and Dautenhahn, 1999; Dautenhahn and Werry, 2000).

2.4 Theoretical Background and Working Hypotheses

The AURORA project deliberately uses a non-humanoid robot, based on the observation that children with autism prefer a predictable, stable environment and that many people with autism have difficulty interpreting facial expressions and other social cues in social interactions. Consequently, they often avoid social interactions since people appear unpredictable and confusing. Generally, using a robot as a remedial toy takes up the challenge of bridging the gap between the variety and unpredictability of human social behaviour (which often appears frightening to children with autism) and the predictability of repetitive and monotonous behaviour which children with autism prefer and which can be performed by mobile robots (see discussion in Dautenhahn, 1999).

We hypothesise that a child with autism 1) is sufficiently interested in 'playing' with an interactive autonomous robot as it is used in the AURORA project, 2) the robot can engage the child in interactions which demonstrate important aspects of human-human interaction (e.g. eye-contact, turn-taking, imitation games), and 3) (as a long term therapeutic goal), while slowly increasing the robot's behaviour repertoire and the unpredictability of its actions and reactions, the robot can be used to guide the children towards more realistic and 'complex' forms of social interactions resembling human-human interaction. This approach is based on two areas of theoretical work.

2.4.1 Mindreading. Generally, humans are from an early age on attracted to self-propelled objects which are moving autonomously and seemingly with 'intention' (Dautenhahn, 1997). In (Premack and Premack, 1995) a *theory of human social competence* is presented that consists of three units: the first unit (*intentional system*) identifies *self-propelled movements in space* and interprets them as intentional, engaged in goal-directed behaviour, such as escaping from confinement, making contact with another intentional object, overcoming gravity (e.g. seeking to climb a hill). Animate and inanimate objects are distinguished since only animate objects can move both in space and time without the influence of other objects. Movement in place is interpreted as animate but not intentional. The second unit is the *social system* which specifies the changes that the intentional objects undergo. It allows to interpret relations e.g. as possession or group membership. The third unit is the *theory of mind system*, which outputs explanation, states of mind, perception, desire, belief, and its variations. These mental states are used to explain the actions.

Effects of the 'intentional stance' produced by the above mentioned mechanisms, in particular the intentional system as the basic unit which selects the objects to be considered, are convincingly demonstrated in (Heider and Simmel, 1944). Here human subjects created elaborate narratives about intentional agents when asked to describe movements of moving geometric shapes shown in a silent film. A more general *behaviour reading* mechanism is also suggested as the basis for anthropomorphism (Mitchell and Hamm, 1997): evidence indicates that for evoking anthropomorphic interpretations the *behaviour* of objects (in Mitchell and Hamm's study animals) is more important than other aspects, e.g. the appearance of an object, or whether a human is familiar with the object. We suggest that the same might apply to inanimate objects such as robots. Every robotics researcher who has ever given a demonstration of autonomous mobile robots to a general audience can confirm how readily humans view robots as people (Bumby and Dautenhahn, 1999).

Premack and Premack's theory of human social competence shows great similarity with Baron-Cohen's suggestion of four mechanisms underlying the human *mindreading system* (Baron-Cohen, 1995). The first mechanism is the *intentionality detector* that interprets motion stimuli (stimuli with self-propulsion and direction) in terms of the mental states of goal and desire. These primitive mental states are basic since they allow making sense of universal movements of all animals, namely approach and avoidance, independent of the form or shape of the animal. The ID mechanism works through vision, touch and audition and interprets anything that moves with self-propelled motion or produces a non-random sound as an object with goals and desires. The second mechanism as part of Baron-Cohen's mindreading system is the *eye-direction detector* (EDD) which works only through vision. The EDD detects the presence of eye-like stimuli, detects the direction of eyes, and interprets gaze as *seeing* (attribution of perceptual states). This mechanism allows interpreting stimuli in terms of what an agent sees. ID and EDD represent *dyadic relations* (relations between two objects, agent & object or agent & self) such as 'Agent X wants Y' or 'Agent X sees Y', however they not allow to establish the link between what another agent sees and wants and what the *self* sees and wants. Sharing perceptions and beliefs is beyond the 'autistic universe', it requires the additional mechanisms SAM (shared-attention-mechanism, allows to build triadic representations: relations between an agent, the self, and a third object) and ToMM (theory-of-mind mechanism). ID, EDD, SAM and ToMM make up a fully developed human mindreading system as it exists in biologically normal children above the age of four. In normal development, from birth to about 9 months a child can only build dyadic representations based on ID and basic functions of EDD. From about 9 to 18 months SAM comes on board and allows triadic representations that make joint attention possible. SAM links EDD and ID, so that eye direction can be read in terms of basic mental states. From about 18 to 48 months ToMM comes on board, triggered by SAM. The arrival of ToMM is visible e.g. through pretend play. Note, that earlier mechanisms are not replaced by newer ones, they still continue to function. According to Simon-Baron's analysis children with autism possess ID and EDD. ToMM is missing in all children with autism while some of them possess SAM.

Referring to this theoretical framework, the working hypotheses (section 2.4) studied in the AURORA project clearly address the ID and EDD mechanisms. In the same way as biologically normal children above 4 years of age detect, are attracted to, and interpret autonomous, self-propelled objects such as robots as 'social agents', we hypothesise that children with autism can accept a mobile robot as a social agent.

2.4.2 Interaction Dynamics. The second strand of theories which the AURORA project is influenced by concerns interaction dynamics between babies and their caretakers as studied in developmental psychology (e.g. review articles in Meltzoff, 1996; Meltzoff and Moore, 1999). A more detailed account of these issues and their relevance in the AURORA project is given in (Dautenhahn and Werry, 2000), and we can only present a brief summary here. Infants seem to detect specific temporal and structural aspects of infant-caretaker interaction dynamics. It is suggested that turn-taking and imitation games allow the infant 1) to identify *people* as opposed to other objects, and 2) to use the *like-me-test* in order to distinguish between different persons. Motivated by this research we suggested a conceptual framework in order to classify different and increasingly complex dynamics in robot-human interactions (Dautenhahn and Werry, 2000). Within this framework, robot-human interactions in the AURORA project are designed where synchronisation of movements, *temporal coordination*, and the emergence of imitation games are used as important mechanisms for making 'social contact' between the robot and the child. It is hoped that such an approach which focuses on interaction dynamics rather than cognitive reasoning mechanisms can incrementally facilitate and strengthen temporal aspects which are so fundamental to the development of social competence and the ability to socially interact with people (cf. Hull, 1983).

2.5 *Summary of Results*

Initial trials in the AURORA project stressed the individual nature of the specific needs of children with autism, but they also showed that most children responded very well and with great interest to the autonomous robot. In a recent series of comparative trials where the children were playing with the robot (condition 1) and also (separately) with a passive non-robotic toy (condition 2) children showed greater interest in interactions with the robot than with the 'inanimate' toy (quantitative data will be published in a forthcoming publication by Werry and Dautenhahn). Also, children showed increased interest in the front part of the robot where the pyro-electric sensor is attached, a sensor with strongly eye-like features (eye-like shape, located at the distal end of the robot's preferred direction of movement, prominent position raised above the chassis, direction of the sensor changing according to 'gaze'). These observations seem to confirm our hypothesis that interactions in the AURORA project can successfully built on mechanisms of intentionality detection (ID mechanism) and eye-direction-detection (EDD mechanism).

The following section discusses how the design issues, which the AURORA project is based on, could be applied to other interactive technologies, e.g. virtual environments.

3. IMPLICATIONS FOR INTERACTIVE VIRTUAL ENVIRONMENTS

We suggest that the following design issues might generalise from the AURORA project to other interactive environments designed as remedial learning environments for children with autism. The discussions focus on the potential of virtual environments as remedial tools for children with autism.

Controlled and safe learning environments. The *autistic spectrum disorders* cover a huge range of different abilities and needs of the children. Even within particular age ranges individual differences can be immense. The target group therefore needs to be identified very clearly, but even then interactive environments need to account for individual needs of the children. Virtual environments can be designed as learning environments (e.g. Cobb et al, 1998) and for rehabilitation (e.g. Wilson et al, 1997), and this technology has also great potential for children with autism (Kijima et al, 1994; Strickland et al, 1995; Strickland, 1996). In such environments input stimuli can be controlled and the behaviour of the child can be monitored. Successive learning sessions can be evaluated in order to monitor progress of teaching objectives, controlled by the teachers. Environments can be customised to account for individual differences. Children can be guided through learning experiences and explore new behavioural opportunities by themselves. Such environments can provide safe environments without or with little intervention by another human, although teachers and/or parents (family) of the children are usually important participants in trials with autistic children. Dorothy Strickland (Strickland, 1996) gives an example of a virtual environment that is used as a learning environment for children with autism. Such environments can partially replace time-consuming, routine teaching sessions, if they are properly integrated with the curriculum and teaching method used in the schools. Alternatively, such environments could be built for use at home, in a playful and exploratory context where children might use the environment in a more creative way. Enjoyment and an increase of the children's quality of life is a goal as desirable as skill learning (cf. Cobb et al, 1998).

Proactive behaviour: In contrast to other children, which enjoy a lively, dynamic and even 'messy' playground, children with autism prefer a predictable, structured and in this way 'safe' environment. The child prefers to be in 'control' of the interaction. The NAS schools use a system known as TEACCH (Treatment and Education of Autistic and related Communication handicapped Children, Watson et al, 1989). This system has been developed to encourage the autistic child to explore and develop pro-active skills and uses a system of stimulus and response. Like other behavioural approaches TEACCH emphasises structure, specific behaviours are targeted, conditions and consequences of eliciting the behaviour are defined, and behaviour is shaped through the use of cueing and prompting. Functionality (behavioural view) and pragmatics (psycholinguistic view) are the central issues in the TEACCH methodology. "More meanings for more purposes in more situations" are taught prior to teaching communication with more complex forms (Watson et al, 1989). Naturalistic, less structured settings with naturalistic consequences are preferred to artificial settings. The TEACCH curriculum addresses a wide spectrum of communicative functions (request, get attention, reject or refuse, comment, given information, seek information, express feelings, social routine) and forms of communication (motoric, gestural, vocal, pictorial, written, sign, verbal). A robotic agent is able to complement this approach as it can prompt through behaviour in a constant and predictable manner. In this way, initiative-taking and spontaneous communication can be encouraged.

Embodied Interaction: Virtual environments as described in (Strickland, 1996) require that the children are wearing VR helmets. This might be appropriate for some children, but we can expect that this in not feasible for many autistic children. Here, 'non-tethered' approaches can be investigated. Particularly promising seem approaches which support interactions involving the whole body, in set ups where the child can freely move, i.e. when the child is not constrained to sitting at a desk, is not required to wear special devices, and is not 'tethered' in any way. Such environments can particularly well address the dynamics of social interactions. Children with autism often show a distorted and usually 'indifferent' attitude towards their body. Self-injurious behaviour, abnormal complex behaviours of the body and eating disorders can be observed. These indications of body image distortions might contribute to their problems in relating to other people. Schools of the NAS have playrooms and various different facilities in order to support multi-modal and bodily experiences. As explained above, interactive environments can provide learning environments more sophisticated and controllable than those commonly used, based on common teaching practises, e.g. addressing issues of visual perception, mindreading and general problem solving. Additionally, interactive environments can explore new teaching practises based on an exploratory and playful approach involving the 'complete child', namely involving physical movement. In contrast to traditional approaches, robotic and other interactive environments (cf. Bobick et al, 1999; Penny, 2000) can allow the child to move around 'freely' or less constrained than when confined to a chair. The issue of embodied interaction can provide new aspects to learning environments, e.g. helping children with autism to explore their bodies and how the body interacts with the environment. Thus, the bodily interaction itself can be as therapeutically relevant as the 'content' of the interaction.

Generalisation: A major problem of all therapeutic approaches to autism is generalisation: a child often shows improved performance in the particular teaching environment (e.g. in classroom) but it has great difficulty in generalising the learning experiences and applying the newly acquired skill to non-classroom situations. In particular virtual environments have an enormous potential here: creating different contexts and environments in the classroom and changing features and shapes of objects in the environment is very time-consuming and often infeasible, while creating alternative scenarios or variations in virtual environments is comparatively easy. This is important for specific learning objectives as well as for a more broader approach, e.g. the general facilitation of imaginative skills. To give an example: If a teacher enacts a story together with children, then the colour of a blanket cannot be changed instantaneously, neither can a sword suddenly appear out of thin air. Normal children can easily compensate for these 'deficiencies' of the real world, their imaginative skills allow to create different worlds, alternative or fictional realities, as it is shown in role-play. However, the imaginative skills of children with autism are often impaired, they prefer the concrete, the visible. The shape of a robot cannot change suddenly; it cannot grow wings and fly away. However, in virtual environments rich, dynamic, and at the same time concrete and visible worlds can be created, although mostly limited to the visual (a child doesn't get wet if it starts raining, the feeling of raindrops on the skin cannot be experienced 'virtually').

Presence: The issue of 'presence' in virtual environments has been discussed intensively for many year (e.g. Heeter, 1992), and the acceptance of virtual environments does strongly depend on whether the user's presence in the artificial environment is believable, i.e. whether he or she has the impression of 'being there'. Often reality is confusing to a person with autism; clear boundaries, meaning, and order seems to be missing. Thus, for children with autism the feeling of 'being there' in the real world is different from what we experience. Possibly, virtual environments will intensify the impairment of presence, and the feeling of 'alienation'. Thus, particular attention is necessary in order to ensure that experiences in virtual environments are made *real* and *meaningful*, namely providing the link to experiences in the real world. Using interactive physical robots avoids this problem, interactions are not necessarily natural but they are grounded in experiences in the real world. However, their interactive abilities (e.g. range of different behaviours), in comparison to software environments, are currently limited.

Holistic perception. People with autism have difficulty in 'holistic perception', namely integrating different perceptual inputs (e.g. merging different perspectives of the same object/person to a *concept* of an object/person). Typically, children with autism will tend to focus on details in an environment and not on the 'whole picture'. For example, if an object is presented to the child one cannot assume that the child directs his/her attention to the object as a whole, it is likely that the child's perception will focus on *aspects* of the object, e.g. colour, shape, structural details etc. In particular a virtual environment seems to be well suited to address this issue, e.g. different aspects of the world can be highlighted, dynamically changed (depending on the child's activities), presented differently etc.

4. CONCLUSION

This article introduced the project AURORA and discussed particular challenges and problems involved in building interactive robotic systems as therapeutic teaching devices for children with autism. Experiences from this project were discussed in the context of virtual learning environments. It is hoped that the development of robust and believably interactive systems (robotic and software) can support the rehabilitation of children with autism, so that ultimately such technology can become an integrated part of the curriculum, being used by teachers and parents and tailored towards specific individual needs of children with autism. To provide an enjoyable and entertaining 'toy' specifically adapted to the needs of the children and increasing the quality of life of children with autism, is an integral part of the AURORA project. However, helping children with autism to develop social skills is methodologically and technically more demanding. Given the nature of autism only long-term studies will reveal if and how this goal can be met.

A *design space* of interactive environments needs to be explored (comprising possible designs of interactive systems) and linked to the space of sets of requirements which Aaron Sloman called *niche space* (Sloman, 1995). One might speculate that (different types of) robotic therapeutic tools might map to (different sets of) requirements addressing primarily bodily, physical interaction, while (different types of) virtual environments might map to (different sets of) requirements addressing primarily imaginative and cognitive skills. There might be niches for various types of interactive environments and socially intelligent agents which could be used in the rehabilitation of children with autism, e.g. humanoid and non-humanoid robots, multi-media interactive environments, and virtual environments ranging from desktop VE's to immersive interactive learning and play environments (Bobick et al, 1999; Penny, 2000). Among the big challenges is the development of appropriate design methodologies and evaluation methods, so that different interactive environments and their effectiveness in the application domain of autism therapy can be assessed and compared.

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