Chapter 1
Social Robots for Pedagogical Rehabilitation:
Trends and Novel Modeling Principles

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ABSTRACT

The use of robots as educational learning tools is quite extensive worldwide, yet it is rather limited in special education. In particular, the use of robots in the field of special education is under skepticism since robots are frequently believed to be expensive with limited capacity. The latter may change with the advent of social robots, which can be used in special education as affordable tools for delivering sophisticated stimuli to children with learning difficulties also due to preexisting conditions. Pilot studies occasionally demonstrate the effectiveness of social robots in specific domains. This chapter overviews the engagement of social robots in special education including the authors' preliminary work in this field; moreover, it discusses their proposal for potential future extensions involving more autonomous (i.e., intelligent) social robots as well as feedback from human brain signals.

INTRODUCTION

A percentage around 4% of the students in member countries of the European Union (EU) are registered in special education programs according to Special Needs Education (2012) European data. At least 10% has been reported in the USA regarding children characterized by a learning difficulty (Cortiella, & Horowitz, 2014), while in Finland a reported 17% of students are enrolled in special education (Meijer, Soriano, & Watkins, 2003). Special scientists such as educators, pedagogues, psychologists and speech therapists suggest that the percentage of children in need for special education is higher than reported, since many cases are not recorded for various reasons (Pastor, & Reuben, 2008). Furthermore, if we also consider the families of children then the percentage of people involved in special education is even

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higher. For the aforementioned reasons, the support of children with Special Education Needs (SEN) is included in national /European /world policies (UNESCO, 1994). Children with SEN are experiencing a variety of difficulties in family as well as at school. Effective special education at an early stage may improve the emotional and social development of children with SEN, their learning capacity, and, finally, improve the quality of life for a significant part of the population. Furthermore, special education may also improve the work skills of people with SEN thus enhancing a nation's workforce. There is a need for a policy framework regarding SEN. The latter has been a subject of debate in particular regarding whether special education itself is a problem of, or the solution to, issues of social justice (Norwich, 2007).

During the last decades robots seem to leave the industrial manufacturing floor and enter other domains such as farming, surveillance, entertainment, education, etc. Educational robotics are used worldwide as learning tools (Miller, Church, & Trexler, 2000) but surprisingly rarely in special education. At the moment, the demand for special education services remains high, yet unsatisfied due to the high cost involved. However, the benefits surpass all costs. Lately, Cyber-Physical Systems (CPSs), including social robots, have been proposed in education with emphasis on special education (CybSPEED, 2017). Note that the concept of CPSs has been introduced to account for technical devices with both sensing and reasoning abilities including a varying degree of autonomous behavior. There are a lot of expectations from CPSs (Serpanos, 2018). Seven types of CPSs are most often discussed, focusing on Disabled People, Healthcare, Agriculture and Food Supply, Manufacturing, Energy and Critical Infrastructures, Transport and Logistics, and Community Security and Safety. To them one additional type has been proposed lately, namely Education & Pedagogical Rehabilitation (CybSPEED, 2017). The CPSs we are interested in here include Social Robots in (special) education such as NAO, Pepper, Jibo, Leka etc. (Papakostas et al., 2018; Ueyama, 2015). In particular, humanoid robots such as NAO are already employed in various contexts for the treatment of children with Autism Spectrum Disorder (ASD) (Amanatiadis et al., 2017; Kaburlasos et al., 2018 January; Lytridis et al., 2018; Ueyama, 2015).

Despite reported evidence, the majority of people are still skeptical regarding the application of robots in Special Treatment and Education (STE) of children. For example, according to a recent survey (Eurobarometer, 2012), European responders appear positive towards robots but 60% of them believe that robots should be banned from taking care of children, the elderly as well as the disabled. Furthermore, only 3% said that robots should be a priority in education, while 34% maintained that robots should be banned from education altogether. All the aforementioned responses were attributed to the people's belief that robots may be dangerous for certain, sensitive categories of people. A more recent survey conducted simultaneously in three Balkan countries (Kostova et al., 2018) has confirmed the aforementioned results, and furthermore it recorded responses encouraging the joint engagement of robots and information technologies. An important question is posed next.

How far can a social robot interact with a child without raising ethical questions? General public opinion is important toward answering the latter question. Note that studies based on public surveys regarding the use of robots in eldercare revealed high acceptance of pet-like therapeutic robots, for humanoid caretaker robots as well as for surveillance care robots (Moon, Danielson, & Van der Loos, 2012). However, rejection of robots is reported occasionally because people often think that robots might replace humans and take their jobs. It seems that negative public opinion is probably the biggest challenge the scientific community must overcome in order to introduce social robots in the field of STE. Adaptation of a robot's appearance and/or behavior would improve the acceptance of robots by human users (Kanda et al., 2008).

The next generation of robot assistants in STE calls for robots tailored to individual needs. Currently, the robots used in special education are semi-autonomous, in sense that a robot has some autonomy from the manufacturer, for example to turn its head or to pronounce certain words, but there is always a human tele-operator in the background that controls the robot. An increased autonomy is expected to increase the usability of a robot. It is expected that providing robots with more intelligence, would make robots more useful. Preliminary application results suggest that robot technology could have a great impact on STE as an assisting tool for both teachers and therapists (Tanaka, Cicourel, & Movellan, 2007). In particular, educational applications of robots are promising for students with disabilities in two different manners: first, the robots can motivate students undertake a wide range of tasks that would otherwise refuse due to their disability and, second, the use of robots may result in an equal participation with peers in robot-based learning activities (Martyn Cooper, & William Harwin, 1999).

SPECIAL EDUCATION FROM AN ENGINEERING POINT OF VIEW

Special education is defined as the education of students with special educational needs in a way that addresses their individual differences. It involves individually planned and systematically monitored arrangement of various teaching procedures and scenarios, suitably adapted equipment as well as alternative materials. Such interventions are designed to support individuals with STE in order to achieve a higher level of personal self-sufficiency and success both at school and in the community that would not had been possible were the students only given access to typical education.

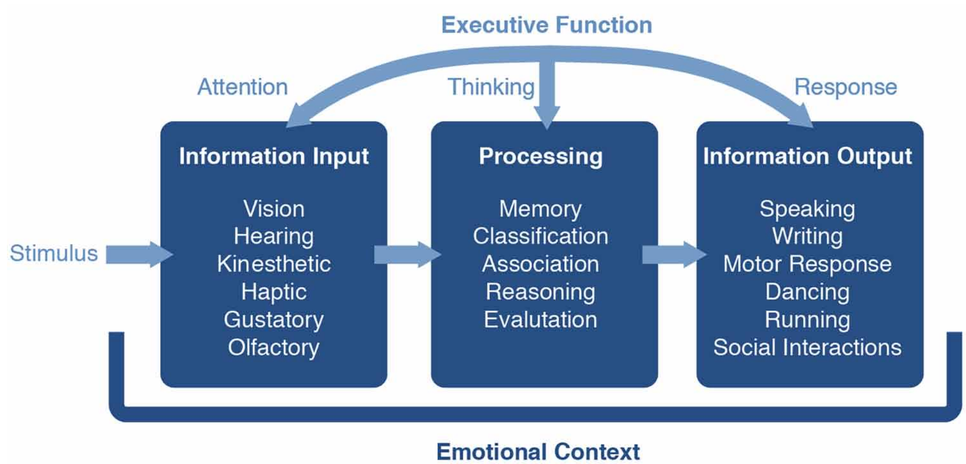
Common special needs include learning disabilities (e.g. dyslexia), communication disorders, emotional and behavioral disorders (e.g. attention deficit hyperactivity disorder), physical disabilities and development disabilities (e.g. ASD and intellectual disabilities). Students with special needs are likely to improve on their learning capacity and benefit from additional educational services based on different teaching approaches, the use of technology and especially adapted areas or resource rooms (Smith, 2007).

One way to study learning disabilities is by the analytic information processing model (i.e., block-diagram) in Figure 1 that explains how students interact with their external world during learning (Kirk et al., 2011). More specifically, first, the children receive information from their senses (vision, hearing etc.); then, they process this information by their memory, classification and reasoning capacities; finally, they respond to the input information by an output (i.e. speaking, writing, action).

This information processing is driven by the Executive Function which is the ability to decide which information to attend, how to interpret it and how to respond to it. Information processing takes place within an Emotional Context that influences every aspect of the proposed model shown in Figure 1.

Special education is necessary when a child is unable to process information effectively. In the latter case the problem might be either in the information input or in the internal processing of information or in the output response. The executive function is the decision-making part of the model that directs a child's attention to an input by choosing the thinking process to be called upon and decide how to respond. All this information processing is carried out within an emotional context which can activate various modules of the model conditioned on stress, anxiety, calmness, confidence, etc. Any deviation from the "typical" information processing described in Figure 1 calls for special education. For instance, autism spectrum disorder (ASD) is a developmental disorder characterized by impairments in communication, social interaction and imagination that may occur to different degrees and in a variety of forms. Children with ASD often have: accompanying learning disabilities and experience inability to relate to

Figure 1. The information processing model assumed during student learning



other people, rare eye contact, difficulty in verbal and non-verbal communication and tendencies towards repetitive behavior patterns (Jordan, 2013). In all, the analytic model of Figure 1 can be used toward analytically designing educational interventions by Social Robots as explained next.

SOCIAL ROBOTS IN SPECIAL EDUCATION

The term "social robots" typically refers to robots engaged in some form of social interaction with humans through speech, gestures, or other means of communication. Moreover, the term "assistive robots" refers to robots that aid people mainly with physical and neuro-developmental disabilities. In conclusion, the term Social Assistive Robots (SARs) has been proposed as the intersection of the previous two families of robots and it refers to robots designed to assist humans via interaction driven by user needs (e.g. for tutoring, physical therapy, emotional expression) using multimodal interfaces involving speech, gestures and various input devices (Fong, Nourbakhsh, & Dautenhahn, 2003). Our interest here is in SARs for pedagogical rehabilitation in special education with special attention to ASD.

In the aforementioned context, our basic Working Hypothesis, namely WH, is the following:

WH: SARs can be used by human teachers as sophisticated stimuli to multiple levels of cognitive processing in children with learning difficulties (also possibly due to preexisting conditions) toward modifying the processing within those levels by triggering underlying brain compensatory mechanisms and, consequently, improve a child's learning behavior based on education delivery methods alone.

We remark that our long-term objective is to improve the learning capacity of an individual human brain by non-invasive methods, namely by educational methods exclusively.

SARs face challenges different from those faced by social or assistive robots alone. For instance, social or assistive robots alone typically focus on reliability, precision of motion and repeatability since they interact physically with a person, whereas SARs emphasize emotional expressiveness, user engagement, physical appearance and robustness during interaction. The social features of SARs are particularly important because they are expected to support the user by coaching, motivating and directing change.

SARs pose important questions regarding how to design an effective, user-friendly system suitable for STE needs. Note that children with STE are sensitive to novel stimuli and have substantial difficulties with attention and engagement. In particular, SARs for autism must balance between non-threatening, goal-oriented treatment and productive interaction (Scassellati, Admoni, & Matarić, 2012).

Physical Appearance of Robots

The first that captures a user's attention is the robot's physical appearance (Tanaka, Cicourel, & Movellan, 2007). The appearance of SARs may range across many patterns including anthropomorphic, humanoid, animal-like, and non-biological. Due to the shortage of standards, different research groups often propose different robot designs. Nevertheless, in all variations, certain physical appearance standards have been adopted. For instance, a SAR cannot appear both extremely human-like and socially simple. A robot that resembles a human might facilitate the transfer of skills in human-robot interactions (van Straten et al., 2017), whereas a less human-like robot might contain distraction thus helping children focus attention on particular skill learning (Lord, & Bishop, 2010). In this context, of particular interest is the so called "uncanny valley" phenomenon, that is a feeling of unpleasantness and fear emerging in people communicating with robots when the physical attributes of a robot exceed a certain degree of resemblance to the human (Mori, 1970/2012; Dimitrova, & Wagatsuma, 2015).

In addition to the physical appearance, realism can be pursued by varying levels of biological motion. A robot that moves its head (Dachkinov et al., 2019) and/or its arms with multiples degrees of freedom looks more human-like than one that moves solely its arms up and down. The level of the capacity to move is dictated by the goals of human-robot interaction. Note that an increased actuation enables more complex expressions, thus increasing anthropomorphism, whereas a deceased actuation reduces the cost of development but it also simplifies the sophistication of interaction.

Designers must also decide about the extent of a robot ability to move around in its environment. For instance, most robots used in ASD therapy research typically involve motion of their body limbs such as arms and head, but other robots are fixed upright on the floor or on a table (Kozima, Nakagawa, & Yasuda, 2007). More rarely robots can move around freely in their working environment. Mobility allows for a greater flexibility in human-robot interaction by increasing the number as well as the types of collaborative activities that can be carried out. Nevertheless, mobility increases the number of parameters to be controlled during interaction thus increasing technical design difficulties (Michaud et al., 2007).

Children-Robot Interaction

Together with physical appearance, a robot's behavior is also important as to how well it can be accepted by humans as well as how effective it can be during a therapeutic session. Despite variations in robots' physical appearance, all SARs aim at generating therapeutic interactions such as elicitation, coaching, and reinforcement of social behaviors with human users. Human-robot interaction is described by the behaviors produced both by the user and by the robot during a session. The goal of an interaction might be to elicit joint attention, to mediate sharing and turn-taking between the user and others, to encourage imitation, etc. The robot can act as a teacher in an authoritative role, as a toy intending to mediate behaviors, or as a proxy to allow the user express emotions or goals (Scassellati, Admoni, & Matarić, 2012). A superb feature of robots is their capacity for repeatability and work without getting tired or complaining. Since robots do not humiliate or belittle people, it occurs that people in special conditions, e.g. autism, have less anxiety in interacting with robots and they are more willing to participate in learning exercises with robots rather than with humans.

Developing robots that socialize with people for sustained periods of time is technologically demanding (Kanda et al., 2004). Nevertheless, recent years have witnessed progress in this area. For instance, in a recent study, a state-of-the-art social robot was introduced in a classroom of toddlers for more than 5 months with the following results. The quality of the interaction between children and robots improved steadily for 27 sessions; then quickly dropped for 15 sessions when the robot was reprogrammed to behave in a predictable manner and finally it improved in the last three sessions when the robot displayed again its full behavioral repertoire. Note that, initially, the children treated the robot very differently than they treated one another. Application results have also demonstrated that current robot technology is surprisingly close to achieving bonding and socialization with human toddlers for sustained periods of time. More specifically, quantitative behavioral studies have demonstrated that in a period of 5 months, long-term bonding and socialization took place between toddlers and the social robot. Rather than decreasing, the interaction between children and the robot increased over time. In particular, children exhibited a variety of social and care-taking behaviors towards the robot and progressively treated it more as a peer than as a toy (Tanaka, Cicourel, & Movellan, 2007).

As mentioned above, the goal of using robots in STE is to encourage children to both engage and develop social skills. Thus, robots used in therapy are designed to take part in different interaction goals such as attract/maintain attention, evoke joint attention, suggest imitation, facilitate turn-taking, etc. Many studies have reported positive effects regarding robot presence on attention and/or engagement therapy scenarios with children (Barakova et al., 2018; Dautenhahn et al., 2009; Feil-Seifer, & Mataric, 2008; Ferrari, Robins, & Dautenhahn, 2009; Kozima, Nakagawa, & Yasuda, 2007; Michaud, & Caron, 2002; Pioggia et al., 2006). Some research provides evidence that robot behavior must be correlated or depend on the users' actions so as to elicit prolonged engagement (Feil-Seifer, & Mataric, 2008; Goan, Fujii, & Okada, 2006; Stanton et al., 2008), whereas other studies fail to confirm such a connection (Scassellati, 2005). However, any engagement recorded is social in nature, and despite social impairment, children with autism are statistically as engaged as typical children during robot interaction (Kim et al., 2012).

Joint attention is omnipresent in typical human communication and essential for learning collaborative skills (Johnson, & Myers, 2007). Some social robots, such as Keepon and NAO, are programmed toward successively searching for a user's eyes and then for an object thus seeking to engage joint attention. Such behaviors performed by robots are likely to evoke joint attention regarding children with ASD. Many studies confirm that children with autism demonstrate spontaneous joint attention behavior when interacting with a robot, for example when looking to an adult and back to the robot or when pointing to the robot and looking to an adult or to another child with the intention of sharing some feature with that person (Dautenhahn et al., 2009; Ferrari, Robins, & Dautenhahn, 2009; Kozima, Nakagawa, & Yasuda, 2005; Kozima, Nakagawa, & Yasuda, 2007; Pioggia et al., 2006; Robins et al., 2005; Werry et al., 2001). Children display the aforementioned behavior despite their previous tendency of avoiding eye contact and/or any engagement with unknown adults.

Imitation is an additional essential mechanism for learning an appropriate behavior. Children with autism face difficulties to imitate other people's social behavior such as wave hello or goodbye (Williams, Whiten, & Singh, 2004). Imitation seems to arise naturally in many child-robot interactions in STE research. In particular, sometimes the children are encouraged by adults or by a robot to imitate the robot's actions (Duquette, Michaud, & Mercier, 2008; Ferrari, Robins, & Dautenhahn, 2009; Robins et al., 2004; Robins et al., 2005); other times imitation occurs spontaneously and develops into a game with the child imitating the robot's behavior and vice versa (Kozima, Nakagawa, & Yasuda, 2005; Kozima, Nakagawa, & Yasuda, 2007; Robins, Dautenhahn, & Dickerson, 2009).

Turn-taking and sharing introduce challenges during social interactions with children with autism. More specifically, children can learn important life skills through social games that involve turn-taking. Robots by their nature, that renders them more animate than typical toys but less socially complex than humans, can elicit turn-taking with children who tend not to engage easily in such a behavior (Dautenhahn et al., 2009; Kozima, Nakagawa, & Yasuda, 2007; Ferrari, Robins, & Dautenhahn, 2009; Robins et al., 2005). For instance, social robot Kaspar has been employed in a turn-based imitation game that resulted in a sensible interaction between two children with ASD (Robins, Dautenhahn, & Dickerson, 2009).

Roles of the Robot

Robots in STE can assume different roles, even during a single therapy session. For example, a robot can act as a teacher or a leader that guides the interaction, as a toy that responds to the child and mediates social behavior between child and others (Vrochidou et al., 2018), as a peer or a proxy that encourages children to express their emotions and/or desires, etc.

Playing is important for the development of children. Robots designed for therapy are presented to children as toys during special therapy sessions. The fact that robots can capture attention, act autonomously and move distinguishes them from conventional toys. In some cases, robots in STE are combined with conventional toys (Kozima, Nakagawa, & Yasuda, 2007), whereas in other cases they are presented in a free-form play session individually (Feil-Seifer, & Matarić, 2009; Kim et al., 2012; Michaud, & Caron, 2002). Robots can also be engaged as peers of children, especially in imitation games (Duquette, Michaud, & Mercier, 2008; Robins et al., 2004). Recall that joint attention is a context where robots can act as effective social mediators. By extending social mediation further, robots can initiate turn-taking games between children with ASD. For example, researchers have reported the case of a teenager who, although previously could not tolerate another child in any playing activity, he was progressively introduced to a turn-taking imitation game first with his therapist and then with another child (Robins, Dautenhahn, & Dickerson, 2009).

Robots can act as teachers taking the lead and guiding social interactions. A robot can verbally ask a child to carry out certain behaviors such as spinning (Michaud et al., 2005), to guide the child through predefined play scenarios (Duquette, Michaud, & Mercier, 2008; Ferrari, Robins, & Dautenhahn, 2009), or to move autonomously in order to engage the child either in an imitation game (Robins et al., 2005) or in free-play interactions on will (Feil-Seifer, & Matarić, 2011). In most cases, a therapist or teacher instructs a child during interaction sessions with robots by explaining and giving instructions, e.g. "touch the robot" or "imitate the robot's behavior" (Robins et al., 2005; Stanton et al., 2008).

More rarely, robots appear to act as proxies or receptacles of emotions or intentions of children. For instance, Kozima, Nakagawa, & Yasuda (2005) have reported cases where children express emotional behaviors toward a robot in the absence of other people; for example, they hit the robot on the head, they stroke it and/or try to comfort it, they wrap the robot with clothes so that it does not get cold etc.

Introducing robots in entertainment, e.g. in the theater, is a promising alternative toward CPSs for pedagogical rehabilitation in special education that needs to be investigated.

Robot Autonomy

Children with learning difficulties, also due to preexisting conditions, might not behave consistently from day to day. More specifically, a child may be highly engaged one day during a therapy session and distracted the very next day. Therapists are ready to handle changes in a child's behavior, therefore so should robots be, if they are to be engaged constructively in therapy.

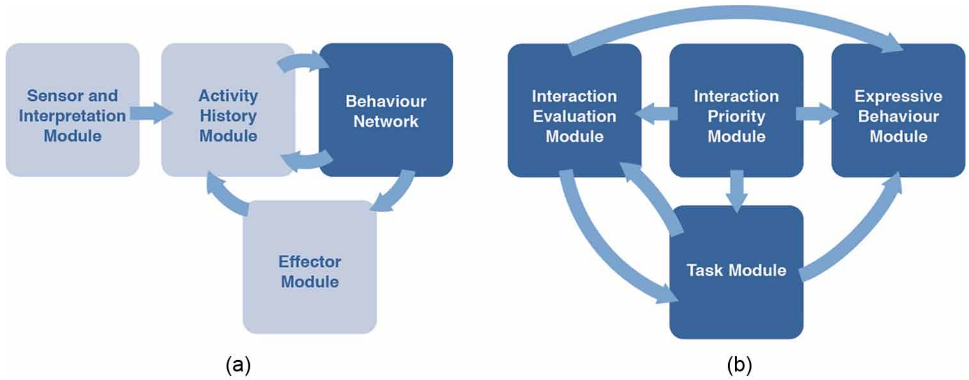
Very often robots in therapy are controlled remotely by the so-called Wizard of Oz (WOZ) technique (Kahn et al., 2008). More specifically, a human programmer controls the robot remotely either from a different room or from the same room. The programmer can monitor human-robot interaction via cameras in the room (Kim et al., 2012; Robins et al., 2004) or via cameras mounted on the robot in order to observe the interaction more closely (Kozima, Nakagawa, & Yasuda, 2005). The WOZ technique makes the robot more adaptive in line to the robot's technical capacities. Although WOZ is effective toward quickly introducing robots in complex environments, it is not considered effective for long-term and/or large-scale use. By designing autonomous robots that could interact socially with individuals, researchers hope to achieve a seamless integration of SARs in therapies. Autonomous robots are only partly designed, since it is difficult to design robots that operate adequately in complex, dynamic and unpredictable environments such as those during therapy. Researchers aim at developing robust and flexible robot controls for real-world-applications (Scassellati, Admoni, & Matarić, 2012).

A control architecture, namely B^{3}IA, that is a behavior-based architecture designed to address the challenges of autonomous robots as tools for children with ASD, has been proposed by Feil-Seifer & Mataric (2008). The robots possess an array of capabilities including sensing and interpreting the actions of children, processing of sensed data, evaluating the interaction, and changing the behavior by user-defined parameters. Figure 2 shows a block-diagram of the B^{3}IA architecture, where each module corresponds to one of the capabilities required by an autism intervention robot. The suggested architecture has been implemented successfully on a wheeled, non-humanoid bubble blowing robot and pilot experimental results have demonstrated improvements in the social behavior of children with autism.

Increased robot autonomy is expected to increase the operational capacities of SARs and thus enhance their potential in (special) education applications. One way of increasing robot autonomy is by making a robot more intelligent. The latter can be pursued by effective mathematical models implementable mainly in software. In particular, SARs call for an enhanced mathematical modeling paradigm due to their interaction with humans according to the following rationale.

The operation of conventional, i.e. non-social, robots typically occurs in a physical environment excluding humans and based solely on electronic sensors; hence, numerical models suffice to drive conventional robots. Nevertheless, when humans are involved, non-numerical data emerge such as words. In the latter context, the Lattice Computing (LC) paradigm has been proposed for modeling based on numerical and/or non-numerical data in any combination for social robot applications (CybSPEED, 2017). Recall that LC has been defined as "an evolving collection of tools and methodologies that process lattice ordered data including logic values, numbers, sets, symbols, graphs, etc" (Kaburlasos, & Papakostas, 2015). LC models can rigorously involve numeric data and/or non-numeric data *per se* without transforming one to another. In this manner it also becomes feasible to compute with semantics represented by a partial (lattice) order relation. Trends in LC appear in (dos Santos, & Valle, 2018; Kaburlasos, 2011; Papakostas, & Kaburlasos, 2018; Sussner, & Schuster, 2018; Valle, & Sussner, 2013). LC models are expected to be instrumental in optimal CPS modeling applications because LC models can (1) deal with both numerical data (regarding any physical system component) and non-numerical data (regarding any cyber system

Figure 2. Schematic of (a) the control architecture and (b) the behavior network of architecture B^3IA



component), (2) compute with semantics, (3) rigorously deal with ambiguity, (4) naturally engage logic and reasoning and (5) process data fast (Papakostas, & Kaburlasos, 2018).

CHALLENGES IN THE STATE-OF-THE-ART

Control architectures for SARs must include sensors as well as efficient software in order to also interpret the intention of children by monitoring them. Sensors could include physiological /biometrics detectors such as blood pressure, pulse, skin conductance and brain activity (Liu et al., 2008) or cameras that detect behavior (Feil-Seifer, & Matarić, 2011). Contact sensors that measure physiological /biometrics data are difficult to apply to people with autism because those people are sensitive to touch; nevertheless, the aforementioned sensors supply more precise information than non-contact sensors.

Interaction with autonomous robots that sense and respond to user behavior is an emerging field of scientific interest (de Haas et al., 2016; Kaburlasos et al., 2018 June). The development of effective robot controls for autism therapy applications might enable consistency of robot behavior, which is important in social assistive applications. Hence, human presence might be restricted, even substantially. Lately, scientific interest focuses on the design of SARs that response to high-level commands, such as verbal commands, from therapists in order to avoid awkward tele-operation of the robot.

In addition to robots that detect and respond to users' actions, an emerging field in robots for STE regards detection of user mood and/or preferences so that robots adapt their behavior in real time accordingly. For instance, a child with sensitivity to bright lights will be negative to therapies involving bright colored videos or images. Human therapists readily recognize and adapt to such circumstances. Robots need also to be flexible likewise during therapies. Significant work is still required before effective / efficient control architectures for autonomous robots are integrated into real-world therapy sessions.

A recent work has proposed a behaviour modulation system for social robots based on emotional speech recognition. In particular, human emotion cues were detected using linguistic features in order to direct the robot towards appropriate behaviours (Lytridis, Vrochidou, & Kaburlasos, 2018). Note that commercial social robots such as NAO have embedded cameras that can detect behaviors; however, the low processing power of commercially available social robots as well as their low-resolution embedded cameras constitute substantial obstacles to overcome for real-time object recognition.

EVALUATION STUDIES

Socially interactive robots can be useful in therapy as well as in special education for a number of reasons (Boucenna et al., 2014). For instance, it might be easier for children with STE needs to interact with robots rather than with humans because robots are less complex yet they are controllably sophisticated enough so as to provide sensory stimuli toward enabling embodied interactions that are appealing to children (Scassellati, Admoni, & Matarić, 2012). Note that Thill et al. (2012) suggest that robots need to be applied in a controlled manner such that only relevant information is presented to the users, furthermore robots are better than people in endless repetition.

Scassellati, Admoni, & Matarić (2012) report encouraging results when children interact with robots regarding engagement, level of attention and novel social behaviors including joint attention and imitation. Cabibihan et al. (2013) present a number of benefits and roles that robots could have; these roles range from friend to therapist. Another study identifies four roles for the interactive robots in clinical applications (Aresti-Bartolome, & Garcia-Zapirain, 2014). More specifically, robots are used to (1) investigate robot-like behavior of children with STE in comparison to human behavior, (2) elicit behaviors, (3) model, teach or practice a skill, and (4) provide feedback on performance. Although most studies report positive effects regarding the use of robots in STE, it is also demonstrated that not all children can benefit from robotic support or can perform better than with a human (Diehl et al., 2012). Mixed results and variability in the nature of affective response is also reported (Kahn et al., 2008).

Regarding teacher acceptance of robots in STE, a recent study (Fridin, & Belokopytov, 2014) indicates that teachers in pre-schools and elementary schools accept the use of a humanoid robot as an interactive tool in the teaching process. Other studies (Costescu, & David, 2014; Oros et al., 2014) report a positive attitude towards the use of robots in (psycho) therapy and education, considering them as useful and potentially effective tools in STE. Recent survey results seem to encourage the joint engagement of robots and information technologies (Kostova et al., 2018). Despite the promising results, the actual current state of the application of robots in STE is still in early stages. More research is required to comprehend the clinical effects as well as the added value of robots in therapy and education. Note that a review by Diehl et al. (2012) has concluded that many studies are explorative; they also have methodological limitations and do not focus on the clinical application of technology. The exploration of robot-based autism interventions is more directed to clinical or to therapy applications, and less to educational applications where children might also benefit from the use of robots for education delivery (Shamsuddin et al., 2015).

POTENTIAL FUTURE RESEARCH

Future advances regarding SARs in education applications call for improvements in both hardware and software as explained next. Currently, there are many open-source projects that can help beginners to get started. A number of open-source hardware platforms (Sparki, Hexy, OpenPilot, Arduipilot, TurtleBot etc.) and open-source software projects (LeJOS, Rock, ROS etc.) already exist and can support robotic research, education and product development (Pachidis et al., 2018).

On one hand, effective hardware design calls for the following specifications: (1) low cost in order to support the pedagogical model of one robot per student, (2) versatility so as to support a variety of curricula, i.e. engage an array of sensors for a broader range of applications, and (3) usability so as the robot has a simple, easy-to-explain design. Design is often the last consideration when incorporating robots in an application; yet studies indicate that the design can make the difference regarding robot acceptance and encourage children participation. Due to the shortage of commercially available robot platforms for education, many research groups design their own robots. Note that most of the reported bibliography applications use either Lego in typical education applications or NAO in special education applications. On the other hand, effective software design needs to support several development environments from block programming to script (Barakova et al., 2013). Furthermore, the software, that is the principal means for making a SAR more intelligent, should support innovative teaching and therapeutic methodologies transferable across geographical and cultural regions. The design of complex activities for a robot to perform cannot be easily supported by current robot intelligence (Serholt, 2018). There is a need to increase SAR intelligence. In the latter context, the aforementioned LC (information processing) paradigm emerges promising according to the following rationale.

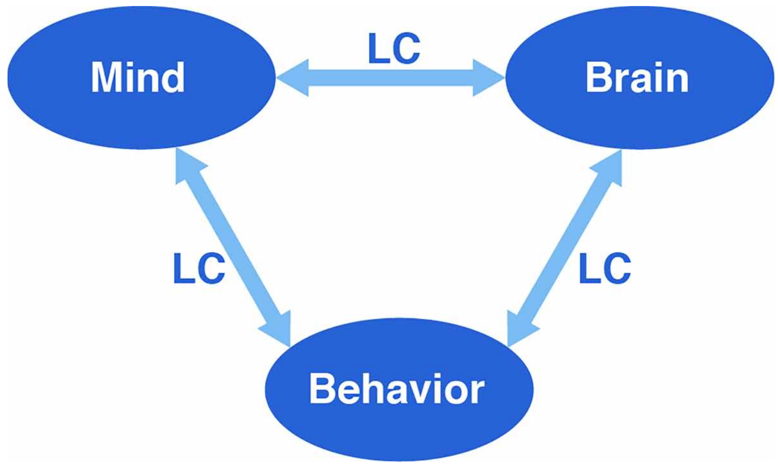
Conventional robot interaction applications with the physical environment are typically pursued based on a 3D digital representation of the physical environment induced from measurements. Likewise, we suggest SAR interaction with a human based on a (structured) lattice data representation of a human's "world model" of perceptions induced likewise from measurements. Note that a number of techniques for inducing lattice-ordered representations of perceptions/concepts has already been presented in the context of Formal Concept Analysis (Ganter, & Wille, 1999). Furthermore, recent work has considered the potential of representing psychological "gestalts" by lattice elements in social robot applications regarding autism treatment (Kaburlasos et al., 2018 January). What might be important is to further associate abstract notions of the human mind with specific brain activity patterns as well as with human behavior as shown in Figure 3. For simplicity here by "Mind" we mean a set of computer algorithms that process information, by "Brain" we mean a set of neurophysiology equations that describe brain activity, whereas by "Behavior" we mean a set of valid descriptions from human psychology – Note that Behavior could be as simple as eye blinking or gaze etc. In any case, lattice-order isomorphisms between Mind, Brain and Behavior are especially meaningful (Kaburlasos, 2004). Furthermore, LC models could be used inside the Mind /Brain /Behavior blocks according to the needs. It is understood that Figure 3 may raise ontological-, philosophical- as well as practical implementation questions which we ignore here. In particular, here we simply assume all the required mathematical functions. Apparently, any implementation of the scheme in Figure 3 calls for interdisciplinary collaboration.

Figure 3 might also be a guideline for developing algorithms toward sharing (subjective) value systems such as intensions (Okanoya, 2018). Recall that the LC paradigm lends itself for developing algorithms that compute with semantics instead of computing solely by number crunching. In addition, due to the inherent hierarchy of lattice-ordered data, a learning algorithm in the LC paradigm has the potential for inducing structures in its application environment be it language, or emotions, etc.

A convenient starting point can be electroencephalography (EEG) signals. For example, Figure 4 shows EEG signals from the UCI repository of machine learning databases (Dua, & Karra Taniskidou, 2017) – This particular data arose from a study that examines EEG correlates of genetic predisposition to alcoholism. It contains measurements from 64 electrodes placed on the scalp sampled at 256 Hz. In particular, Figure 4 shows example plots of a control (i.e., non-alcoholic) subjects; the plots indicate voltage, time, and channel and are averaged over 10 trials for the single stimulus condition.

It is understood that EEG signals record, quite restrictively, integrated neuron activity in selected points on the surface of the brain, therefore EEG signals might miss subtle brain activity patterns. Nevertheless, in carefully designed experiments, EEG signals could provide initial evidence that abstract notions may be associated with specific brain activity patterns. In the aforementioned context, lattice-ordered

Figure 3. Pair-wise interactions, tentatively designed analytically by Lattice Computing (LC) techniques, between Mind, Brain and Behavior might drive social robots



Intervals' Numbers (INs) (Kaburlasos, & Papakostas, 2015) might be useful for representing EEG big data patterns; furthermore, deep learning can be pursued based on several layers of IN processing.

Recall that our objective here is to change the brain toward improving its capacity according to the Working Hypothesis WH that is by educational methods alone without resorting to any surgery and/or medicament. Substantial preliminary work needs to be carried out toward providing clear evidence regarding any utility of Social Robots in (special) education as described next.

Large numbers of brain activity (response) patterns need to be matched painstakingly to the content of (evoking) "story telling" by a human narrator; the latter data are to be used as the Control Group in a number of statistical hypothesis testing experiments. Then, additional brain activity patterns should be recorded likewise by a programmable robot narrator; the latter data are to be used as the Treatment Group in the aforementioned statistical experiments toward identifying specific advantages of social robots in (special) education. For example, Figure 5 proposes tentatively a closed-loop control scheme as an implementation of educational scenarios. Recall that a Social Robot is to be employed as a sophisticated stimulus of the Mind toward changing the Brain and, ultimately, toward changing the Behavior of a human student by educational methods alone. Note that all previous explanations hold even after dropping the "Brain" block either in Figure 3 or in Figure 5. Nevertheless, the engagement of brain signals is expected to increase the robustness of information processing.

CONCLUSION

This paper has described the potential of Social Assistive Robots (SARs) applications in pedagogical rehabilitation. SARs were presented as a subset of the more general and rapidly emerging technology of social robots. Moreover, pedagogical rehabilitation was presented as a specific domain in the more general framework of special education. Trends have been outlined.

Figure 4. EEG signals in 64 channels averaged over 10 trials
(Dua, & Karra Taniskidou, 2017)

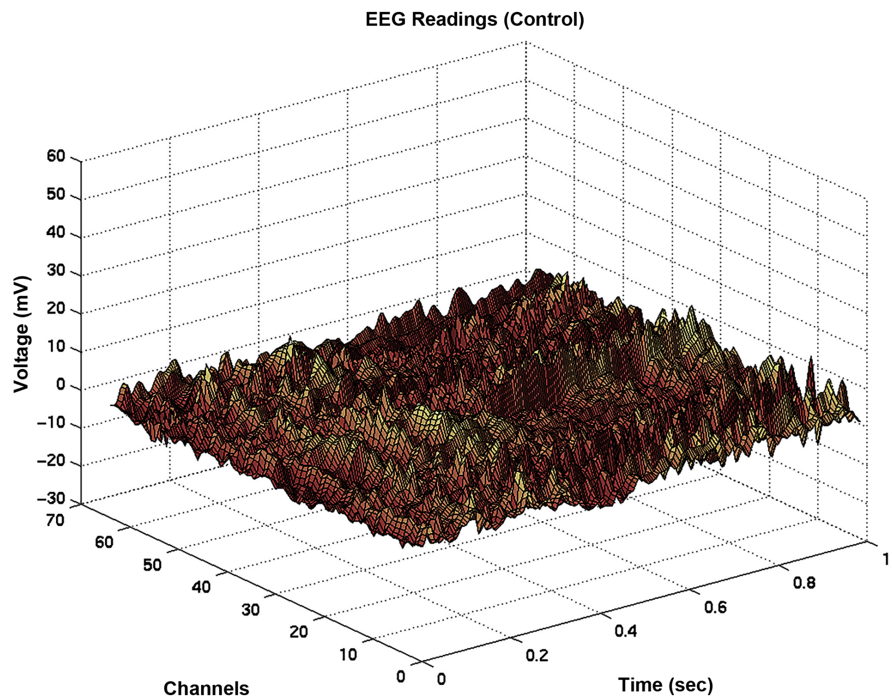
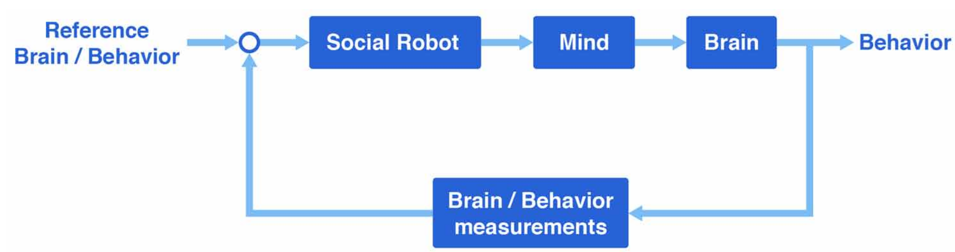


Figure 5. A tentative implementation of educational scenarios



Central in this paper has been the Working Hypothesis WH, which can be summarized as follows: SARs can be used as sophisticated stimuli to multiple levels of cognitive processing in children with learning difficulties toward modifying the cognitive processing, by triggering underlying brain's compensatory mechanisms, and improve a child's learning behavior based on education delivery methods alone.

Apart from improved hardware, the effectiveness of future SARs in pedagogical rehabilitation also depends on improved (intelligent) software. In turn, since the software typically implements mathematical models, effective mathematical modeling techniques are required. In this paper we proposed using models from the Lattice Computing (LC) information processing paradigm toward also computing with semantics represented by partial (lattice) order relation. Future work calls for systematic experimental testing toward demonstrating the validity of specific hypotheses.

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REFERENCES

Amanatiadis, A., Kaburlasos, V. G., Dardani, C., & Chatzichristofis, S. A. (2017, September). Interactive social robots in special education. In *2017 IEEE 7th International Conference on Consumer Electronics-Berlin (ICCE-Berlin)* (pp. 126-129). IEEE. 10.1109/ICCE-Berlin.2017.8210609

Aresti-Bartolome, N., & Garcia-Zapirain, B. (2014). Technologies as support tools for persons with autistic spectrum disorder: A systematic review. *International Journal of Environmental Research and Public Health*, *11*(8), 7767–7802. doi:10.3390/ijerph110807767 PMID:25093654

Barakova, E. I., De Haas, M., Kuijpers, W., Irigoyen, N., & Betancourt, A. (2018). Socially grounded game strategy enhances bonding and perceived smartness of a humanoid robot. *Connection Science*, *30*(1), 81–98. doi:10.1080/09540091.2017.1350938

Barakova, E. I., Gillesena, J. C. C., Huskens, B. E. B. M., & Lourens, T. (2013). End-user programming architecture facilitates the uptake of robots in social therapies. *Robotics and Autonomous Systems*, *61*(7), 704–713. doi:10.1016/j.robot.2012.08.001

Boucenna, S., Narzisi, A., Tilmont, E., Muratori, F., Pioggia, G., Cohen, D., & Chetouani, M. (2014). Interactive technologies for autistic children: A review. *Cognitive Computation*, *6*(4), 722–740. doi:10.100712559-014-9276-x

Cabibihan, J. J., Javed, H., Ang, M., & Aljunied, S. M. (2013). Why robots? A survey on the roles and benefits of social robots in the therapy of children with autism. *International Journal of Social Robotics*, *5*(4), 593–618. doi:10.100712369-013-0202-2

Cortiella, C., & Horowitz, S. H. (2014). *The state of learning disabilities: Facts, trends and emerging issues*. New York: National Center for Learning Disabilities.

Costescu, C. A., & David, D. O. (2014). Attitudes toward Using Social Robots in Psychotherapy. *Transylvanian Journal of Psychology, 15*(1).

CybSPEED. (2017). *Cyber-Physical Systems for PEdagogical Rehabilitation in Special EDucation.* Horizon 2020 MSCA-RISE Project no. 777720, 1 Dec 2017 – 30 Nov 2021.

Dachkinov, P., Lekova, A., Tanev, T., Batbaatar, D., & Wagatsuma, H. (2019). Design and Motion Capabilities of an Emotion-Expressive Robot, "EmoSan". *Proceedings of the Joint 10th International Conference on Soft Computing and Intelligent Systems (SCIS) and 19th International Symposium on Advanced Intelligent Systems (ISIS) in conjunction with Intelligent Systems Workshop (ISWS).*

Dautenhahn, K., Nehaniv, C. L., Walters, M. L., Robins, B., Kose-Bagci, H., Mirza, N. A., & Blow, M. (2009). KASPAR–a minimally expressive humanoid robot for human–robot interaction research. *Applied Bionics and Biomechanics*, *6*(3-4), 369–397. doi:10.1155/2009/708594

de Haas, M., Aroyo, A. M., Barakova, E., Haselager, W., & Smeekens, I. (2016). The effect of a semi-autonomous robot on children. In *Intelligent Systems (IS), 2016 IEEE 8th International Conference on* (pp. 376-381). IEEE. 10.1109/IS.2016.7737448

Diehl, J. J., Schmitt, L. M., Villano, M., & Crowell, C. R. (2012). The clinical use of robots for individuals with autism spectrum disorders: A critical review. *Research in Autism Spectrum Disorders*, *6*(1), 249–262. doi:10.1016/j.rasd.2011.05.006 PMID:22125579

Dimitrova, M., & Wagatsuma, H. (2015). Designing Humanoid Robots with Novel Roles and Social Abilities. *Lovotics*, *3*(112), 2.

dos Santos, A. S., & Valle, M. E. (2018). Max-plus and min-plus projection autoassociative morphological memories and their compositions for pattern classification. *Neural Networks*, *100*, 84–94. doi:10.1016/j.neunet.2018.01.013 PMID:29477916

Dua, D., & Karra Taniskidou, E. (2017). *UCI Machine Learning Repository*. Irvine, CA: University of California, School of Information and Computer Science.

Duquette, A., Michaud, F., & Mercier, H. (2008). Exploring the use of a mobile robot as an imitation agent with children with low-functioning autism. *Autonomous Robots*, *24*(2), 147–157. doi:10.100710514-007-9056-5

Eurobarometer, S. (2012). *382 'Public Attitudes Towards Robots'*. Academic Press.

Feil-Seifer, D., & Mataric, M. J. (2008). B 3 IA: A control architecture for autonomous robot-assisted behavior intervention for children with Autism Spectrum Disorders. In *Robot and Human Interactive Communication, 2008. RO-MAN 2008. The 17th IEEE International Symposium on* (pp. 328-333). Academic Press.

Feil-Seifer, D., & Matarić, M. J. (2009). Toward socially assistive robotics for augmenting interventions for children with autism spectrum disorders. In *Experimental robotics* (pp. 201–210). Berlin: Springer. doi:10.1007/978-3-642-00196-3_24

Feil-Seifer, D., & Matarić, M. J. (2011). Automated detection and classification of positive vs. negative robot interactions with children with autism using distance-based features. In *Human-Robot Interaction (HRI), 2011 6th ACM/IEEE International Conference on* (pp. 323-330). ACM. 10.1145/1957656.1957785

Ferrari, E., Robins, B., & Dautenhahn, K. (2009). Therapeutic and educational objectives in robot assisted play for children with autism. In *Robot and Human Interactive Communication, 2009. RO-MAN 2009. The 18th IEEE International Symposium on* (pp. 108-114). IEEE. 10.1109/ROMAN.2009.5326251

Fong, T., Nourbakhsh, I., & Dautenhahn, K. (2003). A survey of socially interactive robots. *Robotics and Autonomous Systems*, *42*(3), 143–166. doi:10.1016/S0921-8890(02)00372-X

Fridin, M., & Belokopytov, M. (2014). Acceptance of socially assistive humanoid robot by preschool and elementary school teachers. *Computers in Human Behavior*, *33*, 23–31. doi:10.1016/j.chb.2013.12.016

Ganter, B., & Wille, R. (1999). *Formal Concept Analysis*. Heidelberg, Germany: Springer. doi:10.1007/978-3-642-59830-2

Goan, M., Fujii, H., & Okada, M. (2006). Child–robot interaction mediated by building blocks: From field observations in a public space. *Artificial Life and Robotics*, *10*(1), 45–48. doi:10.100710015-005-0375-3

Johnson, C. P., & Myers, S. M. (2007). Identification and evaluation of children with autism spectrum disorders. *Pediatrics*, *120*(5), 1183–1215. doi:10.1542/peds.2007-2361 PMID:17967920

Jordan, R. (2013). *Autistic spectrum disorders: an introductory handbook for practitioners*. Routledge. doi:10.4324/9780203827352

Kaburlasos, V., Bazinas, C., Siavalas, G., & Papakostas, G. A. (2018, June). Linguistic social robot control by crowd-computing feedback. In *Proceedings of the 2018 JSME Conference on Robotics and Mechatronics*. Academic Press. 10.1299/jsmermd.2018.1A1-B13

Kaburlasos, V. G. (2004). A device for linking brain to mind based on lattice theory. In *Proceedings of the 8th International Conference on Cognitive and Neural Systems (ICCNS 2004)*. Boston University.

Kaburlasos, V. G. (2011). Special issue on: Information engineering applications based on lattices. *Information Sciences*, *181*(10), 1771–1773. doi:10.1016/j.ins.2011.01.016

Kaburlasos, V. G., Dardani, C., Dimitrova, M., & Amanatiadis, A. (2018, January). Multi-robot engagement in special education: a preliminary study in autism. In *2018 IEEE International Conference on Consumer Electronics (ICCE)* (pp. 1-2). IEEE. 10.1109/ICCE.2018.8326267

Kaburlasos, V. G., & Papakostas, G. A. (2015). Learning distributions of image features by interactive fuzzy lattice reasoning in pattern recognition applications. *IEEE Computational Intelligence Magazine*, *10*(3), 42–51. doi:10.1109/MCI.2015.2437318

Kahn, P. H., Freier, N. G., Kanda, T., Ishiguro, H., Ruckert, J. H., Severson, R. L., & Kane, S. K. (2008). Design patterns for sociality in human-robot interaction. In *Proceedings of the 3rd ACM/IEEE international conference on Human robot interaction* (pp. 97-104). ACM. 10.1145/1349822.1349836

Kanda, T., Hirano, T., Eaton, D., & Ishiguro, H. (2004). Interactive robots as social partners and peer tutors for children: A field trial. *Human-Computer Interaction*, *19*(1), 61–84. doi:10.120715327051hci1901&2_4

Kanda, T., Miyashita, T., Osada, T., Haikawa, Y., & Ishiguro, H. (2008). Analysis of humanoid appearances in human–robot interaction. *IEEE Transactions on Robotics*, *24*(3), 725–735. doi:10.1109/TRO.2008.921566

Kim, E., Paul, R., Shic, F., & Scassellati, B. (2012). *Bridging the research gap: Making HRI useful to individuals with autism*. Academic Press.

Kirk, S., Gallagher, J. J., Coleman, M. R., & Anastasiow, N. J. (2011). *Educating exceptional children*. Cengage Learning.

Kostova, S., Dimitrova, M. I., Saeva, S., Zamfirov, M., Kaburlasos, V., Vrochidou, E., ... Papić, V. (2018). Identifying needs of robotic and technological solutions for the classroom. *Proceedings of the 26th International Conference on Software, Telecommunications and Computer Networks (SoftCOM 2018), Symposium on: Robotic and ICT assisted wellbeing*. 10.23919/SOFTCOM.2018.8555751

Kozima, H., Nakagawa, C., & Yasuda, Y. (2005). Interactive robots for communication-care: A case-study in autism therapy. In *Robot and human interactive communication, 2005. ROMAN 2005. IEEE International Workshop on* (pp. 341-346). IEEE. 10.1109/ROMAN.2005.1513802

Kozima, H., Nakagawa, C., & Yasuda, Y. (2007). Children–robot interaction: A pilot study in autism therapy. *Progress in Brain Research*, *164*, 385–400. doi:10.1016/S0079-6123(07)64021-7 PMID:17920443

Liu, C., Conn, K., Sarkar, N., & Stone, W. (2008). Online affect detection and robot behavior adaptation for intervention of children with autism. *IEEE Transactions on Robotics*, *24*(4), 883–896. doi:10.1109/TRO.2008.2001362

Lord, C., & Bishop, S. L. (2010). Autism Spectrum Disorders: Diagnosis, Prevalence, and Services for Children and Families. *Social Policy Report*, *24*(2). doi:10.1002/j.2379-3988.2010.tb00063.x

Lytridis, C., Vrochidou, E., Chatzistamatis, S., & Kaburlasos, V. G. (2018). Social engagement interaction games between children with autism and humanoid robot NAO. In *Proceedings of the 9th International Conference on EUropean Transnational Educational*. Springer.

Lytridis, C., Vrochidou, E., & Kaburlasos, V. G. (2018). Emotional Speech Recognition toward Modulating the Behavior of a Social Robot. *Proceedings of the 2018 JSME Conference on Robotics and Mechatronics*. 10.1299/jsmermd.2018.1A1-B14

Martyn Cooper, D. K., & William Harwin, K. D. (1999). Robots in the classroom-tools for accessible education. *Assistive Technology on the Threshold of the New Millennium, 6*, 448.

Meijer, C. J., Soriano, V., & Watkins, A. (Eds.). (2003). *Special needs education in Europe: Thematic publication*. European Agency for Development in Special Needs Education.

Michaud, F., & Caron, S. (2002). Roball, the rolling robot. *Autonomous Robots*, *12*(2), 211–222. doi:10.1023/A:1014005728519

Michaud, F., Laplante, J. F., Larouche, H., Duquette, A., Caron, S., Létourneau, D., & Masson, P. (2005). Autonomous spherical mobile robot for child-development studies. *IEEE Transactions on Systems, Man, and Cybernetics. Part A, Systems and Humans*, *35*(4), 471–480. doi:10.1109/TSMCA.2005.850596

Michaud, F., Salter, T., Duquette, A., Mercier, H., Lauria, M., Larouche, H., & Larose, F. (2007). Assistive technologies and child-robot interaction. AAAI spring symposium on multidisciplinary collaboration for socially assistive robotics.

Miller, G., Church, R., & Trexler, M. (2000). *Teaching diverse learners using robotics*. Morgan Kaufmann.

Moon, A., Danielson, P., & Van der Loos, H. M. (2012). Survey-based discussions on morally contentious applications of interactive robotics. *International Journal of Social Robotics*, *4*(1), 77–96. doi:10.100712369-011-0120-0

Mori, M. (1970/2012). The uncanny valley (K. F. MacDorman & N. Kageki, Trans.). *IEEE Robotics & Automation Magazine*, *19*(2), 98–100. doi:10.1109/MRA.2012.2192811

Norwich, B. (2007). *Dilemmas of difference, inclusion and disability: International perspectives and future directions*. Routledge. doi:10.4324/9780203938867

Oros, M., Nikolić, M., Borovac, B., & Jerković, I. (2014). Children's preference of appearance and parents' attitudes towards assistive robots. In *Humanoid Robots (Humanoids), 2014 14th IEEE-RAS International Conference on* (pp. 360-365). IEEE.

Pachidis, T., Vrochidou, E., Kaburlasos, V. G., Kostova, S., Bonković, M., & Papić, V. (2018). Social Robotics in Education: State-of-the-Art and Directions. *Proceedings of the 27th International Conference on Robotics in Alpe-Adria-Danube Region*.

Papakostas, G., Sidiropoulos, G., Bella, M., & Kaburlasos, V. (2018). Social robots in special education: current status and future challenges. *Proceedings of the 2018 JSME Conference on Robotics and Mechatronics*. 10.1299/jsmermd.2018.1P1-A15

Papakostas, G. A., & Kaburlasos, V. G. (2018). Modeling in cyber-physical systems by lattice computing techniques: the case of image watermarking based on intervals' numbers. *Proceedings of the World Congress on Computational Intelligence (WCCI) 2018, FUZZ-IEEE Program,* 491-496. 10.1109/FUZZ-IEEE.2018.8491653

Pastor, P. N., & Reuben, C. A. (2008). Diagnosed Attention Deficit Hyperactivity Disorder and Learning Disability: United States, 2004-2006. Data from the National Health Interview Survey. Vital and Health Statistics. Series 10, Number 237. Centers for Disease Control and Prevention.

Pioggia, G., Ferro, M., Sica, M. L., Dalle Mura, G., Casalini, S., De Rossi, D., & Muratori, F. (2006). Imitation and learning of the emotional behaviour: towards an android-based treatment for people with autism. In *Proc. Sixth Int. Workshop Epigenet. Robot.* (pp. 119-25). Lund, Sweden: LUCS.

Robins, B., Dautenhahn, K., & Dickerson, P. (2009). From isolation to communication: a case study evaluation of robot assisted play for children with autism with a minimally expressive humanoid robot. In *Advances in Computer-Human Interactions, 2009. ACHI'09. Second International Conferences on* (pp. 205-211). Academic Press. 10.1109/ACHI.2009.32

Robins, B., Dautenhahn, K., Te Boekhorst, R., & Billard, A. (2004). Effects of repeated exposure to a humanoid robot on children with autism. *Designing a more inclusive world*, 225-236.

Robins, B., Dautenhahn, K., Te Boekhorst, R., & Billard, A. (2005). Robotic assistants in therapy and education of children with autism: Can a small humanoid robot help encourage social interaction skills? *Universal Access in the Information Society*, *4*(2), 105–120. doi:10.100710209-005-0116-3

Scassellati, B. (2005). Quantitative metrics of social response for autism diagnosis. In *Robot and Human Interactive Communication, 2005. ROMAN 2005. IEEE International Workshop on* (pp. 585-590). IEEE. 10.1109/ROMAN.2005.1513843

Scassellati, B., Admoni, H., & Matarić, M. (2012). Robots for use in autism research. *Annual Review of Biomedical Engineering*, *14*(1), 275–294. doi:10.1146/annurev-bioeng-071811-150036 PMID:22577778

Serholt, S. (2018). Breakdowns in children's interactions with a robotic tutor: A longitudinal study. *Computers in Human Behavior*, *81*, 250–264. doi:10.1016/j.chb.2017.12.030

Serpanos, D. (2018). The Cyber-Physical Systems Revolution. *Computer*, *51*(3), 70–73. doi:10.1109/MC.2018.1731058

Shamsuddin, S., Yussof, H., Hanapiah, F. A., Mohamed, S., Jamil, N. F. F., & Yunus, F. W. (2015). Robot-assisted learning for communication-care in autism intervention. In *Rehabilitation Robotics (ICORR), 2015 IEEE International Conference on* (pp. 822-827). IEEE. 10.1109/ICORR.2015.7281304

Smith, P. (2007). Have we made any progress? Including students with intellectual disabilities in regular education classrooms. *Intellectual and Developmental Disabilities*, *45*(5), 297–309. doi:10.1352/0047-6765(2007)45[297:HWMAPI]2.0.CO;2 PMID:17887907

Special Needs Education. (2012). European Agency for Development for Special Needs and Inclusive Education. Country Data.

Stanton, C. M., Kahn, P. H., Severson, R. L., Ruckert, J. H., & Gill, B. T. (2008). Robotic animals might aid in the social development of children with autism. In *Human-Robot Interaction (HRI), 2008 3rd ACM/IEEE International Conference on* (pp. 271-278). ACM. 10.1145/1349822.1349858

Sussner, P., & Schuster, T. (2018). Interval-valued fuzzy morphological associative memories: Some theoretical aspects and applications. *Information Sciences*, *438*, 127–144. doi:10.1016/j.ins.2018.01.042

Tanaka, F., Cicourel, A., & Movellan, J. R. (2007). Socialization between toddlers and robots at an early childhood education center. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(46), 17954–17958. doi:10.1073/pnas.0707769104 PMID:17984068

Thill, S., Pop, C. A., Belpaeme, T., Ziemke, T., & Vanderborght, B. (2012). Robot-assisted therapy for autism spectrum disorders with (partially) autonomous control: Challenges and outlook. *Paladyn: Journal of Behavioral Robotics*, *3*(4), 209–217. doi:10.247813230-013-0107-7

Ueyama, Y. (2015). A bayesian model of the uncanny valley effect for explaining the effects of therapeutic robots in autism spectrum disorder. *PLoS One*, *10*(9), e0138642. doi:10.1371/journal.pone.0138642 PMID:26389805

UNESCO. (1994). *World Conference on Special Needs Education: Access and Quality*. The Salamanca Statement. Retrieved from http://www.unesco.org/new/en/social-and-human-sciences/themes/

Valle, M. E., & Sussner, P. (2013). Quantale-based autoassociative memories with an application to the storage of color images. *Pattern Recognition Letters*, *34*(14), 1589–1601. doi:10.1016/j.patrec.2013.03.034

van Straten, C. L., Smeekens, I., Barakova, E., Glennon, J., Buitelaar, J., & Chen, A. (2017). Effects of robots' intonation and bodily appearance on robot-mediated communicative treatment outcomes for children with autism spectrum disorder. *Personal and Ubiquitous Computing*, 1–12.

Vrochidou, E., Najoua, A., Lytridis, C., Salonidis, M., Ferelis, V., & Papakostas, G. A. (2018). Social Robot NAO as a self-regulating didactic mediator: a case study of teaching/learning numeracy. *Proceedings of the 26th International Conference on Software, Telecommunications and Computer Networks (SoftCOM 2018), Symposium on: Robotic and ICT assisted wellbeing*. 10.23919/SOFTCOM.2018.8555764

Werry, I., Dautenhahn, K., Ogden, B., & Harwin, W. (2001). Can social interaction skills be taught by a social agent? The role of a robotic mediator in autism therapy. *Cognitive technology: instruments of mind*, 57-74.

Williams, J. H., Whiten, A., & Singh, T. (2004). A systematic review of action imitation in autistic spectrum disorder. *Journal of Autism and Developmental Disorders*, *34*(3), 285–299. doi:10.1023/B:JADD.0000029551.56735.3a PMID:15264497

ADDITIONAL READING

Amanatiadis, A., Gasteratos, A., Papadakis, S., & Kaburlasos, V. (2010). Image stabilization in active robot vision. In *Robot Vision*. InTech. doi:10.5772/9298

Barakova, E. I., Bajracharya, P., Willemsen, M., Lourens, T., & Huskens, B. (2015). Long-term LEGO therapy with humanoid robot for children with ASD. *Expert Systems: International Journal of Knowledge Engineering and Neural Networks*, *32*(6), 698–709. doi:10.1111/exsy.12098

Dimitrova, M., Lekova, A., Chavdarov, I., Kostova, S., Krastev, A., Roumenin, C., . . . Pachidis, T. A. (2016). Multidisciplinary Framework for Blending Robotics in Education of Children with Special Learning Needs. In *Proceedings of the International Association for Blended Learning Conference* (*IABL* 2016), Kavala, Greece, 22-24 April 2016, pp. 152-155.

Dimitrova, M., Vegt, N., & Barakova, E. (2012). Designing a system of interactive robots for training collaborative skills to autistic children. In *Interactive Collaborative Learning (ICL), 2012 15th International Conference on* (pp. 1-8). 10.1109/ICL.2012.6402179

Gillesen, J. C., Barakova, E. I., Huskens, B. E., & Feijs, L. M. (2011). From training to robot behavior: Towards custom scenarios for robotics in training programs for ASD. In *Rehabilitation Robotics (ICORR), 2011 IEEE International Conference on* (pp. 1-7).

Huskens, B., Verschuur, R., Gillesen, J., Didden, R., & Barakova, E. (2013). Promoting question-asking in school-aged children with autism spectrum disorders: Effectiveness of a robot intervention compared to a human-trainer intervention. *Developmental Neurorehabilitation*, *16*(5), 345–356. doi:10.3109/17518423.2012.739212 PMID:23586852

Mwangi, E. N., Barakova, E. I., Díaz, M., Mallofré, A. C., & Rauterberg, M. (2017). Who is a better tutor?: gaze hints with a human or humanoid tutor in game play. In *Proceedings of the Companion of the 2017 ACM/IEEE International Conference on Human-Robot Interaction* (pp. 219-220). ACM.

KEY TERMS AND DEFINITIONS

Autism: An early childhood mental condition, characterized by difficulty in communication, in forming relations with others and in using language and abstract concepts.

Educational Robotics: Robots provided to facilitate student's development of knowledge, skills, and attitudes.

Human-Robot Interaction: Is the study of interaction between humans as a multidisciplinary field with contributions from human-computer interaction, artificial intelligence, design and social sciences.

Robot Autonomy: The ability of a robot to possess the necessary computational resources when functioning, in terms of hardware and software, so as to be physically embedded in the environment.

SEN: Special education needs refer to people who have learning difficulties or disabilities that makes it harder for them to learn than most people of the same age, which calls for special educational provision.

Social Robots: Is a robot that interacts and communicates with humans by following social behaviors and rules attached to its role.

STE: Special treatment and education is defined as the treatment and education of students with special educational needs in a way that addresses their individual differences.