# Issues of Robot-Human Interaction Dynamics in the Rehabilitation of Children with Autism

**Kerstin Dautenhahn**
Department of Computer Science
University of Hertfordshire
United Kingdom
K.Dautenhahn@herts.ac.uk

**Iain Werry**
Department of Cybernetics
University of Reading
United Kingdom
i.p.werry@reading.ac.uk

## Abstract

The paper discusses dynamics in human-robot interaction. Firstly, we propose a terminology for classifying robot-human interaction dynamics of increasing complexity. Secondly, we address the role of human-robot interaction in a particular application area, namely rehabilitation. Specifically, we discuss the area of autism and how mobile robots can play a therapeutic role in the rehabilitation of children with autism (investigated in the project AURORA). Problems and challenges of this work in progress aiming at 'getting the interaction dynamics right' are discussed.

## 1. Introduction: Building Interactive Robotic Systems

In recent years, the concept of *believability* and believable characters has attracted a lot of attention in the field of autonomous agents ((Bates, 1994), (Dautenhahn, 1998), (Porter and Susman, 2000)). Increasingly, researchers are exploiting techniques which have been originally developed in Arts and animation in order to allow a 'suspension of disbelief'. Here, the 'life-like' appearance of a system (e.g. in terms of realism - how closely a system resembles an animal) does not matter as much as the degree to which the agent a) expresses personality, character and emotions, and b) to what extent the agent is part of a plausible and consistent story which humans (in the role of viewers/readers/users etc.) can relate to. Following the concept of believability it is the behaviour and expression of a robot which makes it 'humanoid' (in the sense of 'being like us'), not the fact alone how many degrees of freedom it possesses or how closely its morphology matches that of a human being.

An example of a clearly non-humanoid and, judging from the responses of people interacting with it, very believable interactive robot is Simon Penny's PETIT MAL ((Penny, 1997), (Penny, 1999)). Here, a double pendulum structure gives the robot an 'interesting' and at the same time unpredictable movement repertoire with very smooth behaviour transitions. Pyro-electric and ultrasonic sensors enable the robot to react to humans by approaching or avoiding them. The system has been running at many exhibitions and attracted much attention despite of its technological simplicity. The robot is a purely reactive system without any learning or memory functionality, the complexity lies in the balanced design of this system, and not in its hardware and software components. Robot-human interactions with PETIT MAL generate interesting dynamics which cannot be explained or predicted from the behaviour of the human or the robot alone. This implementation at the intersection of interactive art and robotics demonstrates the power of dynamics in human-robot social interactions. Combined with recent advancements in the complexity of robot-human interaction, namely the development of robots with articulated 'bodies' (Brooks, 1996) and 'faces' (Breazeal and Scassellati, 1999), a (social) interaction space between human and robotic artifacts develops which demands a terminology.

## 2. Social Dynamics in Robot-Human Interaction

In (Dautenhahn, 1999a) a terminology was proposed for levels of robot-human interaction and degrees of believability. Based on this terminology we discuss different levels of interaction dynamics, starting from the most simple (trivial) forms of interaction and moving up to levels which show different degrees of coupling of the robot's movement dynamics with the human's movements dynamics. Starting point for our discussions is a thought experiment: a human enters a room where a robot is located. The following hypothetical behaviours of the robot (R), and plausible *interpretations* of the robot's behaviour by the human observer and interaction partner (H) can occur, depending on the following levels of interaction:

1. *The immobile robot.* R: the robot is not moving at all. H: the robot does not appear different from any other stationary object in the room. The robot might be coloured interestingly, but it is unlikely to catch the hu-

man's attention or imagination more than an interesting object or painting.

2. *The socially non-responsive robot.* R: the robot moves randomly or in a manner neither temporally nor spatially correlated with the actions of the human. H: The robot is likely to be attributed autonomy, in particular if it seems to pursue a goal, possess intentions etc. due to the 'natural' human tendency to anthropomorphise (see discussion in (Braitenberg, 1984), and (Bumby and Dautenhahn, 1999) for an empirical study on how children attribute goals and personalities to robots). However, it is unlikely that the human will 'bond' with the robot. Depending on the robot's behaviour the human might even feel indifferent or afraid of the robot. The human might do some 'tests' in order to see if the robot reacts to her ('probing'), e.g. repeating certain movements, approaching the robot etc. After a while the human might lose interest since she can neither influence nor control the robot.

3. *The socially responsive robot.* The human is able to influence the behaviour of the robot indirectly. For example, the robot increases and decreases the speed of its movements or changes its orientation depending on the human's activities. However, the robot's movement repertoire itself remains unchanged. PETIT MAL, discussed above, which can show different elements of approach/avoidance/following behaviour towards a human, falls within this category. At this level simple interaction/imitation games can emerge. At this stage, for the first time, the human might tend to call the robot's behaviour (towards herself) 'social'.

4. *Temporal Coordination.* R: the robot's movements are temporally coordinated with the human's movements, although the robot's movement repertoire remains unchanged. As discussed in (Dautenhahn, 1999a) temporal coordination means that movement changes occur simultaneously without requiring a fixed mapping between the human's and the robot's movements. H: the human realises that she can influence the robot when performing appropriate movements, she can modify its behaviour. Synchronised, 'dancing' type interaction dynamics can emerge.

5. *Temporal Coodination and Teaching.* See previous level with the following increase in interaction complexity: The human is now able to shape the robot's behaviour, by means of machine learning techniques. In this way, the human can 'teach' the robot new sequences of movements or reinforce existing movements. Temporal coordination can serve as a 'social feedback' signal for reinforcement learning in robot-human interaction, so that the human can select among movements in the robot's movement repertoire. As a consequence, an 'individual relationship' between robot and human seems to develop. The robot is more likely to be accepted as an interaction partner. An example of investigating temporal coordination and reinforcement in a 'dancing' experiment involving one human and one mobile robot is described in (Dautenhahn, 1999a). An interesting issue which can be addressed on this level of interaction complexity is to have the robot develop a memory of *interaction histories*, as required in (Nehaniv and Dautenhahn, 1998). Teaching or behaviour shaping can be used at all following levels.

6. *Temporal contingency.* Whenever the human does action X the robot does action Y. X and Y are temporally linked and mappings exist between the human's and the robot's movements. X and Y are not equivalent. From the human's point of view the robot is acting 'just when I act'. From a third-person (observer) point of view the robot and the human might look as if they are performing 'turn-taking' or 'imitation games', although the actual actions do not have the same form.

7. *Structural congruence.* X and Y have the same form. From the human's point of view the robot is behaving 'just like me'. This is the complex form of dynamic and structural similarity (equivalence) between the robot's and the human's movements. Structural congruence requires a similarity and *correspondence* of the 'bodies' and movement repertoires of human and robot (see (Nehaniv and Dautenhahn, 1999) for a discussion and formal treatment of the correspondence problem in imitation). On this level the robot might use temporal contingency and structural congruence in order to identify individual humans, see below, so that it can react differently towards different humans depending on the individual interaction histories.

8. *Complex forms of social interaction.* Once reaching this level, higher levels of interactions can develop, requiring robot platforms and control architectures which are able to support complex social interactions (cf. (Breazeal and Scassellati, 1999)). Also, the robot might interact in a group of humans. The more complex the interaction dynamics and the *social relationship* between robot and human develop, the more likely it is that the robot will be accepted as a social interaction partner.

How are these different levels of dynamic couplings between a human and a robot related to what is known about the social development of infants? According to Meltzoff and colleagues ((Meltzoff and Gopnik, 1993), (Meltzoff, 1996)) temporal contingency and structural congruence are important sources of information which an infant uses to explore and 'probe' the identity of persons in its environment. For temporal contingency the child only need to detect that whenever she does X the adult does Y, i.e. the adult behaving 'just when I act'. Equivalences between X and Y need not be detected, as long as X and Y are temporally linked. In the case of structural congruence the child also has to detect that X and Y have the same 'form', i.e. that the adult is behaving 'just like me'. Experiments showed that infants cannot only detect temporal contingency but also structural congruence, which requires a similarity measure.

This shows, that exploring the dynamics of interactions, building up higher complexity as suggested above, can provide levels of interaction dynamics which can result in the 'like me test', i.e. they might be used by a robot to distinguish persons from objects in the environment, and to distinguish between different persons, supporting concepts of 'me', 'you' and 'persons' which are milestones in the cognitive development of a child as well as the basic for empathy and social understanding (Dautenhahn, 1997). As discussed in (Dautenhahn, 1994) imitation games, and in particular the like-me-test for robots could provide a robot with the basic repertoire necessary for behaving socially in a human inhabited environment. This is important in applications where humans live closely together with robots, e.g. in rehabilitation applications.

## 3. Robots in Rehabilitation

Increasingly robust and reliable robot manipulators and mobile platforms are available and more and more robots are used in service robotics and rehabilitation applications. Traditionally, robots are inhabiting industrial environments, or research laboratories, both environments are inhabited by people who are skilled in operating the robots. The situation is very different in rehabilitation applications. Here, typically the robot must interact directly, and often in close physical contact, with a person who is not only unused to having robots in their environment, but also is untrained in their use and control, and additionally is disabled in some way. This makes the method of controlling the robot critical to its success. An interesting approach is taken by Wilkes et al. who formulated a design philosophy called HuDL (human directed local autonomy), (Wilkes et al., 1998), (Wilkes et al., 1999). HuDL is exploiting the symbiotic relationship between the human user and the robot. The basic idea is to make maximum use of the things that humans do well and the things that robots do well. For example, a physically disabled person might have full mental capabilities but physical limitations in mobility and dexterity. These deficits can be compensated by a mobile robot (e.g. a robotic wheelchair with an attached manipulator) which is able to manipulate objects and move in the environment, but with an otherwise very low degree of intelligence. Even with more advanced robot control architectures available today, one can expect that humans will for a long time in the future succeed better in coping with a dynamic, unstructured, complex and unpredictable environment. Thus, the HuDL approach is an example of a research direction where integration of robots in human society is a clear research goal.

Rehabilitation robotics can be classified into two groups. *Direct rehabilitation* involves the robot aiding the human in manipulation or communication tasks in the real world, as and when it is required. The most obvious of this type of rehabilitation is the use of wheelchairs, where the machine acts when it is needed and has an obvious and immediate effect. The second type of rehabilitation, *indirect rehabilitation*, consists of training or learning tasks, which may not come into effect until much later. While most applications in this category consist of mental or learning tasks, not all do. For example, training a persons manipulation after a stroke falls into this area. Cook and Howery (Cook and Howery, 1999) give an example of robot-mediated play. Here a robotic arm enables children with profound physical disabilities to manipulate toys and other objects. This allows them to engage in typical turn-taking and other play activities with adults and peers otherwise not possible for these children. For a greater evaluation of various types of robotic rehabilitation, see (Harwin et al., 1995).

The two categories of rehabilitation robotics lead to two very different approaches and result in different constraints and challenges, although they share many common features. Both categories of rehabilitation are designed to be used by the general public, people with little or no specific training of this type of device and who, additionally, need the robot to be 'straightforward' to operate and robust enough not to be unpredictable or unreliable. This focuses attention on the interface of the robot and the safety issues involved with its operation.

While direct rehabilitation requires us to evaluate carefully the physical side of the robot, indirect rehabilitation concentrates more on the method of controlling the training environment, and the issues involved with the interaction between the robot and the human user. (For an example of the different types of challenge posed and the applications involved in direct rehabilitation, see (Bolomsjo et al., 1995)).

Indirect rehabilitation poses perhaps the greatest potential for development in that the methods and forms which it takes are open ended, from the physical reconditioning to 'traditional' learning software. This field is also a lot more individual, since direct rehabilitation focuses on the tasks involved and indirect rehabilitation concentrates more on the specific type of disability which the user suffers from. Many of the principles involved in this category of robotics have been evident in the area of educational software for many years. For example, the software used in schools for teaching also has the potential to teach those with learning disabilities (see (Cooper et al., 1999) for an overview). The study of how a robot is able to assist people can yield techniques which can further be used in robotics projects, for example the study of communication and learning disabilities in people can result in new insights for robot learning.

### 3.1 Related Work

For 20 years Seymour Papert has been arguing for the use of computer technology in education ((Papert, 1980), (Papert, 1993)) in order to provide a *constructionist* approach towards learning. 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 LOGO which has been widely used in teaching children. A computer-sketching device (a 'turtle' robot) was developed to introduce mathematical concepts of geometry and shape. The turtle is a computer controlled device which is moving according to a set of LOGO instructions. A pen is attached underneath the robot. By lowering or raising the pen the turtle leaves traces on the floor. The concept of a circle can therefore be explored through movements of the turtle in space (differential geometry). LEGO/LOGO was developed as an Artificial Life Toolkit for children (Resnick, 1989). A recent development of the MIT Epistemology and Learning group aims at developing programmable LEGO bricks with embedded computers (see http://el.www.media.mit.edu/groups/el/).

Recently, more and more robotics research groups investigate the domain of robot-human interaction and applications in education/entertainment. The LEGO LAB at University of Aarhus (Denmark) gives a good example ((Miglino et al., 1999), (Lund, 1999)). Generally, we see an increasing acceptance of Papert's *constructionism* which is replacing traditional methods of *instructionism*. Not unsurprisingly, the idea to educate children with interesting (toy) technology was soon applied to the idea of helping children with disabilities. Because of their interactivity and communicative function, robots have been studied early as to their applicability to rehabilitate children with autism who generally show communicative and other social deficits.

In 1976 Sylvia Weir and Ricky Emanuel published a technical report on their work using the LOGO learning environment to catalyse communication in an autistic child (Weir and Emanuel, 1976). They report on their experience with a seven-year-old autistic boy and his explorations in controlling a LOGO turtle. Here, a 'button box' is used as a iconic version of the LOGO programming language where 16 buttons represent the turtle commands (FORWARD, BACKWARD, LEFT, RIGHT, PENUP, PENDOWN, HOOT), with additional buttons for numbers. The button box is the child's interface with the turtle. The turtle is tethered and does not move autonomously. The seven sessions (seven hours in total) were videotaped and later analysed. A record was kept of the sequence of buttons the child pressed. An important observation for Weir and Emanuel was the notion that the turtle's movements correspond to the child's own body movements, e.g. the child started to act out the turtle's behaviour by reference to his own body schemata while exploring the relationships between himself (in control of the turtle) and the turtle as an instrument, which was seen as a step towards a dialogue with other people. To our knowledge this is the first study where a robot was used as a remedial device for a child with autism. Main features of robot-human interaction were: a) the robot did not act autonomously, the child operated the robot from a 'control panel', b) the child did not directly (physically) interact with the robot, c) the report gives little information on the performance of the child (and general characteristics e.g. his mental age) before start of the sessions, d) one child was tested.

An interesting approach using embedded technology for rehabilitation of autistic children is taken in the Affective Social Quotient (ASQ) project, (Blocher, 1999). This project aims to support autistic children in learning about social-emotional cues. Here, short 'emotionally charged' video clips showing one of several emotions (currently happy, sad, surprise, and anger) are shown to the child, 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. Six children were tested and some showed improvement in their matching of emotions.

### 3.2 Autism

Autism is a complex behavioural and cognitive disorder which affects up to two children in every thousand and is three times more likely to affect males than females. There is currently no cure available, so an autistic child will grow up to become an autistic adult. It is not yet known exactly what causes autism, however recent evidence (Rodier, 2000) suggests a genetic origin, resulting in a cascade of developmental and ultimately behavioural and cognitive disorders. It seems however unlikely that a single (genetic or other) factor will be identified which is solely causing autism. Autism encompasses a wide variety of symptoms. At the core of the disorder are learning problems and communication and interaction deficiencies. However, because of the nature of the disorder, if it is diagnosed within the first three years of the child's life, a special education program can be implemented which will maximise the chance of the child growing up into a life which is as self-sufficient as possible. If diagnosis occurs early enough, the resulting treatment will be more effective, and many children have been able to achieve relatively 'normal' lives as a result. Unfortunately, the current resources for autistic children and their families are rare and costly, often involving a special tutor in one-to-one sessions for much of the child's early life and six or seven days each week. Obviously, this level of attention is not cheap or easy to arrange, and while parents are left devoting their life to the care of the child, teachers find their time in great demand.

In response to this need for co-ordinated and efficient rehabilitation methods, a number of groups have emerged, to give the autistic child the maximum chance of a normal life. One of the largest of these is the National Autistic Society, the UK's foremost charity for people with autistic spectrum disorders and their families.

The Diagnostic and Statistical Manual of Mental Disorders IV (DSM-IV), the textbook for working psychiatrists and psychologists, contains a series of lists of symptoms, a number of which from each category must be present for the child to be diagnosed with autism. The NAS has a more descriptive definition, consisting of deficits in three main areas, which they call the triad of impairments:

*Social Interaction*
*Social Communication*
*Imagination*

Each of these symptoms affects way in which an autistic child perceives his environment, and are factors which must be considered when developing a robotic tool for their rehabilitation, which is the goal of the project AURORA (AURORA, 2000) which stands for **Au**tonomous **ro**botic platform as a **r**emedial tool for children with **a**utism.

### *3.2.1 Social Interaction*

When one meets a child with autism, one of the first symptoms that is noticed is that autistic children do not seek interaction in the way that 'normal' children do, and do not seem to be particularly interested in their environment. Observing a playground with children with autism means observing a collection of individuals who will hardly ever play with each other. Typical interaction/turn-taking games are missing. They will often go to great lengths to avoid interaction altogether. Autistic children will often not acknowledge the presence of another person in their environment, even when that person is actively trying to engage the child's attention. This may be due to a number of reasons, including the fact that people can be unpredictable - autistic children require extreme stability and enforced routine, while people can show very complex behaviour which is very difficult to predict for the autistic person. Also, a person is able to communicate in a number of different ways. We use speech on many levels, such as the actual words used and the tone of voice, as well as body posture and body language and a variety of subtle movements which serve as cues to the context and communication. Autistic children have great difficulties filtering their sensory input. In order to improve their interaction, they must concentrate on only one aspect and are often observed focussing all of their attention on small details, for example the spinning of a single wheel of a toy car. Susanne Schäfer (Schäfer, 1997) gives a first-person account on the difficulty for an autistic child to understand what it means if another child is pointing with his arm to the sky saying "Plane, plane!". The autistic child might in such a situation pay attention to the other child's arm, hand, or any other detail of the situation. To understand and master joint attention and declarative pointing (which normally begins to emerge at about 12 months in human infants) is of great difficulty for children with autism.

When communication is presented to people with autism in a 'parallel' fashion, they are likely to become confused and frightened. The use of a robot as a facilitator for interaction avoids some of these problems. Autistic children are used to playing with toys. Our initial tests showed that a mobile robot is perceived as a toy by autistic children. In addition, it is carefully controlled and is predictable, while still allowing the child to interact with it on his own terms. The children are not frightened by the robotic agent and enjoy the chance to interact through the medium of play, involving free bodily movements and making physical contact with the robot. Interaction can be channelled using a limited number of methods, and the robots rigidity and expressive limitations can be an advantage, as the children do not become confused or 'drowned' in the interaction.

### *3.2.2 Social Communication*

Perhaps the second symptom noticed when meeting an autistic child, is that they appear extremely quiet and reserved, or even 'withdrawn'. The autistic child often has difficulty with speech, and in many cases will not use speech at all. In addition, the autistic child will not understand the meaning of various gestures and facial expressions. Autistic children have a difficulty with abstract meanings and concepts, and so nouns are often the most used words. In this way, autistic children are sometimes able to communicate using picture representations. Sentence structure becomes more difficult, and many autistic children are unable to change the subject of sentences. In addition, the children may use echolalia, simple repeating phrases which have been heard, and not use speech as a form of communication at all. A fundamental part of communication and dialogue is the concept of turn-taking, and a great effort is spend on teaching children this concept. A robot is able to teach communication using both voice and movement. Turn-taking can be implemented through simple games and communication via pictures can be performed. Although the robotic agent is not perceived as another person, a certain intelligence is attributed to it, bridging the gap between the often too rich communication of people, and the extremely limited ability of simple toys to engage and inform.

#### *3.2.3 Imagination*

The third of the impairments observed by the NAS is a deficiency in the area of imagination and imaginative play. Autistic children show extremely limited ability to project outside of their directly sensed environment. They are unable to make the 'leaps of faith' required to project unreal situations and attributes to real events and objects. Supporting generalisation is a major issue in therapies for autistic people. A toy car will always be a toy car, even if it flies, and if an association of the word 'ball' is made with a cricket ball, a tennis ball may not be recognised as a 'ball' at all. This has many ramifications in our daily life as we assume that the objects which look like us and behave like us, also have thoughts, feelings and desires like us. Sarcasm, irony or lying are generally difficult or impossible to understand for people with autism. For example, their honest reply to the question "Do you know what time it is?" is likely to be "Yes" or "No" showing that they take the 'literal' meaning of language and do not grasp the underlying meaning of the question. Without the ability to generalise beyond what we can directly perceive, people become two-dimensional objects without intentions, knowledge and an 'inner life' which may be different from ours (see (Baron-Cohen et al., 1985), (Hendriks-Jansen, 1997), for a fuller examination of the consequences of this). One of the consequences of this is that autistic children have a strong preference for repetitive action, unwilling to explore and break the routine and stability, and unable to see the possibilities beyond the current action. A robot will be familiar in its behaviour, providing the stability and security which is needed, but it will also be able to vary from the established routine by small amounts and persuade the child to try new ideas within an established framework.

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 in a positive way, and uses a system of stimulus and response. A situation is set up, or arises, to which the child must respond. The response is then prompted and encouraged in small steps and a correct or desired response is rewarded and reinforced. A robotic agent is able to complement this approach as it can prompt through behaviour which is both constant and predictable, and then reward a desired response, thus reinforcing it. Tabular 1 compares TEACCH with alternative therapies, tabular 2 lists relevant URLs. The following examples illustrate the TEACCH philosophy.

> "For instance, a student who is learning to sign 'open' in order to get assistance in opening things might be given a tightly closed peanut butter jar at snack time, a child-proof container with screws on it during his vocational training, and be sent to get a ball from a locked cabinet prior to a physical education class." (Watson et al., 1989), page 3.

> "...'towel' was introduced to Nat during his daily one-to-one session with the teacher. Prior to the session the teacher went around the room scattering cookie crumbs and dribbling water on various desks, cabinets, and chairs. During the session, she took Nat to each of these 'messy' locations, thus exposing him to repeated functional contexts in which he would want a towel. After confronting Nat with each messy situation, the teacher used a graded series of prompts to encourage him to request the towel." (Watson et al., 1989), page 84.

In the AURORA project it is hoped that a robotic agent will be able to contribute to the rehabilitation process of autistic children, and to provide an additional means and method by which rehabilitation goals can be achieved. The nature of the robot results in the children viewing it as a toy, and this reduces the stress of the interaction. A robot will be able to instruct the child in roles of turn taking, by providing a sequence of actions, and both prompting the child and waiting for a specific stimulus from the child. Some of the most frequent tasks that autistic children are asked to perform at the NAS schools are those of matching and sorting, and sequences of actions. The children are encouraged to group objects by their characteristics, such as colour, shape or use, and to perform tasks in a strict sequence of actions.

These types of task lend themselves well to the use of a robot. The robot can perform shapes and simple matching tasks which the child can observe and interact with, or a series of actions can be performed by the robot, which may wait for an action from the child at key points. In this way, a robot is able to become a teaching aid, helping the children to learn tasks and actions which can be built on later by teachers and parents.

| Tabular 1: Therapies for Children with Autism | | | | |
|---|---|---|---|---|
| Name | ABA Therapy (Applied Behaviour Analysis) | TEACCH (Treatment and Education of Autistic and related Communication handicapped Children) | Holding Therapy | Music Therapy |
| Description | Usually a one-to-one series of consultations with a therapist. Undesirable actions and behaviours are ignored, while desired behaviours are rewarded. | Preferably a one-to-one session, but normally a small group of around two to four children for each therapist. Situations are constructed and the desired response is prompted and rewarded. | The goal of this treatment is to bridge the gap between the child and the caregiver. The caregiver will attempt to comfort the child. The caregiver may hold the child for a period of time, even if the child struggles against this. | The medium of music is used to encourage the child to interact and learn communication skills. Simple songs are used with rhythm to teach the child various nouns and concepts. |
| Structure | ABA therapy is highly structured, involving concentrated sessions of learning responses to stimulus and situations. | TEACCH therapy is structured around a series of short activities. Desired responses are rewarded, while undesired behaviours are ignored and not rewarded. Activities are kept brief to minimise boredom, and naturally occurring situations are taken advantage of. | The caregiver will sit with the child and offer physical closeness at times of stress. This allows the process to be relatively unstructured. | The treatment is structured around the child and the songs and sounds that the child is able to use. |
| Freedom of Expression | Freedom of movement and expression is limited. | Movement is limited within the bounds of the activity. However, expression is actively encouraged. | The child's expression is limited to contact and interaction. | The child is able to express himself freely, within the bounds of the musical medium used. |
| Spontaneity | Spontaneity is restricted due to the teaching method. | Spontaneity is encouraged in all activities. A spontaneous response from the child is often preferred to a strictly 'correct' answer. | Spontaneity is encouraged, along with an effort to reach out to the child. | Spontaneity is encouraged within the limits of the task and the structure of the therapy. |
| Intrusiveness (Personal sphere) | Not intrusive, but the highly structured routine and lack of the child's ability to avoid the teaching session can lead to distress. | The teaching is non-intrusive and the child is encouraged to respond but not forced. | This treatment can be very intrusive, often involving holding the child when they are struggling. | This method is non-intrusive. |
| Combination with other treatments | ABA is designed to be used without other methods, although some are complimentary. | TEACCH is designed to be used without other methods, but some can be complimentary and used in a home environment. | This treatment should be used in conjunction with other, more traditional, methods. | This system should be used with other treatments, and assumes that the child is aware of fundamental concepts and is vocal. |

| Tabular 2: URLs | |
|---|---|
| NAS | URL: http:www.oneworld.org/autism_uk/index.html |
| ABA | URL: http://members.tripod.com/RSaffran/faq.html |
| TEACCH | URL: http://www.unc.edu/depts/teacch/ |
| Holding Therapy | URL: http://www.autismuk.com/index13.htm#hold |
| Music Therapy | URL: http://www.autism.org/music.html |

Figure 1: An autistic boy playing with the Labo-1 mobile robot which was kindly donated by *Applied AI Systems* Inc. The child is not afraid to let the robot come physically very close to his body, including the face.

Figure 2: The child frequently 'reaches out' to the robot, 'testing' its front sensors and eliciting the robot's response to approach or avoid. After 20 minutes the teacher ended the interaction since the child had to go back to class.

In addition, a robot can increase the attention span of the child, simply by being engaging and less threatening than a human, and can display patterns of movement such as shapes and sequences as a dance. The robot is able to mimic the child, and vice versa, to provide either a stimulus or reward for an action. Main features of robot-human interaction of the AURORA project (cf. previous work described in section 3.1) are: a) the robot can move autonomously, b) the child is interacting with the robot mainly by full-body movements, c) the tests are done in schools of the NAS where the children's performances are well known, d) a group of 5-10 children is tested. For more details on the AURORA project, e.g. the robot, see (Werry and Dautenhahn, 1999), (Dautenhahn, 1999b).

The following list summarises theraupeutic issues which we hope to address in the AURORA project. We hope that in one or several of these areas the children will show improvements a) during the interaction with the robot (short-term evaluation, first stage), and b) show improvements in other contexts, e.g. are able to generalise their experiences (long-term evaluation, second stage). We describe how these issues are currently addressed with conventional teaching methods, and what a mobile robot could add to therapy. The current implementation of the robot is not able to show the full range of capabilities, the list shows the long-term perspective.

1. *Attention span.* In normal (TEACCH) teaching practice children are frequently prompted and their attention is directed towards objects, features and situations explicitly. The interactions with the mobile robot are widely unstructured and rely on spontaneous emergence of interaction. Because the robot provides an interesting interaction partner for the child, the child will be encouraged to pay attention to the robot's behaviour.

2. *Eye-contact.* Children are usually explicitly asked to make eye-contact when they meet people. 'Eye-contact' with the robot is here interpreted as making eye-contact with what the children perceive as the robot's 'front' (indicated by the robot's preferred direction of movement and sensors located at the front end of the robot's chassis).

3. *Pro-active behaviour.* In schools of the NAS teachers put much effort in creating situations which encourage proactive behaviour. To give an example: in regular 'tea time' situations teachers and children are sitting around a table, drinks and cookies are available. Children have to *ask* for particular food items, either verbally or using cards depicting food items. The robot we use cannot deliver food items, but it can exhibit interesting behaviour (single movements or movement patterns, word utterances) based on the child's behaviour. Therefore, if a child wants the robot to behave in a particular way, it has to 'ask' the robot (the appropriate form of the 'question' triggering a desired response can be adapted to the child's needs). The child may ask verbally, using movements (like approach, avoidance) or using certain body movements or gestures. This approach is also suitable to teach the usage of behavioural and verbal cues in pro-active behaviour.

4. *Turn-taking and imitative interaction games.* One way of teaching turn-taking in schools of the NAS is to let e.g. two children play with a toy and take turns in operating the toy. A teacher is guiding and structuring the interactions. Turn-taking with a mobile robot can involve the whole body, or parts of the body (see Figures 1 and 2). Turn-taking is emerging from unstructured interaction.

5. *Increase in play and language skills* at the expense of ritualistic behaviour. Generally, the robot can realise the full range of behaviour from simple, repetitive, highly predictive behaviour to more complex form of behaviour,

including elements of unpredictability. In this way, it is hoped that children can encouraged to 'play' is a less structured and ritualistic manner.

Our tests of the robot with groups of children with autism were encouraging. They showed that the children enjoyed interaction with robot, did not show any sign of fear (all of them soon approached and touched the robot), paid particular attention to the 'front' of the robot (were the main sensors are located). The attention span and level of interest of the children varied widely, from a few to 20 minutes. Often, the children clearly 'tested' the robot (by frequently reaching out with his hand towards the robot's front sensors), and visibly enjoyed (laughing) when the robot reacted with approach or avoidance behaviour. Such simple interaction games (level interaction dynamics 3 as characterised above) can serve as an important starting point for slowly progressing towards more complex forms of interactions, which could ultimately involve peers and teachers, with the robot in the role of a 'social mediator'. A new series of tests has started involving a speech interface which allows the robot to 'comment' on its perceptions and actions. Results and evaluation methods will be addressed in a forthcoming publication.

## 4. Conclusion

We discussed general issues of social dynamics in robot-human interaction and proposed a terminology which characterises increasingly complex types of dynamics in robot-human interaction. We introduced the project AURORA which addresses social dynamics in robot-human interaction in the specific context of rehabilitation of children with autism. Using robots as remedial 'toys' and teachings aids for children with autism is a long-term project, and while we go along we are learning about general issues of robot-human interaction which might also proof valuable in other rehabilitation or non-rehabilitation contexts. However, the domain of autism is particularly relevant since people with autism show specific deficits which develop very early in a non-autistic infant (if not innate, see discussions on neonatal imitation, (Meltzoff, 1996)) and which in non-autistic adults usually operate on an unconscious level (e.g. joint attention, reading social cues in facial expressions and postures etc.) so that we tend to take them for granted and have difficulty imagining how the social world would be experienced without these powerful means to relate to and interpret the social world.

The goals of the project AURORA are twofold: 1) helping children with autism to enjoy social interactions and ultimately making steps to bond with the (social) world, in this way increasing the quality of life for children with autism, 2) studying general issues of human-robot interface design with the human-in-the-loop, in particular a) the dynamics of perception-action with respect to both the robot and the human, b) the role of verbal and non-verbal communication in making interactions 'social', c) the process of adaptation, i.e. humans adapting to robots as social actors, and robots adapting to individual cognitive needs and requirements of humans as social actors.

## 5. Acknowledgements

The project AURORA is conducted in collaboration with Radlett Lodge School. We are grateful to Patricia Beevers, the teaching staff of Radlett lodge school, the parents of autistic children who gave us permission to perform the tests, and last but not least to the children at Radlett Lodge School. The project is supported by EPSRC GR/M62648. We are grateful to Takashi Gomi and his team at Applied AI Systems Inc. for the donation of the Labo-1 robot and continuing support and encouragement.

## References

AURORA (2000). Url: http://homepages.feis.herts.ac.uk/∼ comqkd/aurora.html. Last referenced on 27th of April, 2000.

Baron-Cohen, S., Leslie, A. M., and Frith, U. (1985). Does the autistic child have a "theory of mind". *Cognition*, 21:37–46.

Bates, J. (1994). The role of emotion in believable agents. *Communications of the ACM*, 37(7):122–125.

Blocher, K. H. (1999). Affective Social Quest (ASQ). Teaching emotion recognition with interactive media and wireless expressive toys. Master's Thesis for Master of Science in Media Technology Massachusetts Institute of Technology, MIT, USA.

Bolomsjo, G., Neveryd, H., and Eftring, H. (1995). Robotics in rehabilitation. *IEEE Transactions on Rehabilitation Engineering*, 3(1):77–83.

Braitenberg, V. (1984). *Vehicles: Experiments in Synthetic Psychology*. MIT Press, Cambridge.

Breazeal, C. and Scassellati, B. (1999). How to build robots that make friends and influence people. Proc. IROS99, Kyonjiu, Korea.

Brooks, R. (1996). Behavior-based humanoid robotics. In *Proc. 1996 IEEE/RSJ International Conference on Intelligent Robots and Systems, IROS 96*, pages 1–8.

Bumby, K. and Dautenhahn, K. (1999). Investigating children's attitudes towards robots: A case study. In *Proc. CT99, The Third International Cognitive Technology Conference, August, San Francisco, see on-line proceedings at http://www.added.com.au/cogtech/CT99/*, pages 391–410.

Cook, A. and Howery, K. (1999). Robot enhanced interaction and learning for children with profound physical disabilities. In Bühler, C. and Knops, H., (Eds.), *Proc. AAATE Conference 1999, The 5th European Conference* *for the Advancement of Assistive Technology, November, Düsseldorf/Germany*, pages 291–296. IOS Press.

Cooper, M., Keating, D., Harwin, W., and Dautenhahn, K. (1999). Robots in the classroom - tools for accessible education. In Bühler, C. and Knops, H., (Eds.), *Proc. AAATE Conference 1999, The 5th European Conference for the Advancement of Assistive Technology, November, Düsseldorf/Germany*, pages 448–452. IOS Press.

Dautenhahn, K. (1994). Trying to imitate – a step towards releasing robots from social isolation. In Gaussier, P. and Nicoud, J.-D., (Eds.), *Proc. From Perception to Action Conference, Lausanne, Switzerland*, pages 290–301. IEEE Computer Society Press.

Dautenhahn, K. (1997). I could be you – the phenomenological dimension of social understanding. *Cybernetics and Systems*, 25(8):417–453.

Dautenhahn, K. (1998). The art of designing socially intelligent agents: science, fiction and the human in the loop. *Applied Artificial Intelligence Journal, Special Issue on Socially Intelligent Agents*, 12(7-8):573–617.

Dautenhahn, K. (1999a). Embodiment and interaction in socially intelligent life-like agents. In Nehaniv, C. L., (Ed.), *Computation for Metaphors, Analogy and Agents*, pages 102–142. Springer Lecture Notes in Artificial Intelligence, Volume 1562.

Dautenhahn, K. (1999b). Robots as social actors: Aurora and the case of autism. In *Proc. CT99, The Third International Cognitive Technology Conference, August, San Francisco*, pages 359–374.

Harwin, W., Rahman, T., and Foulds, R. A. (1995). A review of design issues in rehabilitation robotics with reference to north american research. *IEEE Transactions on Rehabilitation Engineering*, 3(1):3–13.

Hendriks-Jansen, H. (1997). The epistomology of autism: making a case for an embodied, dynamic, and historical explanation. *Cybernetics and Systems*, 25(8):359–415.

Lund, H. H. (1999). AI in children's play with LEGO robots. Technical report, AAAI 1999 Spring Symposium Series, AAAI Press, Menlo Park, CA.

Meltzoff, A. (1996). The human infant as imitative generalist: a 20-year progress report on infant imitation with implications for comparative psychology. In Galef, B. G. and Heyes, C. M., (Eds.), *Social Learning in Animals: the Roots of Culture*, pages 347–370. Academic Press, New York.

Meltzoff, A. and Gopnik, A. (1993). The role of imitation in understanding persons and developing a theory of mind. In Baron-Cohen, S., Tager-Flusberg, H., and Cohen, D. J., (Eds.), *Understanding other minds*, pages 335–366. Oxford University Press.

Miglino, O., Lund, H. H., and Cardaci, M. (1999). Robotics as an educational tool. *Journal of Interactive Learning Research*, 10(1):25–47.

Nehaniv, C. and Dautenhahn, K. (1998). Embodiment and memories - algebras of time and history for autobiographic agents. In *Proceedings of 14th European Meeting on Cybernetics and Systems Research EMCSR'98*, pages 651–656.

Nehaniv, C. L. and Dautenhahn, K. (1999). Of hummingbirds and helicopters: An algebraic framework for interdisciplinary studies of imitation and its applications. In Demiris, J. and Birk, A., (Eds.), *Learning Robots: An Interdisciplinary Approach*. World Scientific Press.

Papert, S. (1980). *Mindstorms: Children, Computers, and Powerful Ideas*. Basic Books, New York.

Papert, S. (1993). *The Children's Machine. Rethinking School in the Age of the Computer*. Basic Books, New York.

Penny, S. (1997). Embodied cultural agents: at the intersection of robotics, cognitive science and interactive art. In *Socially Intelligent Agents*, pages 103–105. AAAI Press, Technical report FS-97-02.

Penny, S. (1999). Agents as artworks and agent design as artistic practice. In Dautenhahn, K., (Ed.), *Human Cognition and Social Agent Technology*, chapter 15, pages 395–414. John Benjamins Publishing Company.

Porter, T. and Susman, G. (2000). Creating lifelike characters in pixar movies. *Communications of the ACM*, 43(1):25–29.

Resnick, M. (1989). LEGO, LOGO, and Life. In Langton, C. G., (Ed.), *Proc. of an Interdisciplinary Workshop on the Synthesis and Simulation of Living Systems, Los Alamos, New Mexico, September 1987*, pages 397–406.

Rodier, P. M. (2000). The early origins of autism. *Scientific American*, 282(2):38–45.

Schäfer, S., (Ed.) (1997). *Sterne, Äpfel und rundes Glas. Mein Leben mit Autismus.* Verlag Freies Geistesleben und Urachhaus GmbH, Stuttgart, Germany.

Watson, L. R., Lord, C., Schaffer, B., and Schopler, E. (1989). *Teaching spontaneous communication to autistic and developmentally handicapped children*. Irvington Publishers Inc., New York.

Weir, S. and Emanuel, R. (1976). Using LOGO to catalyse communication in an autistic child. Technical report, DAI Research Report No. 15, University of Edinburgh.

Werry, I. and Dautenhahn, K. (1999). Applying robot technology to the rehabilitation of autistic children. Proc. SIRS99, 7th International Symposium on Intelligent Robotic Systems '99.

Wilkes, D. M., Alford, A., Cambron, M. E., Rogers, T. E., II, R. A. P., and Kawamura, K. (1999). Designing for human-robot symbiosis. *Industrial Robot*, 26(1):49–58.

Wilkes, D. M., Alford, A., Pack, R. T., Rogers, T., II, R. A. P., and Kawamura, K. (1998). Toward socially intelligent service robots. *Applied Artificial Intelligence*, 12(7-8):729–766.