Over the past 20 years, robots have been introduced as “social agents” for adults and children in a variety of contexts, including adult group homes, day care centers, clinical centers, and some classrooms. This research has shown the potential of robots to be used as companions, mentors, and educators as the students engage and are motivated by the robots (Diehl, Schmitt, Villano, & Crowell, 2012; Robins, Dautenhahn, Te Boekhorst, & Billard, 2005; Robins, Dickerson, Stribling, & Dautenhahn, 2009; Scassellati, 2005, 2007; Stanton, Kahn, Severson, Ruckert, & Gill, 2008). In this chapter we discuss several types of findings from research settings where robots have been shown to have unique findings with typically developing children and children with autism spectrum disorder (ASD). A unique new set of tools are being developed for students with autism, of which sensors, and robots show the greatest promise (Goodwin, 2008) Our purpose in writing this chapter is to allow teachers to imagine contexts in which robots might supplement, improve, and enhance their teaching with students with special needs. In particular, we focus on the potential for robots to allow greater independence and differentiation for students with ASD in classrooms that employ the Universal Design for Learning (UDL) approach, a set of principles for developing curriculum that gives all individuals the opportunity to learn (see CAST, http:www.cast.org/udl).

There are several reasons why robots might be of special benefit to teachers working with students who have autism. Robots may assist students with ASD in four specific areas:

1. Cueing and joint attention
2. Social skills learning
3. Language and communication
4. Motor skills learning

In addition to assisting the student with these key areas, Robots can also be beneficial to the teacher and can be used as an embodied social agent, assisting with communicating ideas, cueing and providing a model for the student on an ongoing basis. Teachers are often bogged down by the need to collect data while teaching; robots may be of assistance by providing ongoing assessment by evaluating how students are behaving automatically in realistic environments and in real time.

Before venturing into the world of robots, we must first clearly define what we mean by a robot. When defining robots, we can imagine several different kinds of robotic devices: robots for manufacturing, robotic vacuum cleaners, and interactive toys. As referred to in this chapter, robots can loosely be defined as objects that can be remotely controlled or programmed to be fully or semi-autonomous and self-controlled through sensors and actuators. Under this definition, any object that is programmable—for example, a small consumer off-the-shelf microcontroller such as an Arduino1 with attached sensing capabilities (i.e., light, audio, motors)—can be seen as a robot.

Here, we introduce some of the robots that we explore in this chapter. Keepon Pro (Figure 5.1), developed by BeatBots, is a social therapeutic robot that has been used in various studies with children with ASD to facilitate social development and assist with imitation, eye gaze, and joint attention. My Keepon is an entertaining dancing robot that is based on Keepon Pro and includes a built-in microphone and touch sensors.

CosmoBot (Figure 5.2), developed by AnthroTronix, Inc., is a robot for use with children with and without disabilities to promote educational and therapeutic activities. CosmoBot has been tested with children with a range of abilities, including children with autism, down syndrome, cerebral palsy, muscular dystrophy, apraxia, neurodevelopmental disorders, and language development disorders, as well as children with neurotypical disorders.

Nao, developed by Aldebaran Robotics, is an autonomous, humanoid robot that can be used in a variety of contexts that range from education to entertainment.

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1Open-source prototyping platform (http://www.arduino.cc).
Using Therapeutic Robots

Nao has been used by researchers to investigate its use with older adults and in teaching students about science, technology, engineering, and math (STEM) through programming. Nao has also been used in the classroom with children with ASD.

Kismet is a robot developed at MIT in the 1990s. Kismet simulates emotion through various facial expressions, vocalizations, and movement. Facial expressions are created through movements of the ears, eyebrows, eyelids, lips, jaw, and head.

KASPAR (Kinesics and Synchronization in Personal Assistant Robotics; Figure 5.3) is a minimally-expressive, therapeutic robot developed by Dr. Kerstin Dautenhahn, Professor of Artificial Intelligence, and the Adaptive Systems Group at the University of Hertfordshire's School of Computer Science. KASPAR has been used in research to improve the social interaction and communication skills of autistic children (Dautenhahn & Werry, 2005; Robins et. al. 2005; Robins et al. 2009).

Bandit (Figure 5.4) was designed by researchers at the University of Southern California. The child-sized metallic robot has humanlike features: a movable mouth, archable eyebrows, and camera eyes (Feil Seifer & Mataric, 2005, 2009).

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Figure 5.2. Photograph of CosmoBot. CosmoBot is an 18-inch tall humanoid robot with a blue head and torso. He is made from a plastic material and can rotate his head and hands to convey a variety of emotions.

Figure 5.3. Photograph of Kaspar. Kaspar is a child-sized humanoid robot that is fully clothed and has hair. Kaspar has the ability to change facial features, move its arms, and blink its eyes.

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Tito and Roball (Figures 5.5 and 5.6) are both mobile robots that were developed by researchers at the Université de Sherbrooke in Quebec, Canada. Tito was designed to study how a mobile robot could facilitate reciprocal interactions, such as imitation with autistic children. Roball, although not a humanlike robot, is an autonomous robotic ball that has been used in studies to evaluate the influence of autonomous motion on children between 12 and 18 months of age. (Michaud & Caron, 2002; Michaud & Theberge-Turnel, 2002; Micaud et al., 2005)

Figure 5.4. Photograph of Bandit. Bandit has a rotating head, torso, and arms resembling a small child. Bandit has a grey plastic frame, red wire lips, chrome eyes with pupils, and dark grey eyebrows, all of which can move to convey emotion.

Figure 5.5. Photograph of Tito. Tito is a robot with moving arms, torso, and an oval-shaped head. He is a yellow with a plush stuffed body with a red shirt and blue legs and feet.
Using Therapeutic Robots

Muu (Figure 5.7) was developed by Michio Okada, of Advanced Telecommunication Research (ATR), an international institute. The robot Muu focuses on social bonding with humans. The character also works as an embodied interface that mediates the social bonding that people establish in everyday conversations. Christoph Bartneck extended Muu with the ability to express emotions and named it emotional Muu, or eMuu. (Miyamota, Lee, Fujii, & Okada, 2005)

Pleo is an animatronic toy dinosaur that moves autonomously and responds to its environment and users touch; for example it can be fed and petted. Pleo has been used in a variety of studies ranging from speech prosody to studying individuals’ social attachment to artificial pets. (Kim, Leysberg, Short, Paul, & Scassellati, 2009; Scassellati, 2005)

Note that the only commercially available robots from the foregoing list are My Keepon, Nao, and Pleo; however, it is our goal in this chapter to inspire teachers to work with engineers (and maybe some high-functioning students) to create and program their own robots using relatively accessible and inexpensive technology. We include a section at the end of this chapter with programming and technology resources available for this purpose. We are confident that as you are reading this

Figure 5.6. Photograph of Roball. Roball is a robotic ball roughly 8 inches in diameter. It is plastic with red, yellow, and blue stripes.

Figure 5.7. Photograph of Muu. Muu is a cone-shaped robot with one large center glass eye. Its body is pastel colored, and the eyes have large dilated pupils.
chapter, some enterprising student has already designed the right robot for use in your classroom.

UNIVERSAL DESIGN FOR LEARNING

The UDL approach attempts to remove barriers to learning through applying three principles dealing with forms of representation, expression, and engagement. (Refer to Chapter 2 for more details from the developers of UDL, CAST.) Robots can fulfill each of these areas through their multimedia and sensory functions that can be specifically tailored for each child with ASD and allow independence. Interactive robots produce a response in children with ASD that may surpass what can be achieved through human therapists alone (Kim et al., 2009; Scassellati, Admoni, & Mataric, 2012). Through appropriate development of targeted treatment, the robot creates a means of engagement and learning that has been previously unavailable to educators within a classroom with this population of children. When we envision robots in the classroom, we often think of such robotics programs as LEGO or VEX, which teach students how to program and engineer moving objects using basic parts. In the classroom with students with ASD, we will want to consider “social” robots, that is, objects human-and animal-like devices that interact with the user in physical and nonphysical ways to cause an effect or to cue the student regarding his or her behavior.

Only a handful of robots have been tested, mostly in laboratory learning settings to determine the basic affinity that children with ASD might have for them relative to interacting with only a human therapist or parent. In the next section we will highlight existing research studies with robots that have shown results in the four primary domains noted earlier: cueing and joint attention, social skills learning, language and communication, and motor skills learning. The research includes findings related to children with neurotypical disorders and ASDs.

Cueing and Joint Attention

In this section we provide some documentation of studies that support the idea of robots eliciting greater participation in the learning process.

Robots Can Naturally Motivate Students with Autism to Learn  

In order to learn effectively, students need to be able to pay attention in class and stay on task. Those individuals who work with students with ASD begin with typical attention-eliciting tasks focusing on getting the student to follow eye gaze by finger pointing and turning the student’s head and therefore his or her attention to the learning task. Teachers often need to build in rewards for attending and staying on task. Robots can be harnessed to increase these important social interactions because the student with ASD is more likely to watch and be interested in a robot (Dautenhahn & Werry, 2004; Diehl et al., 2012; Scassellati et al., 2012; Werry & Dautenhahn, 1999; Werry, Dautenhahn, Ogden, & Harwin, 2001). The robot itself can become the reward for the behavior a teacher wants to elicit in the student (Costa, Santos, Soares, Ferreira, & Moreira, 2010; Costa et al., 2009). A difficulty for persons with ASD is hyperarousal of the parasympathetic nervous system (e.g., as evidenced by galvanic skin response, heart rate, or breath rate) (Goodwin et al., 2006).
Research on the impairments in ASD to the parasympathetic autonomic system may shed some light on why interactions with humans can be so difficult for this population, leading to avoidance or even self-stimulatory or self-injurious behaviors (Goodwin et al., 2006; Hirstein, Iverson, & Ramachandran, 2001; Tochi & Kamio, 2003). The problem with this type of reaction is that the atypical behaviors result in a lack of interaction with others; thus, children with ASD often do not get the practice with others they require to learn joint attention skills. However, recent studies using robots in a therapeutic capacity have demonstrated the reduction of self-stimulatory, repetitive, or stereotyped behaviors associated with hyperarousal in children with ASD (Duquette, Michaud, & Mercier, 2007). This result is a promising indicator that the robot in itself acts as a calming device, given its predictability, reducing hyperarousal. The Duquette et al. study (2007) also demonstrated the child’s preference for the robot in lieu of animated characters or mobile objects and toys, a finding that replicates other research (Breazeal, 2003a; Kidd & Brazeal, 2006). Preference for the robot over animated objects or toys indicates the intrinsic value of the more human-like robot for interaction in this population. In addition, robots can easily pace the degree of interaction and are themselves data-tracking devices (e.g., built-in camera, timing mechanisms). This combination of findings suggests that the robot is a perfect therapeutic device to initiate the early skills necessary as a foundation for more complex ones.

Research of students with autism has shown that they are more likely to attend to a robot than to the teacher and will spend more time with the robot than with other types of toys or animated devices (Dautenhahn & Werry, 2004; Diehl et al., 2012; Robins et al., 2005; Robins et al. 2009). One study that included CosmoBot (Boser et al., 2011) demonstrated that less verbal students seem to enjoy and are drawn to the more machinelike CosmoBot, verbalizing and engaging with the large eyes on the robot. In contrast, animal-like animatronic toys included in the study were less engaging to students on the spectrum even though their typically developing counterparts enjoyed and spoke to them. It seems some of the random natural and less predictable behavior of these toys made them less appealing to students with ASD. No such issues were observed of the children who were typically developing and of the same ability level. The fact that students with autism are specifically drawn to machinelike, systematic devices has been pointed out by other researchers working with this population. Simon Baron-Cohen and the team at the Autism Research Centre at the University of Cambridge developed the “Transporters” (see Chapter 9) and found that students with ASD can be taught to recognize and imitate facial emotion using the mediator of a mechanical or computerized object, in this case a train with a face on the front. Baron-Cohen argues that people with ASD prefer systematic knowledge and patterns to the less predictable emotional connection with others. They have a preference for more systematic, rather than empathetic, information processing. Robots may perhaps appeal to this systematic preference because they can be designed to mimic or reproduce human qualities and biological movements (Braezael, 2004; el Kaliouby, Picard, & Baron-Cohen, 2006; Pierno, Mari, Lushner, & Castiello, 2008; Pioggia et al., 2008). Keepon Pro is designed with an appearance somewhere between the minimalism of such robots as Roball or Muu and the anthropomorphism of such robots as Kismet or KASPAR. This design is motivated by a belief that the basic traits common to people and animals (e.g., lateral symmetry, two eyes) are
important cues to the potential for social agency. At the same time, keeping the appearance simple so that it is aligned with the robot's behavioral capabilities is important for helping people understand and feel comfortable with the robot's behavior. Keepon has been involved in several years of longitudinal studies, with over 400 recorded hours of interaction between Keepon and hundreds of children. Keepon has been observed to serve as a pivot for social interaction between children with ASD and their peers and caregivers; as a mediator for simplified interaction between therapist teleoperators and children with ASD; and as a tool for facilitating and recording these social interactive behaviors (Kozima, Michalowski, & Nakagawa, 2008).

Robots Can Act as Social Mediators in Human-to-Human Interaction

Engagement between students increases when a robot acts as the intermediary. This engagement could take place in environments where students are playing together with a robot or where they are encouraged to build or program a robot themselves. Robots can be used to facilitate turn taking, joint attention, and skills sharing in students or used in conditions requiring forced collaboration, that is, at times when some event does not happen unless there is shared collaboration. Forced collaboration also ties into facilitating teamwork, a 21st century skill that can be aided by the use of a robot.

Earlier studies of children with ASD with low verbal skills have demonstrated an increase in social behaviors in the presence of a robot as measured by imitation, touch, proximity, and gaze (Michaud & Caron, 2002, Robins, Dautenhahn, & Dubowski, 2006; Robins Dickerson, Stribling, & Dautenhahn, 2004). The preference of children on the autism spectrum for, and increased social behavior with, robots arises due to their social simplicity, predictability, and responsiveness (Robins et al., 2004). Results from a study showed seven of ten children with ASD demonstrated greater interest in teleoperated robots than in animatronic toys. The majority of these subjects also demonstrated greater imitative behaviors with their peers in the context of the robots. Seven of the ten children with ASD turned or walked away from mechanical animals. A number of different types of social interactions were observed with the two robots (smiles, vocalizations, gestures, gaze). As verbal abilities increased, engagement with the animatronic animals increased (Boser et al., 2011).

Social Skills Learning

The field of socially assistive robotics (SAR) has arisen out of a recognition that there is a need for assistive technologies to support the increasing numbers of persons with lifelong conditions, including diabetes, autism, obesity, and cancer (Feil-Seifer & Matarić, 2005; Feil-Seifer & Matarić, 2009). The field's efforts are in developing affordable technologies for monitoring, coaching, and motivating from both a cognitive and a physical level, addressing the range of needs from prevention to rehabilitation.

Robots Can Help Teach Social Skills and Assist in Social Situations

The key innovation in SAR is developing systems capable of assisting users through social, rather than physical, interactions resulting in various behavioral therapy applications. The field focuses on using data from wearable sensors, cameras, or
other means of perceiving the user's activity in order to provide the robot with information about the user that allows the machine to appropriately encourage and motivate.

It may seem counterintuitive to assume a robot would be the best social mediator for a child with social impairments; however, there are several arguments to address why robotic devices can serve to bridge the gap between the complex and unpredictable world of human social behavior and the safe, predictable world of simple toys in ASD (Duquette et al., 2007). Persons with ASD have described the difficulty they have with the social world (Grandin, 1995), including the stress and high levels of arousal that social situations incur (Grandin, 1992). The strategies they have adopted involve decreasing stimulation and complexities and learning explicit rules, for example, “to smile when someone smiles at you.” Relying on scripts and simplified social rules can be adaptive, described as “a way of decreasing environmental variance so that the social world can be reduced more effectively to a regular, predictable, and systemizable set of scripts” (Baron-Cohen & Belmonte, 2005, p. 116).

Robins et al. (2004) examined turn taking and imitation with robots and children with autism. These studies allowed for children to improve in simple contexts and then slowly increased the unpredictability of the robot’s actions. Robins et al. (2006) found that children with ASD learned to interact with the experimenter or a second person by means of the robot. For example, when the experimenter did not mimic the child correctly using the robot as a puppet, the child with ASD sought out the person behind the robot to correct him, thereby initiating social engagement. Our approach here builds on the robot as a co-participant in the human interactions to allow for the more immediate transfer of behaviors with the robot to occur in natural situations with other humans and also to allow the robot to act more as a mediator than as a substitute for another human. Such transfer of social skills has been observed in research using the diamond touch table to facilitate collaborative games and storytelling between children with autism and their peers. The paradigm of “forced collaboration,” where the technology does not produce an effect unless social interaction occurs, seemed to force students into using sharing, turn taking, and interactive skills that transferred to playing without the table as well (Gal et al., 2009).

A number of research projects in the field of embodied interaction have developed robots explicitly for interaction with children. For example, Kismet (Breazeal, 2003a) is a pioneering example of a “sociable robot.” Kismet engaged people in natural and intuitive face-to-face interaction by exchanging a variety of social cues, such as gaze direction, facial expression, and vocalization. Kismet’s elicitation of caretaking behavior from people (including children) enabled a form of socially situated learning with its human caregivers.

Scassellati (2007), who has been building and using social robots for the study of children’s social development, observed children with ASD interacting with a robot with an expressive face and found that they showed positive protosocial behaviors (e.g., touching, vocalizing, smiling at the robot) that were generally rare in their everyday life. Michaud and Caron (2002) and Michaud and Theberge-Turnel (2002) have devised a number of mobile and interactive robots, including Roball and Tito, and have observed interactions with children with ASD in order to explore the design space of child–robot interaction for fostering self-esteem. Okada and
colleagues (Miyamota et al., 2005) developed a creaturelike robot, Muu, to observe how autistic children spontaneously collaborate with the robot in such shared activities as arranging colored blocks and found increased interest and engagement with this robot as well as shared social activities.

Robots Can Provide Sequenced and Individualized Social Learning

Teachers who work with students on the autism spectrum need to monitor the ongoing abilities of their students, making adjustments to items learned as old items are mastered while also checking for maintenance of already learned materials. There are data management technologies available to correlate specific task data with individual education plan goals and outcomes (see Chapter 12). Several papers have discussed the benefits of using technology that is comfortable to the student (due to its ‘predictability’) that can automatically adjust to meet the student’s need (Belmonte et al., 2004; Liu, Conn, Sarkar, & Stone 2007, 2008). Although computer software can also achieve this goal for discrete, academic subjects material (e.g., Vizzle, iPad apps), a robot can gradually adjust its level of social interaction to modify the level of social stimuli provided. By adopting a robot in social interaction learning, we can gradually teach a social skill in step-wise fashion, for example, starting with machinelike behavior and gradually introducing more humanlike behaviors, allowing one sense to be explored at a time. Robots can be programmed to deliver just the right kind of reward after a behavior is exhibited and cue appropriately to elicit the behavior. These rewards and cues need to gradually adapt to the child’s learning, something which is at times difficult for a therapist to incorporate during the learning session because the assessment of learning may take time to gather; in contrast, the robot can immediately and automatically gather this information and use it to provide the appropriate learning stimulus and response.

Robots provide an opportunity for teachers to implement tools that can develop cognition, speech, and perception in a manner that is preferred, familiar, and supportive to the child with ASD. Robots can be a special social partner that initially allows for the needed development of social interaction and play in a medium that promotes engagement that is not observed with humans. Robotics used efficiently allows for the transition of these same skills to human interaction quickly and appropriately (Bird, Leighton, Press, & Heyes, 2007; Cook, Adams, Encarnacao, & Alvarez, 2012). Table 5.1 lists ways in which robots can assist children of different ages and developmental levels to learn basic problem solving and abstract cognitive skills, which are necessary for higher-order social interaction.

Robots Can Assist with Language and Communication Skills

Interactive robotics have been created in various shapes, colors, and forms to foster socially appropriate behaviors and evoke improvement in executive function. This technological platform allows flexibility and creates educational scenarios that may be individually tailored to the child’s learning style and specific interests. This adaptability allows teaching in a manner that is both appropriate and uniquely engaging for a child with ASD. In addition the predictability of the robot, the consistency of the speech patterns and the simplicity of verbal commands provide a uniformity and obviousness that facilitates the learning and generalization in children with ASD (Gillesen, Barakova, Huskens, & Feijs, 2011; see Table 5.2).
Although the core features of ASD are well recognized, the more subtle, yet pervasive, dysfunction of motor abilities is often overlooked or misunderstood. Associated symptomatology includes gross and fine motor deficits with motor dysfunction evident as early as the first year of life, which continues throughout the child's lifetime (Carper, Moses, Tigue, & Courchesne, 2002; Herbert et al., 2002; Herbert et al., 2004; Samango-Sprouse, 2007). It is these motor dysfunction and planning deficits that are intriguing and very responsive to interactive robotics as a form of intervention.

Table 5.1. Robot-related skills

<table>
<thead>
<tr>
<th>Skill</th>
<th>Definition for Robot Use</th>
<th>Age Considerations for Children Developing Typically</th>
<th>LEGO Robot Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No interaction</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>1</td>
<td>Cause and effect [causality]</td>
<td>&lt;3 years: action in switch, tried to use disconnected switches</td>
<td>Use switch to drive robot, knocking over blocks with robot, drawing circles on paper by holding a switch down and turning robot</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt;4 years: understood switch made robot move</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Inhibition [negation]</td>
<td>4 years: begin to understand that switch release stops robot</td>
<td>Releasing switch to stop robot</td>
</tr>
<tr>
<td>3</td>
<td>Binary relations [binary logic]</td>
<td>5–6 years: understood rocker switch had two opposite effects</td>
<td>2 switches turning robot right or left or go and stop</td>
</tr>
<tr>
<td>4</td>
<td>Sequencing [coordination of multiple variable spatial concepts—multiple dimension]</td>
<td>5 years: could fine-tune a movement by reversing to compensate for overshoot, etc.</td>
<td>Moving roverbot to a specific location in two dimensions</td>
</tr>
<tr>
<td>5</td>
<td>Symbolic play</td>
<td>6 years: child ID action in robot not switch, planning of tasks is possible</td>
<td>Interactive play with pretense, i.e., serving at tea party, exchanging toys with friends, pretending to feed animals—all using robot</td>
</tr>
<tr>
<td>6</td>
<td>Problem solving</td>
<td>7 years: designed robot and thought about coordinated effects, planning was possible, can understand simple programs and debug</td>
<td>Changing strategies to solve a problem such as avoid an obstacle, changing task to meet the child's own goal, simple programming</td>
</tr>
</tbody>
</table>

Motor movements naturally involve planning and an internal model of the intended external action. Planning is one of the more complicated operations for humans. It is an intricate process and requires the development of a specific, premeditated action, surveillance of the identified action, and the alteration of the existing plan if necessary, and then the execution of the action. Numerous studies demonstrate deficiencies in planning and flexibility across a variety of motor and cognitive tasks in children with ASD (Hill, 2004; Ozonoff & Jensen, 1999; Pennington & Ozonoff, 1996). Other studies have focused on the impairments in action imitation (Mostofsky et al., 2006; Williams, Whiten, & Singh, 2004). Some studies have found improvements in basic action imitation for children with autism using robots (Pierno et al., 2008; Pioggia et al., 2008). The AuRoRa project (Robins et al., 2004; Robins et al., 2005; Robins et al., 2009) reported that even simple mobile robots provided autistic children with a relatively repetitive and predictable environment that encouraged spontaneous and relaxed interactions (e.g., chasing games). Billard, Robins, Nadel, and Dautenhahn (2007) developed a doll-like anthropomorphic robot, Robota, for mutual imitative play with autistic children; Robins et al. (2004) analyzed two children playing with Robota and observed mutual monitoring and cooperative behavior to draw desirable responses from it.

Robots Can Promote Science, Technology, Engineering, and Mathematics

Students with ASD, while often excellent with visual and numeric aspects of STEM areas, do not thrive in the areas of problem solving, verbal or abstract number abilities, and, of course, the collaborative aspects necessary for developing technological skills in the 21st century classroom. Although engineering and math are a draw for students on the spectrum, these students may not be able to complete the mathematics areas that are their strengths because they often cannot complete the math sequence. For example, Temple Grandin often bemoans the fact that she was not

<table>
<thead>
<tr>
<th>Learning objectives and description of robot behavior:</th>
</tr>
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<tbody>
<tr>
<td>1. Imitation: Robot displays arm movements that have to be imitated by the child.</td>
</tr>
<tr>
<td>2. Imitation, joined attention, turn taking: This is the same as #1, except with the added dimension of turn taking.</td>
</tr>
<tr>
<td>3. Asking for help: Robot asks for help on a task and client needs to ask if the offered help is useful.</td>
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<tr>
<td>4. Self initiation: Robot states it can do a cool move (e.g., a dance). Client is then provoked to enquire about the move.</td>
</tr>
<tr>
<td>5. Problem solving: Robot asks help from the client. Client offers solutions and asks if this is the right solution.</td>
</tr>
<tr>
<td>6. Asking questions, self-management: Robot engages in a simple dialogue with the client about different topics. Client takes leading role in what to talk about.</td>
</tr>
<tr>
<td>7. Sharing, turn taking: Client and robot play a game where blocks have to be colored using a magic wand. Players need to share the wand, using proper turn taking.</td>
</tr>
<tr>
<td>8. Evaluation of a movement: Robot wants to learn to wave like the client. Client needs to coach the robot to learn this move.</td>
</tr>
<tr>
<td>9. Introducing yourself, introducing the robot: Robot greets client and asks for his or her name. Robot then becomes sad, and client is provoked to enquire what is wrong. Robot states it does not have a name yet and offers to think of a name.</td>
</tr>
</tbody>
</table>

Source: Gillesen, Barakova, Huskens, & Feijs, 2011.
allowed to continue through to trigonometry because she could not master the highly verbal and abstract areas of algebra. Students with autism need to be drawn into these areas by focusing on their areas of strength in math and science and providing support necessary for their planning and verbal, attention, and executive function needs. Robots could provide such support by helping students visualize, enabling interactive engagement in the curriculum, and providing ongoing updates and assessment of skills, thereby allowing repetition necessary for students to engage in the content area.

Combining robotics with computerized instruction that is engaging, compelling, and easily adapted to the individual can meet part of the need for individualized instruction in life skills. Gamelike interactions that effectively address learning goals are appropriate to the cognitive levels of learners, meet learners’ needs for materials that look and feel appropriate to their age and self-image (including selection of an avatar), and have considerable potential to improve the effectiveness of life skills preparation. In addition, as computer-based games, they can be used both in the school context and at home, with benefit to generalization of the skills addressed. Computers are intrinsically compelling for young children and can provide a source of motivation for many children who are typically difficult to engage. Increasingly, young children observe adults and older children working on computers, and they want to do so, too. Children get interested because they can make things happen with computers (National Association for the Education of Young Children, 1998) and the interaction with sounds and graphics keeps the children’s attention. Children also tend to enjoy the control they have over the computer.

Such computer programs as Google SketchUp have shown to be engaging for high-functioning children on the spectrum. In addition, for some children on the spectrum, especially those who are nonverbal, SketchUp serves as a way to communicate, allowing them to share their thoughts through crafted images. Other children learn life skills that help them to achieve educational and career goals they might not have even aspired to before SketchUp. Visual programs like SketchUp can provide students with new methods for creating visual content and sharing it with their peers in the classroom. TinkerCAD provides a user-friendly interface that is accessible in a browser to develop 3-D computer-aided design models that can then be printed by a 3-D printer, thereby enabling 3-D design to be brought into the physical world without expensive software or high-technology skill.

Developmentally appropriate software engages children in creative play, mastery learning, problem solving, and conversation. The children control the pacing and the action. They can repeat a process or activity as often as they like and experiment with variations. They can collaborate in making decisions and share their discoveries and creations.

Robotics is one of the latest technological innovations, and a humanoid robot is an ideal learning tool for classes at all levels. Several educational researchers have reviewed various robotics kits, including NAO, VEX, and Lego Mindstorms, among others, for their ability to teach engineering and STEM skills (Beer & Chiel, 1999; Catlin & Blamires, 2010; Gura & King, 2007; Johnson, 2003; Ribeiro, Coutinho, & Costa, 2011). Robots allow students to connect theory with practice and discover a wide range of robotics-related fields, such as computer science, engineering, and mathematics. Students gain hands-on experience using a robot such as NAO, through which, when used in the lab, they discover such exciting topics as
locomotion, grasping, audio and video signal processing, voice recognition. A software program called Choreographe allows students to program the robot to do what they would like it to do in an easy-to-learn programming environment. By merging sciences like mathematics, physics, and psychology, robots provide cutting-edge innovations that all engineering students need to master. Thus, robotics is the perfect tool for teaching STEM subjects. The NAO robot also allows teachers to integrate teamwork, project management, problem solving, and communication skills in a stimulating setting. NAO offers the flexibility for developing interdisciplinary projects. For students with ASD, the development of team-building and problem-solving skills together with their known propensity for mechanical and logical things makes robotics part of an ideal learning environment.

BRINGING A ROBOT INTO THE CLASSROOM

Today’s children have grown up with technology and have been called “Digital Natives” because interaction with technology is key to most activities in which they engage. The question facing educators is simply this: “Does growing up with technology change the way students learn enough to require changes in the methods used by teachers?” Marc Prensky coined the term digital natives in his seminal work “Digital Natives, Digital Immigrants,” published in 2001. In his article, Prensky assigns this term to a new group of students enrolling in educational establishments that have grown up surrounded by and engrossed with technology; he explains that these Digital Natives require a new language and methodology for learning. Prensky states, “Digital Immigrant instructors, who speak an outdated language (that of the pre-digital age), are struggling to teach a population that speaks an entirely new language. We need to invent Digital Native methodologies for all subjects, at all levels, using our students to guide us” (2001, p. 5).

Robots used in the classroom can prepare students for learning in environments that are increasingly digital (Sneider & Rosen, 2009). For this kind of digital learning, sensors and sensing equipment can provide the necessary support. Robots can serve as an embodied camera that provides a first-person record of human-to-robot interactions, thereby providing much richer information than can be obtained from a wall-mounted camera. Eye movements, micro facial expressions, and quiet vocalizations can be captured by a robot much more sensitively than by a recorder in the distance. Robots can bridge the divide between digital native and digital immigrants enabling a common language to engage students in learning.

Using Robots to Guide Learning

We envision a shift in education where technology is integrated within the classroom environment and curriculum, where robots will assist in the inclusive classroom, thereby providing new methodologies for learning. Below we outline three UDL key concepts that can be used to facilitate learning with robots in the classroom: representation, expression, and engagement (Cast, 2011).

1. Multiple means of representation (The “what” of learning). Robot technologies can be thought of as a platform, like a computer, that can present content in an interactive way with pacing adjusted to the user. Robots can provide variability in delivering content thereby reinforcing the “what” of learning by providing learners various ways of acquiring information and knowledge.
2. **Multiple means of expression (The “how” of learning).** The manipulation of existing robotic devices by either deconstruction or construction requires a variety of hands-on skill, from real-time programming to soldering and wiring using varies aspects of cognitive and motor ability. Technologies ranging from pre-created hardware to plug-and-play devices provide learners with alternative methods to demonstrate what they have learned in the classroom. Many of these devices can be integrated into the core curriculum (i.e., Math, English, Science, and Social Studies) by providing alternative methods for assessing learning in nontechnical subjects.

3. **Multiple means of engagement (The “why” of learning).** The uncanny ability of robots to engage a child and sustain the child’s interest over time is a critical component of the argument for why educators should work with robots. Interest in robotics is growing and cuts across gender and ethnic lines. Furthermore, robotics can be seen as a way to challenge students to learn about subjects in a new and interactive way. Over 250,000 students participated in robotics competition programs in 2012, including over 10,000 students in first through third grade through such programs as FIRST (For Inspiration and Recognition of Science and Technology) and the Robotics Education and Competition Foundation. Robotics can assist in sparking learners’ interests, present a challenging learning environment, and motivate students to learn.

In addition to the enhanced interest in learning robotics there is a new trend in design and making technology accessible. Technologies are seemingly getting smaller and more affordable, enabling families and communities to take part in what was once considered to be a field accessible only to engineers. With the advent of open-source hardware and software, the tools to invent and manufacture are readily accessible to parents, therapists, and educators; it is with this shift of openness that we delve into developing do-it-yourself technologies for your classroom.

**Benefits of Do-It-Yourself Technology**

Core ideas in engineering require the ability to view a problem and come to a proposed design solution. Of significance are the connections of ideas between engineering, science, technology, and mathematics. These “big ideas” (Executive Office of the President, 2010; National Research Council [NRC], 1996) also correlate with the National Science Education Standards, which emphasize the “interdependence of science and technology and suggest that students should understand and acquire the capabilities of engaging in technological design” (NAE, 2010, p. 24).

In particular, the “Abilities of Technological Design” for Grades K–4 involve identifying a problem and proposing a solution, implementing solutions, and then evaluating a product or design and communicating about it. These steps are outlined as follows (National Academy of Engineering, 2010; National Association for the Education of Young Children, 1998):

1. **Identify a simple problem.** Children should develop the ability to explain a problem in their own words and identify a specific task and solution related to the problem.

2. **Propose a solution.** Students should make proposals to build something or get something to work better; they should be able to describe and communicate
their ideas. Students should recognize that designing a solution might have constraints, such as cost, materials, time, space, or safety.

3. **Implement proposed solutions.** Children should develop abilities to work individually and collaboratively and to use suitable tools, techniques, and quantitative measurements when appropriate. Students should demonstrate the ability to balance simple constraints in problem solving.

4. **Evaluate a product or design.** Students should evaluate their own results or solutions to problems, as well as those of other children, by considering how well a product or design met the challenge to solve a problem.

5. **Communicate a problem, design, and solution.** Student abilities should include oral, written, and pictorial communication of the design process and product. Through the NSF National Science Digital Library Program, the Teach Engineering Digital Library was created to provide teachers with the curricular materials to bring engineering into the K–12 classroom (http://www.teachengineering.org).

The engineering design process is “a pedagogical strategy that promotes learning across disciplines...and introduce[s] young students to relevant and fulfilling STEM content in an integrated fashion through exploration of the built world around them" (Teach Engineering, 2013). Logical problem-solving skills are integral to engineering design, and games are fundamentally suited to teaching problem-solving skills because the player must discover and manipulate the game elements. Emerging out of the goals to teach logical problem-solving skills, to create engaging game content, and to incorporate engineering design came the idea of using robotics as the focal point. Robotics allows students to experience design, innovation, problem solving, and teamwork at the same time they are talking about math, science, and technology. Universities, corporations, government agencies, and non-profits are all using robotics as a way to build STEM literacy in the next generation (Sneider & Rosen, 2009).

By using open-source hardware and software, these engineering design principles can be put into practice. Educators and students can develop their own do-it-yourself robots for the classroom. Such tools as the Arduino and consumer 3-D printers (MakerBots) enable simple and effective methods to rapidly prototype a design solution. These devices allow for basic projects that can be scaled up to provide a more complex platform to work with once the basic skills are acquired. It is not difficult to imagine building robots with these tools in the school environment; projects like the Romibo2 robot project, for example, suggest the implications of prepackaged do-it-yourself robotics for therapy. Romibo uses open-source hardware and minimalistic design to enable a low-cost flat-packed do-it-yourself robot that non-engineers can construct and program (think IKEA for robotics). With the advent of these open and lower cost technologies, educators will no longer have to envision what kind of robots they would want designed for their classrooms; instead, educators and students will be empowered to create robots that will maximize learning for all students on the spectrum.

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Romibo is an open-source do-it-yourself robot for therapy (http://www.romibo.org/therapy).
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