Towards Interactive Robots in Autism Therapy: Background, Motivation and Challenges

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Towards interactive robots in autism therapy

Background, motivation and challenges*

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This article discusses the potential of using interactive environments in autism therapy. We specifically address issues relevant to the Aurora project, which studies the possible role of autonomous, mobile robots as therapeutic tools for children with autism. Theories of mindreading, social cognition and imitation that informed the Aurora project are discussed and their relevance to the project is outlined. Our approach is put in the broader context of socially intelligent agents and interactive environments. We summarise results from trials with a particular mobile robot. Finally, we draw some comparisons to research on interactive virtual environments in the context of autism therapy and education. We conclude by discussing future directions and open issues.

1. Introduction

This article discusses the potential use of interactive environments as learning and teaching tools for use in the therapy of children with autism. Our discussions draw upon experience gained in the Aurora project, which studies how to develop autonomous, mobile robots as therapeutic tools for children with autism (Dautenhahn 1999; Werry and Dautenhahn 1999; Werry et al. 2001a; Dautenhahn and Werry 2000, 2002). 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-

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1960's, Papert and his colleagues at the MIT AI LAB developed the programming language LOGO that has been widely used in teaching children. A remote controlled device (a 'turtle' robot) was developed which moved according to a set of LOGO instructions (cf. the LEGO/LOGO Artificial Life Toolkit for children; Resnick 1989). The LOGO programming language and LEGO robots have since been used widely in education.

It is expected that a new generation of children will increasingly use computer technology in a variety of contexts (professional, educational and recreational), including interactive robotic toys, digitally enhanced objects and tangible interfaces (Laurel 1993; Tapscott 1998; Cassell and Jenkins 1999; Druin and Hendler 2000). New interactive systems and novel interfaces are also likely to impact on methods of therapy and rehabilitation. 'Persuasive' technology (Fogg 1999) is technology that can influence the opinions, attitudes and behaviour of people. In particular, the physical shape and behaviour of socially intelligent agents, that display aspects of human-style social intelligence (Dautenhahn 1998; Dautenhahn (ed) 2000), are likely to change how we can teach social intelligence to humans who have difficulties in understanding and displaying social behaviour.

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, 1999; Dautenhahn (ed) 2000; SIA 2000; Dautenhahn et al. (eds) 2002). Interesting interactive robotic systems include 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, used as research platforms in order to study how a human can teach a robot, using imitation, speech and gestures. Increasingly, robotic platforms are being developed to be interactive playmates for children (e.g., Montemayor et al. 2000; Cañamero and Fredslund 2000). Besides commercial purposes (see Sony's Aibo robot), such interactive robotic systems can potentially be utilised as learning environments or in rehabilitation/therapy applications, as studied in the Aurora project, which we describe in more detail in the next section.

2. The AURORA project

2.1 Autism

Autism is a developmental disorder defined by diagnostic criteria specified in DSM-IV (Diagnostic and Statistical Manual of Mental Disorders, American Psychiatric Association, 1994). Individuals with autism show a broad spectrum of difficulties and (dis)abilities, and they vary greatly in their levels of overall intellectual functioning. However, all individuals diagnosed with autism posses a common set of symptoms. The National Autistic Society (NAS 2003) 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 others' 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. These are associated with a significantly reduced repertoire of activities and interests, stereotypical behaviour, and a tendency of fixation to stable environments. Rates of occurrence are given which range between 5–15 in 10000. Unlike 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. For example, 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' (cf. the autobiographic accounts by Grandin (1995), Grandin and Scariano (1996), Schäfer (1997)). Instead of picking up and interpreting social cues 'naturally' they must learn and memorise rules about what kind of behaviour is socially appropriate during interaction with non-autistic people. Autism is not, as is often assumed, 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 about how best to support people with autism: either it is argued that efforts should be undertaken to teach people with autism the skills they need to interact and survive in the world of typically-developed people, or it is suggested that they might be happier living separately in a world specifically designed for them. Empowering people with autism, allowing them to make their own choice on whether or not to link with the world of non-autistic people poses many challenges. In order to understand people with autism we have to not only better understand the causes of autism, but also find ways to empower them, for example by using computer and robotic technology, so that they have the choice of whether and to what extent they want to connect to other people.

2.2 Interactive technology in autism therapy

In 1976, Sylvia Weir and Ricky Emanuel (Weir and Emanuel 1976) published research which used a LOGO learning environment to catalyse communication in a seven-year-old boy with autism. They reported positive effects from his explorations in controlling a LOGO turtle on his behaviour. Although the mobile robot was remotely controlled, this was, to our knowledge, the first study that investigated a mobile robot as a remedial[1] device for children with autism. However, unlike our work on the Aurora project: (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; and (c) only one child was tested.

More recently, François Michaud and his team at Université de Sherbrooke, have investigated different designs of *autonomous robots*, using a variety of modalities for interaction with people, e.g. music, colour and visual cues. In contrast to Weir and Emanuel, they use interactive rather than remote-controlled technology with children with autism. The goal of this work is to engineer robots that can best engage different children with autism, by exploring the design space of autonomous robots in autism therapy. Michaud and Théberge-Turmel (2002) present narrative accounts of playful interactions of children with autism with different robots. The robots vary significantly in their appearance and behaviour, ranging from spherical robotic 'balls' to robots with arms and tails that can play games with the children. The main difference between this project and our work is that, rather than focusing on the engineering aspects of robotic design, our work is primarily guided by therapeutic issues. Moreover, the study of quantitative and qualitative evaluation and analysis techniques for assessing robot-child interactions, which is not addressed in detail by Michaud et al., is central to the Aurora project.

A therapeutic approach, using interactive *computer technology* with children with autism, was taken in the Affective Social Quotient (ASQ) project (Blocher 1999). Here, computers were used to support children with autism in learning about social-emotional cues. Short 'emotionally-charged' video clips were used together with a set of stuffed 'dolls' (embodying one emotional expression) through which the child could interact with the movies. By touching the dolls, the child could match a doll with a video clip. A child could explore emotional situations by picking up dolls with certain emotions, or the system prompted the child to pick up dolls that go with certain clips. A therapist was able to control and monitor the interactions. The system showed that the human-intensive, repetitive aspects of existing behavioural therapy techniques can potentially be automated.

2.3 Brief project description

Since the end of 1998 the project Aurora (AUtonomous RObotic platform as a Remedial tool for children with Autism) has investigated how an autonomous mobile robot can be developed into a remedial tool to encourage children to become engaged in a variety of different interactions important to human social behaviour. Such interactions include: eye contact, joint attention, approach, avoidance, following, imitation games etc. We focus on these particular behaviours since, as we explain in more detail below, they play an important role in human social cognition and development, and have been studied extensively in autism research. Moreover, from a practical point of view, these are behaviours that can realistically be studied with current robotic technology.

Our work is primarily concerned with how robots can be designed and programmed to be useful in autism therapy or education. As a long-term goal we envisage that (various designs of) robots could be used with children with autism by teachers and carers in schools or by parents at home. The project is mainly based on Artificial Intelligence, Robotics and Assistive Technology, and is exploratory in nature, but it is informed by the literature in autism research. Potentially, our work might be relevant to psychologists considering the use of interactive robots as *experimental tools* in the context of autism research and intervention.

1. a

1. b

Figure 1. (a) The toy truck (left) and the mobile robot Labo-1 (right) used in the comparative study. Labo-1's 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 four-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 (which 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.
(b) Two children with autism interacting with the Labo-1 robot. The photo on the left shows a child who is playing a 'chasing game' with the robot. The photo on the right shows a child who played with the robot for an extended period of time until he needed to go back to class. He was not afraid to interact with the robot at very close distance. 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.

Figure 1 shows one of the mobile robots used in the Aurora project. In this paper we concentrate on trials we conducted with this particular robot. The children who were interacting with the robot were between 8–12 years of age, and included non-verbal children, i.e., children who could not use language or usually did not use language.

Teaching methods for children with autism that address therapeutic issues (e.g., eye contact, joint attention, turn taking, reading mental states, and emotions) usually involve constrained teaching sessions (e.g., Howlin et al. 1999). In contrast, robot-human interactions in the Aurora project are deliberately chosen to be playful, unconstrained and unstructured. Specifically, 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 choose how they interact with the robot (touching, approaching, watching from a distance, picking it up, etc.). Interference by adults is only necessary when the child is about to damage the robot, or when the child (by pressing buttons) switches off the robot so that it needs to be restarted. These conditions are very different from those typical of other projects on robot-human interaction (e.g., Kismet or the Robota dolls, both mentioned above), 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 vicinity of an interactive robot that is not moving).

2.4 Theoretical background and working hypotheses

Although we have recently investigated different humanoid and non-humanoid robotic designs (cf. Dautenhahn and Billard 2002; Robins et al. 2004), in most of our work we have been deliberately using mobile, non-humanoid robots that allow for unconstrained interactions as described above. Children and adults with autism have difficulty interpreting facial expressions and other social cues in social interaction. Consequently, they often avoid social interactions since people appear unpredictable and confusing. In contrast to other children, who enjoy a lively, dynamic and even 'messy' playground, children with autism prefer a predictable, structured and, in this way, 'safe' environment. A child with autism prefers to be in 'control' of the interaction. A simple, non-humanoid, machine-like robot seems therefore very suitable as a starting point for therapeutic interventions. Generally, using a robot as a remedial toy meets the challenge of bridging the gap between the variety and unpredictability of human social behaviour (which can often appear 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 (1) a child with autism 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 gaze, turn-taking, imitation games), and (3) (as a long term therapeutic goal) by 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 'complex' forms of interaction, as found in social human-human interactions. In order to illustrate the latter point, let us consider three different scenarios that represent three different levels of complexity of robot-child interaction:

- Scenario A: In this very simple context the robot possesses a small behaviour repertoire, each behaviour being triggered by a certain sensory input that is provided either by the child or by other inanimate features in the room. In this scenario, walls and chairs trigger obstacle avoidance, the perception of a human being triggers approach behaviour, etc. The behaviour of the robot at a particular moment is solely based on its current perceptions, i.e., it behaves in a purely reactive manner. In other words, its control programme can be conceived of as a set of stimulus-response rules (Arkin 1998).
- Scenario B: In a more complex and 'natural' context (i.e., more similar to human-human interaction), the behaviour of the robot is influenced by its previous experience, in particular its interaction history. It can distinguish individual children and adapt to their particular interaction and play styles. Such a robot responds differently to individual children, e.g., it can encourage children that are usually more withdrawn and show low activity levels, or it can show less encouragement for children with high activity levels (as far as interactions with the robot are concerned).
- Scenario C: The robot possesses a large behaviour repertoire, including behaviours that specifically target particular therapeutically useful interactions such as imitative behaviour. On this level of complexity the robot can change its behaviour during the interactions with the children, based on its knowledge of the child's usual interaction style and on an 'agenda' (programmed, say, by teachers, carers, or parents) that is therapeutically relevant. For example, when interacting with a child that is usually withdrawn, the robot could begin by initiating interactions on complexity level A, e.g., it can initiate very simple following-chasing and turn-taking games. Once it

> detects that the child is engaged in interactions, it could introduce more complex behaviour, or new behaviours that are therapeutically useful, e.g., movement imitation, verbal communication, etc.

Other levels of complexity of robot behaviour leading to increasingly more 'natural' interactions are possible.

Two areas of theoretical work inspire our approach. Since the Aurora project is not investigating the *nature of autism*; nor are we trying primarily to identify how children with autism are different from other children, in the trials that are reported in this paper we did not use control groups of non-autistic children. Furthermore, since we focus on the possible educational and therapeutic effects of robots in autism therapy our work is not firmly rooted in *any particular* theory of autism. However, we can clearly identify certain concepts and theories originating from autism research that are relevant to and have influenced our work. In the next sub-sections we describe some selected work in autism research and developmental psychology that has informed our work.

2.4.1 *Mindreading*

Generally humans are, from an early age on, attracted to self-propelled objects that move autonomously and seemingly with 'intention' (Dautenhahn 1997). Premack and Premack (1995) present a *theory of human social competence* that consists of three units: the first unit (*intentional system*) identifies *self-propelled movements in space* and interprets them as produced by intentional objects that are 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). In this way animate and inanimate objects can be distinguished, since only animate objects can move both in space and time without the influence of other objects (e.g., a stone can roll downhill, but not uphill without interference by external forces). Movement in the same location, however, is interpreted as animate but not intentional. The second unit in Premack and Premack's theory is the *social system*, which specifies the changes that the intentional objects undergo. This allows one to interpret relations as possession or group membership. The third unit is the *theory of mind system*, which outputs explanations of the actions performed in terms of states of mind such as perception, desire, and belief.

The 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, were convincingly demonstrated in a classical experimental study (Heider and Simmel 1944). In this study, human subjects created elaborate narratives about intentional agents when asked to describe movements of animated geometric shapes shown in a silent film. Based on Heider and Simmel's studies, more recent studies have confirmed and further refined their results. For example, Oatley and Yuill (1985) showed that cues signaling a social context increase people's tendency to use personal and mentalising descriptions. Rimé et al. (1985) demonstrated that the replacement of geometric shapes by human-like shapes reduced the intensity with which subjects attribute emotional states, thus showing that *patterns of movement* are more powerful in evoking anthropomorphic interpretations than the *appearance* of the characters. It has been shown that children as young as three years can interpret simple patterns of movements as intentional, goal-directed behaviour (Montgomery and Montgomery 1999). Thus, the interpretation of patterns of movements as 'goal-directed' and 'intentional', and the interpretation of interactions among such moving objects as 'social' or 'mentalistic', is fundamental to social intelligence in pypically developing humans.

Bowler and Thommen (2000) showed that children with autism are able to distinguish mechanical motion from intentional action as well as control groups of children who were matched according to chronological and verbal mental age. Abell et al. (2000) investigated the attribution of mental states in children with autism in more detail. Using computer animations of geometrical objects, similar to the original Heider and Simmel study, they distinguished between interpretations in terms of *actions* in descriptions of randomly moving objects (e.g., an object bouncing off a wall), interpretation of *goal-directed* (G-D) behaviour in descriptions of objects that interacted with each other (e.g., fighting, following each other, etc.), and the use of *mentalising* descriptions for sequences that involved characters responding to 'mental states' (e.g., mocking, persuading, tricking, etc.). In the random condition the subjects were told to see 'just triangles', in the G-D condition the objects were given animal roles, and in the theory-of-mind condition the objects were identified as people. Results show that children with autism have impairment in using appropriate mental concepts when describing animations that involved mental states, even when these same children passed standard false belief tasks. This demonstrates the need to study mentalising capabilities for interpreting real-time interactions that might not be adequately captured by standard false belief tasks.

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 using narratives the *behaviour* of objects (in Mitchell and Hamm's study animals were used) is more important than other aspects, e.g., the appearance of an object or whether a human is familiar with the object. People seem to apply these behaviour-reading mechanisms quite readily 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).

There are many theories that aim to explain autism at a biological, developmental, cognitive, or neurobiological level. For example, the narrative deficit hypothesis of autism suggests a vital role of preverbal transactional processes in early development (Bruner and Feldman 1993; see also discussion in Dautenhahn 2002). However, the hypothesis of a specific *theory of mind deficit* in autism is at present the most widely accepted theory. Many researchers have contributed to the ToMM framework, including Uta Frith (see Frith et al. 1991), Alan M. Leslie (1994), and Simon Baron-Cohen (see Baron-Cohen et al. 1985). It should be noted, however, that a deficit in theory of mind cannot account for the whole spectrum of symptoms that are characteristic of autism. For example, a deficit in executive function (e.g., in planning, impulse control, initiation of action, etc.) has been proposed that could account for the tendency towards repetitive and stereotypical behaviour (Russell 1997).

Premack and Premack's theory of human social competence bears similarity to Baron-Cohen's suggestion (1995) of four mechanisms underlying the human *mindreading system*. The first is the *intentionality detector* (ID) that interprets motion stimuli (stimuli with self-propulsion and direction) in terms of the mental states of goal and desire. These mental states are basic since they allow for 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 producing a non-random sound as an object with goals and desires. The second mechanism in Baron-Cohen's mindreading system is the *eye-direction detector* (EDD), which only works through vision. EDD detects the presence of eye-like stimuli, detects the direction of the eyes, and interprets gazing as *seeing* (attribution of perceptual states). This mechanism allows for the interpretation of stimuli in terms of *what an agent sees*. ID and EDD represent *dyadic relations* (relations between two objects, agent and object, or agent and self), such as 'Agent X wants Y' or 'Agent X sees Y'; however, they do not allow for the establishment of a link between what another agent sees and wants and what the *self* sees and wants.

Sharing perceptions and beliefs is assumed to be beyond the 'autistic universe' and requires two additional mechanisms: SAM, the shared-attention-mechanism that allows us 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 typically developing children above the age of four. In typical 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 is added, triggered by SAM. The arrival of ToMM is visible for instance through pretend play. It should be noted that earlier mechanisms are not replaced by newer ones, for the former continue to function. According to Baron-Cohen's analysis children with autism possess ID and EDD. ToMM is missing in all children with autism, while some of them possess SAM.

As pointed out in the present section, biologically typically developing children above four years of age detect, are attracted to, and interpret autonomous, self-propelled objects such as robots as intentional agents. Most of the children we work with in the Aurora project are minimally verbal or nonverbal, and the trials in which they interact with a robot are not specifically designed for distinguishing the attribution of goal-directed behaviour from the attribution of mental concepts (Abell et al. 2000). Moreover, due to our application-oriented approach that is grounded in Artificial Intelligence, Robotics and Assistive Technology, we do not test the children explicitly with respect to SAM, ToMM or mentalising abilities. This would go beyond the scope of our project. As stated previously, our work is not directly based on any particular theory regarding the nature of a theory of mind in children; it is therefore not our primary aim to make any claims regarding the children's theory-of-mind abilities. However, the theory-of-mind framework raises many issues (self-propelled movements in space, eye gaze, etc.), which in our opinion lend themselves to investigation with autonomous robots. We therefore propose that, *potentially*, robots could be a useful tool for diagnostic purposes, as well for theory-of-mind research in autism.

2.4.2 *Homo imitans: Interaction games children play*

The second strand of theories which the Aurora project is influenced by address interaction dynamics and imitation games played by children. Imitative and rhythmic interaction games (comprising, for instance, vocalisations and body movements) between infants and caretakers, such as imitation and turn taking, play an important part in the development of social cognition and communication in humans (cf. Bullowa 1979; Užgiris et al. 1989; Meltzoff 1996; Meltzoff and Moore 1999; Trevarthen 2001; Nadel and Butterworth 1999). Research in developmental psychology shows that infants seem to detect specific temporal and structural aspects of infant-caretaker interaction dynamics; they are born ready to communicate by being able to reciprocate in rhythmic engagements with the motives of sympathetic partners. Moreover, it has been suggested by Meltzoff and his colleagues (e.g., in Meltzoff and Moore 1999) 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.

Imitation also plays an important part in play and *social learning* in both children and adults. It is necessary for the individual's social acquisition of a variety of skills, ranging from vocal imitation in language games to imitation of body movements (e.g., when instructed how to tie shoe laces). Similarly, research in robotics and software agents endeavours to employ imitation as a means of social learning, using machine learning approaches. Importantly, the *social function of imitation* in human-human interaction is increasingly recognised as a means to engage others in interaction, to express interest, and to develop the coordinated interaction central to verbal and nonverbal 'dialogues'. For a comprehensive overview of research on imitation in animals and robots see the contributions in Dautenhahn and Nehaniv (2002).

Imitation is an important mechanism of social learning in human culture, but also a powerful means of signalling interest in another person, used for purposes of *communication.* According to Nadel et al. (1999), immediate imitation is an important *format of communication* and is a milestone in the development of intentional communication. It links the imitator and the imitated in synchronised activity, creating intersubjective experiences by sharing topics and activities. Even unconscious temporal synchronisation and rhythmic coordination of movements between people play an important role in communication and interaction in human culture, as demonstrated by early studies in proxemics (Hall 1966). Temporal synchronisation of behavioural dynamics has also been implemented in studies with robot-human interaction, e.g., Dautenhahn (1999).

Opinions on deficits of children with autism with respect to imitation vary (e.g., Rogers 1999; Charman et al. 1994) and often depend on the particular psychological theories on the nature of autism that the particular research group supports. It is agreed, however, that, in general, children with autism seem to imitate less frequently; in particular they seem less able to imitate actions and gestures (Jordan 1999).

In autism research, several studies have investigated the impact of imitation in interactions of children with autism and an adult experimenter. For example, Tiegerman and Primavera (1981) tested the effect of three play conditions on the frequency and duration of object manipulation of children with autism. In a study with six children, each child was exposed 11 times to three different conditions. The first involved the experimenter imitating the child's actions for exactly the same duration with the same kind of objects (duplicates). Thus, in this condition, the child controlled the interaction. In the second condition, the experimenter performed a different movement with the same, duplicate object, using the same interaction time, but never imitating the child. In the third condition the experimenter randomly manipulated the objects, without any correspondence to the object, action or interaction time used by the child. Thus, in the third condition, the child had no control over the experimenter's behaviour. Results showed that the imitative interaction condition was most efficient in increasing the frequency and duration of object manipulation in the children with autism. This study points out the vital impact of imitative behaviour in child-adult interactions on the child's performance (in this case an increase in object manipulation).

In a more recent study, Escalona et al. (2002) found that children with autism showed more proximal social behaviour (touching) when an unfamiliar adult imitated the child, compared to the experimenter contingently responding to, but not imitating the child. In the study, which included twenty children with autism, the behaviour was judged in the context of a 'still-face' condition right before and after the contingency/imitation phase. The contingent condition facilitated distal social behaviour (attention). Additionally, motor behaviour and vocal stereotypies were found to be reduced. The authors interpret the results as confirming a previous study (Nadel et al. 2000), which suggested that in the imitation condition children with autism develop social expectancies that lead to an increase in attempts to initiate interactions. This suggests the 'special nature' of imitation as a means to facilitate social interaction, and ultimately to create intersubjectivity.

Escalona et al. (2002) suggest that imitation could be used as an effective means of intervention with young non-verbal children with autism, a suggestion that is in line with our investigations into imitative behaviour in the interaction of robots with children with autism. Indeed, our work focuses primarily on the *social role of imitation* (Dautenhahn 1994), i.e., imitation as a format of communication that creates intersubjectivity in human-human interaction. We propose that the important link between the dynamics of imitation, turn-taking and social interactions can be explored with robots.

From an Artificial Intelligence perspective, we previously suggested a conceptual framework 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 potentially the emergence of imitation games can be used as important mechanisms for 'social contact' between the robot and the child. It is hoped that such an approach, focusing on interaction dynamics rather than cognitive reasoning mechanisms, can incrementally facilitate and strengthen the temporal aspects fundamental to the development of social competence and the ability to socially interact with people (cf. Hall 1983; Farnell 1999).

There are potentially at least two different ways that contingent and imitative behaviour can be used in the Aurora project. Firstly, can a robot that shows behaviour contingent with a child's performance or that imitates a child's movements increase the child's social behaviour (cf. Escalona et al. 2002)? Secondly, can we encourage a child to imitate a robot's movements? In the latter case, either the robot might be used to assess a child's imitation skills, or the imitative behaviour might be used as a stepping-stone towards more complex interaction. In our work with the mobile robot we focussed on very simple imitation games where the robot and the child take turns, e.g., in approach and avoidance games. The 'imitative behaviour' that we study is therefore far simpler than the conditions usually used in autism research.

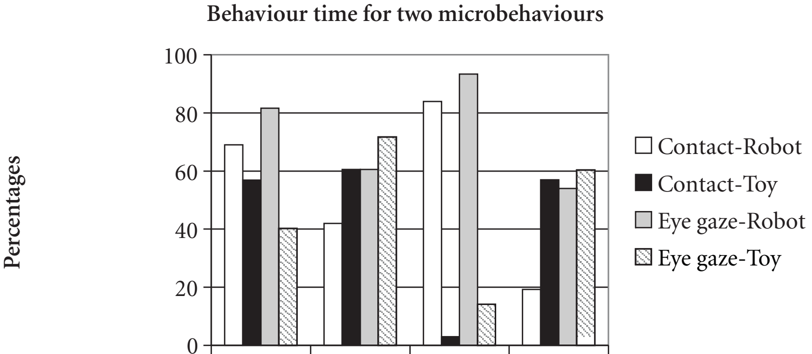
Note that 'social behaviour' in the context of robot-child interaction is quite different from child-adult or child-child interaction. It is therefore not clear whether any 'social behaviour' shown by a child towards a robot will be generalised and applied to interactions with people (see below, for a discussion on generalisation).

2.4.3 *Overview of results*

The results mentioned in this section refer to Scenario A (Section 2.4), where a purely reactive robot (Figure 1) tries to engage children with autism in simple, imitative, interaction games, based on elements of turn-taking. The robot's behaviour is guided by a small set of rules, which makes it much more predictable and less complex than human behaviour. However, the robot's behaviour is not completely predictable. For example, the same 'approach child' behaviour will never be repeated precisely; it will rather be performed in variations. This issue is important to our work, since we must avoid perpetuating stereotypical and repetitive behaviour that is characteristic of autism.

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 series of comparative trials, where the children played with a mobile 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.

The study just mentioned allowed us to compare the way in which the children interacted with the robotic platform to the way they interacted with a standard toy. In order to evaluate robot-human interactions we developed a



	A	B	C	D
□ Contact-Robot	69.03	41.95	83.9	19.24
■ Contact-Toy	56.91	60.55	2.99	57
▒ Eye gaze-Robot	81.64	60.56	93.33	53.99
▧ Eye gaze-Toy	40.24	71.67	14.18	60.33

Child

Figure 2. This figure displays selected results that are part of a larger comparative study that involved 18 children and tested the two conditions (robot versus toy truck). Results are shown for four boys with autism with regard to the microbehaviours eye gaze and contact time (cf. Werry et al. 2001a). Contact time measures any instances when the child touches, operates or handles the robot or the toy truck. Depicted are the percentages of the micro-behaviours observed during the duration of the trial (approximately four minutes of exposure to the robot followed by exposure to the toy truck). Full results of the comparative study are presented in Werry (2003).

technique for evaluating quantitatively video data of robot-child interaction (Dautenhahn and Werry 2002). The technique is based on micro-behaviours (Tardiff et al. 1995), including, among others, eye gaze (looking at the robot/toy), contact (operating, touching or manipulating the robot/toy), and attention (towards the robot/toy). For a group of 18 children with autism, the statistical results showed a significant increase in the interaction levels of the children with the robot when considering the amount of eye gaze and attention directed at the robot. However, when exposed to the toy the results showed a significant increase in the children's contact time (a combination of operating the robot with touching and handling — pushing, picking up, etc. — the toy and the robot). Since the non-robotic toy does not do *anything* unless children touch and manipulate it, the results for contact time might not be very surprising. Figure 2 gives an example of the quantitative results of this study for four children, clearly pointing out individual differences. The complete results for 18 children are presented in Werry (2003).

In the above mentioned study, our evaluations considered each behaviour independently of the others. Generally, one also needs to examine the combination of behaviours, since isolated incidences may not give accurate results. For example, child D interacted with the robot by allowing it to approach him. When the robot was very close, the child took several steps backwards and again waited for the robot to follow him. Then, when the child could not go back any further due the room's walls, he took several small steps into the robot's space and waited for the robot to reverse away from him before repeating this. In one instance, when the robot moved too far so that the child could no longer be detected by the robot, the child stepped sideways to continue the interaction. Also, when this child was given the toy truck, he spent most of the interaction time simply lifting it and the rest of the trial time ignoring it.

Note that eye gaze in this particular study refers to the child gazing at the robot. *Eye gaze* in our study is therefore not reciprocal (the robot does not 'look back'), as it is the case when people make *eye contact*. In typically developing children, eye gaze and eye contact are a vital part of social development: Dyadic eye gaze is important to the regulation and management of face-to-face social interaction (Lee et al. 1998; Leekam et al. 1997). Some studies provide evidence that children with autism use less eye gaze in interactions as compared to typically developing children (Wing and Gould 1979; Stone et al. 1997). Eye gaze has also been shown to be more useful than verbal performance in discriminating between children with autism and a control group of children with moderate learning difficulties (Ruffman et al. 2001). The study also demonstrated that the children with autism who showed least eye gaze toward a correct location (associated to the task) had the most severe autistic characteristics. Many training programmes for children with autism include the training of eye gaze behaviours and eye contact. The training criteria for 'normal eye gaze frequencies' do however vary tremendously. As shown by Arnold et al. (2000), peer-to-peer eye gaze in small playgroups of familiar typically developing children (5–10 years old) were significantly less than previously reported data that was based on adult-child or adult-adult dyads. Thus, it remains unclear how much 'eye gaze' behaviour should be taught to children with autism. But whatever the 'normal eye gaze frequencies' are, research suggests that eye gaze is an educationally and therapeutically relevant behaviour. In our work we assume that it can be used as an indicator of interest- and engagement-level, similar to attention and contact behaviours, although we are aware that for children with autism the correlation between these behaviours and levels of engagement/interest might be less straightforward than for typically developing children. Any interpretation of our data therefore must be cautious.

For more details on the quantitative and qualitative evaluations of children with autism interacting with robots in the Aurora project, see Werry et al. (20001a,b), Dautenhahn and Werry (2002), Dautenhahn et al. (2002b), Werry (2003). Evaluation is a major issue in our work. A range of different qualitative as well as quantitative evaluation techniques are needed in order to reveal not only statistical regularities and patterns, but also *meaningful events of behaviour in context.* For instance, an application of *Conversation Analysis* has revealed interesting aspects of how the robot can elicit communication and interaction competencies of children with autism (Dautenhahn et al. 2002; Robins et al., in press).

2.4.4 *An example*

In order to exemplify the types of interaction that occur in the Aurora project, we now provide a narrative account of one particular boy with autism interacting with a mobile robot, displaying some 'typical' behaviour also observed in other children with autism. The example shows different ways of how a boy with autism plays with a mobile robot. This indicates that, in addition to the quantitative observational data used to assess the occurrence of micro-behaviours such as eye gaze (cf. Figure 2), other behaviours are difficult to evaluate without considering the *context* in which they occur. We shall call the boy with autism that took part in the comparative study Olaf.

Olaf interacted with the robot before he was exposed to the toy truck. On entering the room, he investigated the toy that was located on the floor and then he exited the room. When he re-entered the room, the trial started. On entering the room for the second time, he looked around before one of the investigators showed him the robot and turned it on. As this was happening Olaf again looked around the room. There seemed to be not enough to keep his attention, as the robot was not acting at that point. However, twelve seconds into the trial, he again noticed the robot and approached it. The robot was still inactive and he walked away from it again. However, he continuously glanced at the robot, for periods between one and three seconds. Thirty seconds into the trial, the robot began to move as one of the investigators prompted it to move. This seemed to catch Olaf's attention: he again looked at the robot and stopped moving around the room. He continued to gaze at it for eight seconds, before moving away. However, he continued to watch the robot as he moved around it for thirteen seconds. At this point, he became interested in the experimenter and the video camera. After moving around the room, he avoided the robot as it moved towards him, but kept observing it. Seventy-five seconds into the trial, Olaf bent down to interact with the robot at its level, looking around it, investigating it and touching it gently. When the investigator turned the robot around and it headed towards him, Olaf was not disturbed by the robot's movement towards him, and did not attempt to move away, even though he was seated on the floor. He even leaned lower to gaze at the sensor of the robot, commonly treated by the children as the 'front' of the robot. In total, Olaf was seated on the floor for seventy seconds, and spent fifty seven seconds gazing at the robot. Two minutes and forty seconds into the trial, Olaf reached for the toy truck and brought it out, interacting with both the toy and the robot simultaneously.

Initially, Olaf was more interested in the toy than the robot, but twenty seven seconds after the toy was brought out, he used the toy to interact with the robot. He did this by placing the toy in front of the robot, and it backed away. It is significant to note that Olaf did not engage in this type of operation of the robot without the toy being there, and that no one had told him that the robot would behave in this way. He then continued to 'push' the robotic platform backwards by placing the toy in front of it, so as to trigger the robot's forward sensors. Eighty seconds after the toy was brought out, Olaf switched his attention back to the robot, ignoring the toy and gazing at the robot for twenty seven seconds, at which point Olaf again distributed his attention between the toy and the robot, operating the robot by using the toy.

This type of behaviour is typical for Olaf. He appeared cautious in his interactions, and looked around the room frequently. He kept a distance from the robot and appeared uncertain about interaction of any kind. He seemed to be encouraged to interact with the robot through using the toy rather than in a direct manner. This might indicate a willingness to engage in interaction. It is hoped that, with further familiarity with the robot, Olaf will be more confident in the way that he uses the robot, to a point where he might be able to explore the interactions and to learn from them.

Several other trials have been conducted in the Aurora project. For example, in a different set of trials (dual-child trials) we investigated three pairs of children with autism who were simultaneously exposed to the robot. Different play styles could be observed. These trials point towards the possible role of the robot as a *mediator* — a device that mediates interactions between people (Werry et al. 2001b; Robins et al. 2004; Robins et al., in press). This mediating role is very different from how we used the robot in the single child trials, where the robot's purpose was to teach basic interaction skills through play. Generally, besides the obvious role of a robot as a therapeutic interaction partner, different roles of robots in autism therapy can be envisaged (Dautenhahn 2003).

2.5 Current work

Our current and future work with mobile robots primarily targets scenarios B and C mentioned in Section 2.4. Specifically, this includes the following research directions:

- Long-term studies with children with autism, using repeated exposures to the robot, identifying possible therapeutic or educational effects (Robins et al. 2004; Robins at al., in press).
- Comparative studies with different types of robots, identifying differences in the appropriateness of different robot designs as a therapeutic toy (e.g., mobile as opposed to humanoid robots (Dautenhahn and Billard 2002).
- Addressing the "imitation deficit" in children with autism by designing scenarios for studying whether and how children with autism can be encouraged to engage in imitative interaction games with robots.
- Further detailed analysis of robot-child interaction, including the identification of different play patterns. In this research direction we study typically developing children as well as children with autism (see Dautenhahn et al. 2003 and Salter et al. 2004 for initial studies on identifying play patterns with typically developing children).
- Development of robots that can adapt to individual children and their needs, robots that can 'grow' with the child's changing needs and individual

preferences, and that can guide the child through different therapeutically relevant interactions. This is by far our most long-term goal.

3. Comparison of robotic and virtual environments

In this section we outline some of the design issues that play an important role in the Aurora project. We then discuss these in the context of interactive virtual environments, in order to demonstrate differences or commonalities between robotic and virtual environments in autism therapy.

3.1 Controlled and safe learning environments

The *autistic spectrum disorder* covers a huge range of different abilities and needs. Even within particular age spans individual differences can be immense. The target group therefore needs to be identified very clearly. However, even then interactive environments must be taken into account for specifying the individual needs of the children. Virtual environments can be designed as learning environments. Applications include the treatment of specific phobias (North et al. 2002) such as fear of flying, teaching social skills to people with Asperger Syndrome (Cobb et al. 1998; Parsons and Mitchell 2002), as well as other areas of therapy and rehabilitation (e.g., Greenleaf 1994; Wilson et al. 1997). Virtual environments also have a potential use for children with autism (Kijima et al. 1994; Strickland et al. 1995; Strickland 1996). In such environments input stimuli can be controlled and the child's behaviour can be monitored. Successive learning sessions can be evaluated in order to monitor the progress of teaching objectives, which are controlled by the teachers. Environments can be customised to account for individual differences. Children can be guided through learning experiences and encouraged to explore new behavioural opportunities by themselves. Such environments can provide safe environments with little or no intervention by another human, although teachers and/or parents (family) of the children are usually important participants in trials with children with autism. Dorothy Strickland (1996) gives an example of a virtual environment used as a learning environment for children with autism. Such environments can partially replace time-consuming, routine teaching sessions, if they are properly integrated within 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).

3.2 Proactive behaviour

One of the diagnostic criteria for autism in DSM-IV is "a lack of spontaneous seeking to share enjoyment, interest, or achievements with other people (e.g., by a lack of showing, bringing, or pointing out objects of interest)". As discussed by Mundy (1995), there is evidence that young children with autism have, compared to typically developing children, a lower tendency to *initiate non-verbal joint attention acts*. Such acts usually involve eye contact and gestures to show objects to others or to share the experience of an object or an event with others (intersubjectivity). In contrast, they seem less impaired in using eye contact and gestures to initiate non-verbal requesting acts, e.g., for eliciting aid in requesting objects or events from social partners. It has been suggested that deficits in self-initiated, social-approach behaviours may be central to the psychopathology in autism (Mundy 1995). Not unsurprisingly, teaching pro-active social behaviour plays an important part in educating children with autism. Many special needs schools for children with autism 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 child with autism 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 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: 9). 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, give information, seek information, express feelings, social routine) and forms of communication (motoric, gestural, vocal, pictorial, written, sign, verbal). A robotic or virtual 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 potentially be encouraged.

3.3 Embodied interaction

Virtual environments as described by Strickland (1996) require that the children are wearing VR helmets. This might be appropriate for some children, but we can expect that this is not feasible for many children with autism. 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 move freely, i.e., where 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 address particularly well the dynamics of motor behaviour in (social) interactions. Children with autism often show a distorted and usually 'indifferent' attitude towards their body. DSM-IV mentions "stereotyped and repetitive motor mannerisms (e.g., hand or finger flapping or twisting, or complex whole-body movements)" as a diagnostic criterion for autism. Also, self-injurious behaviour, abnormal complex behaviours of the body, and eating disorders can be observed. Leary and Hill (1996) provide an overview of extensive evidence of movement disturbance and abnormalities in motor behaviour in individuals with autism. Interestingly, it seems that symptoms of movement disturbance are not necessarily directly linked to the perceived functioning level. Based on the existing evidence, it seems that people with autism show body image distortions, i.e., an impairment in the mental construct of a body image that comprises the individual's perceptual experience of his body, his emotional attitude towards his own body, and the conceptual understanding of his body in general (as defined in Gallagher 1995). Body image distortions are likely to impact on an individual's abilities, will, and motivation to relate to other people. In order to support movement and physical play, special needs schools for children with autism usually have playrooms and various different facilities for 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 more 'freely', or less constrained than when confined to a chair. Embodied interaction can enrich learning environments, e.g., by helping children with autism to explore their own bodies and how they interact with their environment. Thus, bodily interaction itself can be as therapeutically relevant as the 'content' of the interaction.

3.4 Generalisation

A major problem in all therapeutic approaches to autism is generalisation: A child often shows improved performance in the particular teaching environment (e.g., in classroom) but has great difficulty in generalising the learning experience and applying the newly acquired skill to non-classroom situations. Virtual environments have a good potential in this respect: Creating different contexts and environments in the classroom and changing features and shapes of objects in the environment is very time-consuming and often not feasible, whereas creating alternative scenarios or variations in virtual environments is comparatively easy. This is important for specific learning objectives as well as for a 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, nor can a sword suddenly appear out of thin air. Typically developing children can easily compensate for these 'deficiencies' of the real world, for their imaginative skills allow them to create different worlds and alternative or fictional realities, as shown by role-play. However, as 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'). However, the issue of how a child with autism can transfer skills learnt in virtual environments to the real world remains unsolved.

3.5 Presence

'Presence' is a key issue in designing virtual environments (e.g., Heeter 1992): The acceptance of virtual environments does depend strongly 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 seem to be missing. Thus, for children with autism the feeling of 'being there', in the real world, is likely to be different from what we experience. Possibly, virtual environments 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*, thus providing the link to experiences in the real world. Using interactive physical robots avoids this problem to some extent. Such interactions are not necessarily 'natural' (i.e., children interact with a robot and not with another human being), but the interactions are grounded in experiences in the real world in the sense that the children are interacting with a *physical robot in the real world*, not with a *virtual agent in a synthetic environment*. However, given the current state of the art as far as robots that can be used as toys for children are concerned, the robots' interactive abilities (e.g., range of different behaviours) are limited in comparison to what is technically possible in software environments.

3.6 Holistic perception

As discussed by Frith (1989) and Frith and Happé (1994), people with autism have a tendency to process perceptual information at the local rather than the global level. The *weak central coherence theory* can explain why people with autism outperform other people in standard visual illusions, since they focus on individual parts of a figure rather than the *gestalt*, or why people with autism are less proficient than other persons in using the contextual cues necessary to disambiguate homographs with identical spelling but context-dependent different pronunciation (Happé 1997). Interestingly, it has been shown that central coherence in people with autism is weak, not lacking. Plaisted et al. (1999) demonstrated that under a 'selective attention' condition (where the experimenter overtly points out to the subjects whether they should pay attention to the global or local level in a pattern recognition test) children with autism performed in the same way as a control group of typically developing children. Unlike the divided attention condition (without priming), in the selective attention condition both groups showed global precedence effects, demonstrating that global proceedings seem to be intact in children with autism. Plaisted et al. suggest two possible interpretations of their results: (a) while for typically developing children the output of local processing is inhibited by global processing, this mechanism requires overt priming in children with autism, or (b) children with autism might voluntarily attend selectively to local processing and local information.

Typically, in their natural environment, children with autism tend to focus on features and details of objects and sensations in their environment that are of little interest to other people. 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 rather likely that the child's perception will focus on *aspects* of the object, e.g., colour, shape, texture, structural details, etc. Persistent preoccupation with parts of objects is also used as a diagnostic criterion in DSM-IV. In the Aurora project it is therefore vital to 'hide' any wires, buttons or other features of the robot that might attract the children's attention. Such changes in the environment are easier to achieve in a virtual environment where different aspects of the world can be hidden, highlighted, dynamically changed (depending on the child's activities), presented differently, etc.

4. Conclusion

This article introduced the project Aurora and discussed its background, motivation as well as particular challenges and issues involved in developing interactive robotic systems as therapeutic teaching devices for children with autism. Some comparisons were drawn between robotic and virtual learning environments. It is hoped that the development of robust and believable interactive systems (robotic and software) can support the education and therapy of children with autism, so that ultimately such technologies can become an integrated part of the curriculum, being used by teachers and parents and tailored towards specific individual needs of children with autism. Providing an enjoyable and entertaining 'toy' specifically adapted to the needs of the children, thereby increasing the quality of life of children with autism, is an integral part of the Aurora project. However, helping children with autism develop social skills is methodologically and technically demanding. Given the nature of autism, only long-term studies will reveal if and how this goal can be met.

From an Artificial Intelligence research point of view children with autism constitute a very special user group with immense heterogeneity. It is unlikely that one specific robotic design can be used generically. Based on our experience thus far we assume that only a range of robotic designs can meet the particular requirements of particular groups of children and individuals. Thus, the *design space* of interactive environments needs to be explored and linked to the space of sets of requirements, the *niche space* (Sloman 1995). One might speculate that (different types of) robotic therapeutic tools might serve for (different sets of) requirements addressing primarily bodily, physical interaction, while (different types of) virtual environments might serve for (different sets of) requirements addressing primarily imaginative and cognitive skills. There might be niches for various types of interactive environments with virtual or robotic agents which could be used in the therapy of children with autism, e.g., humanoid and non-humanoid robots, multi-media interactive environments, digitally enhanced toys, 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 and education can be assessed and compared.

Future robot developments and trials with children with autism will tell whether our initial goal, namely to facilitate social interaction skills of children with autism in interactions with robots, can be reached. It needs to be demonstrated whether and how the children can generalise any skills learnt during play with the robot to peers or adults. Note that the development of an 'attachment' of a child with autism to a robot is not our primary aim; we rather hope to further the interaction skills of a child with autism with *people*. Future results will clarify to what extent robots can contribute to either educational or therapeutic aims.

One issue in the Aurora project which is at present quite unclear, and which we have therefore not yet addressed explicitly, is the role of *affective* aspects in child-robot interactions. We exploit the fact that children with autism seem to find interactions with a mobile robot rewarding and enjoyable (we observe many positive facial and vocal expressions during the trials), but we do not address the affective dimension of interaction specifically. Yet, if we succeed in teaching a child to show pro-active social behaviour skills towards a robot, can this be achieved without any affective feedback from the interaction partner, as it is the case with robots? Can we teach imitative skills with a machine, i.e., without genuine intersubjectivity? How would 'intersubjectivity' between a child with autism and a robot look like? Should one 'fake' or 'simulate' affect in robots, e.g., by equipping robots with articulated faces and other means to express emotions? If we do, what are the ethical issues involved in encouraging the development of affective attachment of a child with autism with a robot that is not more than a machine, and that does not possess genuine emotions? From the perspective of a person with autism, and her needs, are these ethical concerns really relevant?

Notes

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1. Among the many possible meanings of 'remedial', we use the term to reflect our goal of *improving* (social) skills in children with autism.

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