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Young Children Using Assistive Robotics for Discovery and Control

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Can young children with severe disabilities learn to use a robot to accomplish tasks? Can they learn that they have some control over their environment? What are new developments in robotics that might benefit these very young children? This article provides the latest in robotics—exciting news for teachers, parents, and caregivers of young children with severe disabilities.

Considering the Developmental Needs of Young Children

The physical manipulation of objects is a major contributing factor in the development of cognitive and language skills in very young children. Children are active learners, and development is an interactive process between the child and the environment. Very young children face a critical task in learning to recognize the relationships between their actions and the effects of those actions on the environment (Hanson & Hanline, 1984). In developing these relationships, the young child learns to initiate and exert control over both social and nonsocial aspects of his or her environment. For a child with a severe developmental disability, this important learning of cause and effect and the development of a personal orientation as an active agent in the environment are far more challenging than for children without disabilities.

For these reasons, the direct manipulation of objects with an assistive robotic system that is controlled by a child is a promising area to explore with children with severe manipulation disabilities (Howell & Hay, 1989). The disabling conditions that are associated with poor control, or little or no use, of the upper extremities include cerebral palsy, arthrogryposis, spinal muscular atrophy, muscular dystrophies, rheumatoid arthritis, multiple sclerosis, poliomyelitis, spinal cord injury, head injury, and locked-in syndrome. The number of people with these conditions who also have severe manipulation disabilities in the United States is estimated to be at least 150,000 (Stanger & Cawley, 1996).

As a first step in the process of exploring the use of assistive robotics with young children with severe disabilities, Cook and his research team developed a robotic system that incorporated a commercially available robotic arm (Cook, Hoseit, Liu, Lee, & Zenteno, 1988; Cook, Liu, & Hoseit, 1990; Hoseit, Liu, & Cook, 1986). The primary questions addressed by the initial research were whether a very young child would interact with a robotic arm and whether that interaction would involve the purposeful use of the arm as a tool to accomplish some desired or requested action. This research differs from the increasing use of robotic systems to assist in tasks at work, in the home, or at school by older people with disabilities (see Foulds, 1986, for many examples). Service providers involved with these other applications have not typically considered either the developmental demands or the developmental benefits of robotic arm use by very young children.

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Meeting Leah

The child that we spotlight is this article is Leah, a toddler with developmental delay and quadriplegic athetoid cerebral palsy. When the team began working with her, she had not begun to walk; and she had problems using her hands to grab and manipulate objects, although she was almost 2 years old. She also had difficulty speaking, but she was able to communicate some of her needs by vocalizing or gesturing toward a person or object that she wanted. Leah came to understand that when she hit a switch, the robotic arm moved (cause and effect) and that an object placed in a cup out of sight was still there (object permanence). She also understood that the robotic arm could bring things closer to her (tool use). These language and cognitive skills are typical of a 1-year-old child.

Despite her physical and cognitive difficulties, Leah was outgoing. She engaged communication partners in a variety of ways, including gesturing and taking toys to them to play. Despite the challenges presented by her disabilities, she loved to explore her environment. During one of our initial sessions with her, Leah and her parents played with a purse into which we had placed several different objects. She sat on the floor with her knees together and her feet spread out in back of her for support. As her mother handed her the purse, she struggled to turn it upside down to empty it, since she couldn't reach inside it. As each object fell out, Leah was delighted with her "discoveries"—such as the sound of keys and the shiny surface of a pocket mirror. She played with each object, grasping it loosely with the palm of her hand rather than her fingers, turning it around and over, handing it to her parents, and smiling and laughing to express her delight.

Enabling Leah

In our research, we explored an unusual way to enable Leah to increase her interaction with, and control over, her world. The team configured for her a small robotic arm and computer control system. We wanted to determine if a robotic arm would assist a toddler like Leah in reaching for and manipulating objects such as toys, developing some problem-solving skills, and increasing her use of language. In broader strokes, our overarching goal was for Leah to learn a general orientation of *personal agency* that teachers, therapists, and parents could build on (e.g., Ford & Thompson, 1985). In our conception, a sense of personal agency is manifested by direct and independent action toward items and people in the immediate environment, the function of which is to successfully control or influence these items and people to satisfy needs or desires.

Most children learn about objects by grasping and manipulating them with their fingers, mouthing them, and playing with them either alone or with others. In interactions with adults, children also learn the names of objects and how to talk about them while engaged in these manipulation tasks (e.g., put the block *in* the box," Meyers, 1994). This integral relationship between the physical manipulation of objects and the development of cognitive and language skills leads to the high likelihood that a child with severe motor development problems will have significantly impaired skills (Nof, Karlan, & Widmer, 1988).

Leah used the robotic arm purposefully as a tool to retrieve items.

Leah, like other children her age, needed to "learn by doing," and her interaction with objects in her environment was a critical part of this learning process. Because of her physical limitations, she had difficulty reaching objects, grasping them with her hands, manipulating them, and playing with them with other people. Through use of the robotic arm system, we hoped Leah would learn to overcome these limitations. If she used the robotic arm successfully, Leah could perform such activities as retrieving an object that was too far away from her to reach, picking up objects that were too small for her to grasp, or handing a toy to a friend. In addition, this "augmentative manipulation" (Heckathorne, 1986) might help her to learn such things as how to share toys, how an object looked from different perspectives (e.g., a shiny object catching the light when it is turned), and what prepositional words like *in, out, on,* and *under* meant. And finally, the team also hoped that Leah's use of the robotic arm would help her learn to actively initiate interaction with others, rather than be a passive observer.

The direct manipulation of objects with an assistive robotic system that is controlled by a child is a promising area to explore with children with severe manipulation disabilities.

The interaction with Leah took place at an early intervention program for children up to 36 months of age. Children in this program have disabilities that are associated with delays in their development of physical, cognitive, and language skills. Parents regularly participated in the program with their children. A team of professionals from many different disciplines helped assess the child's abilities and learn about her strengths and weaknesses. This team included infant/parent educators, occupational therapists, physical therapists, speech-language pathologists, and a clinical psychologist. The team provided the children with activities intended to promote their development, enhance strengths, and reduce weaknesses. The program also offered support activities to parents.

Meeting the Robot

The technology system that the team used with Leah consisted of a personal computer, software for robotic control and data collection, a small robotic arm, a single switch, and a joystick (Cook et al., 1988). The arm was about one-half the size of an adult human arm. It had an "elbow" and "shoulder" that rotated, and it could turn at its base. One could move the robotic arm to many different positions. At the end of the arm were two "fingers" that could be used to grip objects. The team "trained" the arm to complete a task through use of the joystick to move the arm through a desired movement (e.g., pick up a toy and hand it to Leah). During training, the movements were stored in the computer's memory so they could be repeated. This procedure made it easy for a teacher, therapist, or parent to train a specific movement that was of interest to Leah.

Four major phases characterized our program:

1. Our training of the robotic arm to perform specific actions.
2. Our teaching Leah how to control the robot.
3. Leah's initiations of the movements using a single switch.
4. Our monitoring of Leah's behavior prior to, during, and after robotic arm movement.

Training the Robot—and Leah

Our interaction with Leah began with an initial interview of the clinical program staff and her parents regarding objects that she preferred and the actions of the robotic arm that were most likely to be of interest to her. Her parents and the program staff suggested robotic arm movements based on tasks in which she typically attempted to engage. These included bringing a cracker to her when she activated the arm and dumping the contents of a cup to discover what was inside. Because many different movements were stored in the computer's memory, the team could easily change movements during a session to maintain Leah's interest.

The use of the robotic arm with Leah began with a period of familiarization during which we played with her and determined what her general reaction to the robotic arm was. During these sessions, she was curious about the arm and reached out to play with it. We then modeled for Leah the pressing of a switch to cause the robotic arm to move. We placed the switch in front of her and placed an object to be retrieved by the arm in her view but out of her reach. Leah appeared to be interested in seeing the robotic arm begin to move. After our repeated modeling, Leah eventually pressed the switch. She became excited and laughed when it moved. When it stopped, she vocalized and pointed to the arm in a movement that indicated she wanted the arm to repeat the movement. We recorded the number of times that she pressed the switch and the nature of her collateral behaviors (e.g., whether she looked at the switch, looked at the arm, or was restless).

> **Children were not fearful of the arm, and they were able to learn to use a switch to control it. Significantly, the children's gross motor and fine motor skill levels were less related to success in using the robotic arm than were their cognitive and language levels.**

To be able to draw inferences about Leah's understanding of cause-and-effect relationships, we systematically observed her behavior as she interacted with the arm. When Leah looked at the switch, then pressed the switch, and then turned to watch the arm move—all in immediate succession—we speculated that she knew that pressing the switch caused the arm to move. To interact successfully with a robotic arm, a user must not only learn the controlling inputs to which the robot responds, but also anticipate the movements that those inputs precipitate (Van der Loos & Leifer, 1996).

Near the end of our training sessions, Leah almost always looked at the switch before pressing it, then looked at the arm immediately after pressing the switch. We also observed the antecedents and consequences to determine any functional purpose to Leah's robotic arm activations. Leah showed us that she was attempting to retrieve an object using the robotic arm by pressing the switch to bring objects, such as a cracker, close to her. When the cracker was still out of reach, she pressed the switch again to bring it closer, then reached for it with her own hand. If it was still out of reach, she pressed the switch again. She repeated this sequence of actions until she could finally reach the cracker with her own hand. She also requested that new objects be placed in the cup so she could discover what they were by tipping the cup using the robotic arm. Leah showed heightened curiosity when the robotic arm began to bring the cup toward her, and she smiled and laughed when the cup was tipped and its contents fell on the table. She requested that this task be repeated by looking with an earnest expression at her mother, then at the cup, and squealing with delight.

Sequences such as these led us to conclude that Leah used the robotic arm purposefully as a tool to retrieve items such as a cracker or a cup containing a secret object (Cook et al., 1990). This tool use is unique to robotic arms when compared to the motorized toys or computer graphics typically employed as reinforcement for actions by students with severe disabilities, and it was highly motivating to Leah. The use of the robotic arm also showed her parents and the clinical program staff that Leah could solve problems, and it gave them a better understanding of her general capabilities.

Using the Robot as a Tool

In our research program, 50% of the children with disabilities and 100% of the nondisabled children actively interacted with the robotic arm and used it as a tool to obtain objects out of reach and manipulate them (Cook et al., 1988, 1990; Hoseit et al., 1986). All of the children with disabilities with a developmental age of at least 7 to 9 months interacted

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with the robotic arm, and those below this developmental level did not. All children older than 8 months interacted with the robotic arm as a tool. This study demonstrated that very young children can use a robotic arm to accomplish tasks that are of interest to them. The team also found that children were not fearful of the arm, and they were able to learn to use a switch to control it. Significantly, the children's gross motor and fine motor skill levels were less related to success in using the robotic arm than were their cognitive and language levels.

The research team currently is conducting further education-related research to determine the degree to which very young children will use assistive robotics for exploration and discovery and how this affects their cognitive and language skill development. Cook et al. (1988) developed for practitioners a hierarchy of assistive robotic movements, based on the complexity of the actions that a child needs to carry out, and therefore the degree of personal agency a child needs to manifest, to accomplish a specified task. In this hierarchy, a child progresses through the following levels:

- Simply playing back preprogrammed sequences of robotic actions, such as Leah performed.
- Selecting different switches to control different robotic movements (e.g., "reach," "grab," "rotate wrist") that can be used together to complete a more complicated task (e.g., reach for a cup, grasp it, and rotate it to dump its contents).
- Moving the robot to any location and then performing any robotic action by pressing switches corresponding to "up," "down," "left," "right," "open," "close." This latter level allows unlimited exploration and discovery by the child. For example, a child could use the arm in a sandbox to grab a shovel, fill a pail with sand, and dig in the sand to find hidden objects.

Using Robots: Guidelines for Assistive Robotics

From our own research program and an analysis of other clinical reports on assistive robotics (e.g., Heckathorne, 1986; Howell, Damarin, & Clarke, 1989; Howell & Hay, 1989; Nof et al., 1988; Topping, 1996; Van der Loos & Leifer, 1996; Verburg, Kwee, Wisaksana, Cheetham, & van Woerden, 1996), we offer the following recommendations to teachers and therapists who are interested in using assistive robotics for children and adults with severe manipulation disabilities:

1. Determine the range of the workspace in which the student might be required to (or desire to) perform manipulation activities, the manipulation characteristics of the educational activities to be accomplished within that space, and the dimensions of the three-dimensional space that the robot can address (termed the robot's "operational envelope").
2. Evaluate the degree of structure in the educational work environment; structured environments are composed of objects and materials in fixed locations, which the student will engage in manipulation activities that are predefined. The more structured the environment, the simpler the cognitive and physical demands placed on the student and the more efficient the student's performance in that environment. Structured environments, however, typically require prior set-up by teachers and parents and limit the student to only those activities that were previously prepared for. In completely unstructured school, work, and living environments, users of a robot must be able to perform the most sophisticated oversight functions by first deciding which task should be carried out and then explicitly guiding the robot's movements through all of the task requirements using their own judgment and sensory capacities.
3. Assess the student's abilities and control interface needs for adequate control of the robot. The alternate input devices that can be used with assistive robotics can be tailored to the student's type and degree of disability and the amount of precision required by the educational tasks (e.g., keyguard, multiple-switch array, touch screen, eyebrow switch, sip-and-puff switch, speech recognition).
4. Select a control interface that minimizes the cognitive load on the student. The control mechanism should be easy, obvious, and intuitive to the largest extent possible, while still providing sufficient precision in the robot's operation for the intended educational tasks. At first, permit the student to control the robot throughout its operational envelope with only a minimal number of switch closures. Computer displays, if used, should be uncomplicated.
5. Train to achieve *heightened automaticity* of the robot-controlling responses of the student. You want the student to remain focused on the educational content of the activity, rather than having to attend closely to operating the robot. The training method of "increasing assistance" (modeling, verbal, gestural, and physical prompts) has been successful in this instruction.
6. Consider the balance between the amount of student-directed and computer-controlled robotic movements and, as the student's motivation and understanding of cause and effect grows, adjust this balance to facilitate greater student independence. (You

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can preprogram sequences of robotic movements to be activated by a single switch closure for ease of operation, but such programming results in limited versatility for the student. On the other hand, you can program the robot so that the student can activate each individual component movement by a separate switch closure and thereby combine the movements into an infinite number of sequences, but this "micro-management" results in more complicated and slower student-robot interaction. At the beginning of training, avoid giving the student control over too many robot options to prevent frustration with the number of choices to be made in accomplishing meaningful action by the robot.) Students with severe cognitive disabilities most likely will begin with single-switch activation of complete motion sequences before they can use multiple-choice switch arrays for different subsequences and then discrete activation of each individual movement.

Educational and Assistive Robotic Systems and Resources

Logo Robotics
Terrapin Software
10 Holworthy Street
Cambridge, MA 02138
Voice: 800-774-5646
Fax: 617-492-4610
E-mail: info@terrapinlogo.com
Web: http://www.terrapinlogo.com
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Fax: 312-654-8227
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Web: http://www.learningtoys.com
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Fax: 310-638-8347
E-mail: owi@ix.netcom.com
Web: http://www.owirobot.com/menu.html
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Lynxmotion, Inc.
104 Partridge Road
Pekin, IL 61554-1403
Voice: 309-382-1816
Fax: 309-382-1254
E-mail: jfrye@lynxmotion.com
Web: http://www.lynxmotion.com
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Advanced Design, Inc.
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Tucson, AZ 85704
Voice: 520-544-2390
Fax: 520-575-0703
E-mail: desk@robix.com
Web: http://www.robix.com/
The Robot Store
Mondo-tronics, Inc.
4286 Redwood Highway, #226
San Rafael, CA 94903
Voice: 800-374-5764
Fax: 415-491-4696
E-mail: info@mondo.com
Web: http://www.robotstore.com
The Manus Manipulator
Exact Dynamics b.v.
Einsteinstraat 6-c
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The Netherlands
Voice: 011-31-0316-334114
Fax: 011-31-0316-331327
E-mail: dynamics@worldonline.nl
Web: http://home.worldonline.nl/~dynamics
Handy 1
Rehab Robotics Ltd.
Suite 33
Keele University Science Park
Keele, Staffordshire ST5 5BG
United Kingdom
Voice: 011-44-1782-712774
Fax: 011-44-1782-713230
Web: http://homepages.enterprise.net/dallaway/rrjump/
Robot for Assisting the Integration of the Disabled
Oxford Intelligent Machines Ltd.
12 Kings Meadow
Ferry Hinksey Road
Oxford, OX2 0DP
United Kingdom
Voice: 011-44-0865-204881
Fax: 011-44-0865-204882
E-mail: sales@oxim.demon.co.uk
Web: http://www.oxim.demon.co.uk/
Rehabilitation Robotics Jumpstation
Webmaster: Dr. John L. Dallaway
Senior User Interface Software Engineer
Cygnus Solutions Ltd.
Sunnyvale, CA
Voice: 800-294-6871
E-mail: john.dallaway@bigfoot.com
Web: http://homepages.enterprise.net/dallaway/rrjump/
Robotics Internet Resources Page
by The Laboratory for Perceptual Robotics
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University of Massachusetts
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Web: http://www-robotics.cs.umass.edu/robotics.html
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Web: http://www.robotics.com robots.html
Robotics Frequently Asked Questions
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Carnegie Mellon University
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E-mail: nivek@cmu.edu
Web: http://www.frc.ri.cmu.edu/robotics-faq/TOC.html

7. Design a training protocol that is appropriate to the student's developmental level, providing a structured learning environment and gradually increasing levels of performance (see box, "Training Sequence for Students").
8. In all stages of training, structure the learning situation so that the robot performs a *useful task* for the student. As a result, student interest in the activity and motivation to use the robot will be greater, and the student will be more likely to use the skill in other situations.
9. Consider the mode and the amount of complementary feedback to provide to the student about the robot's position and movements. Visual feedback is naturally available to students by the robot's actual movement, but this information is not always correctly interpreted by students. For example, when students look directly at the front of the robot, their visual perspective is the reverse of the orientation of the robot—so that telling the robot to "turn right" will make it turn *to the student's left*. Under such control situations, the student must be able to adopt the perspective of the robot when issuing movement commands.
10. Regularly evaluate student progress toward the educational objectives to determine whether the robot continues to assist in meeting the manipulation needs and to determine what modifications might be needed for the following: the student's training on the robotic system, the robot's operating characteristics, or the student's objectives. Teacher-friendly assistive robotics applications should provide automatic data recording of the frequency, type, and time of the student's activations of the robot and generate reports on the student's progress based on these data.
11. Be sure to incorporate physical restraints and software safeguards over the robot's movements to ensure the student's safety during any intentionally or unintentionally activated robot movements; do not allow the student to enter the robot's operational envelope; and conduct regular checks on these features.

Training Sequence for Students

The following framework for a training sequence in robotics can lead to improved cognitive skills and a greater sense of personal agency for students with severe disabilities:

1. **Arrange the learning situation so that the student can, with a simple switch closure, explore objects of interest through simple preprogrammed and consistent actions of the robot.**
2. **After the student achieves a criterion level of performance at this stage, arrange the situation so that the student can now manipulate the objects in ways that are specific to the properties of the object—in unique and functional ways.**
3. **Once the student learns at this stage, change the response requirements for robot operation so that the student has to stay engaged with the robot to achieve the end result. Program the robot to pause at various points in the movement until the student re-presses the switch.**
4. **After the student has become fluent at this stage, provide him or her the opportunity to sequence and coordinate the component parts of the robot's movement into more complex and novel chains. Experiment by changing the environmental demands and task requirements to encourage the student to become more facile with this sequencing and to generalize his or her augmentative manipulation skills.**

Exploring Robotics

The use of assistive robotic systems with young children with disabilities is still in an exploratory stage. Many exciting and challenging issues remain to be investigated. The cost of robotic systems continues to decrease, and the availability of applications specifically for this population increases (see box, "Educational and Assistive Robotic Systems and Resources" for commercial robotics systems and the box "Annotated References" for descriptions of key assistive robotics articles).

The ability to control one's environment plays a large role in determining an individual's self-perception. If children learn they can affect their world, then they will acquire an enhanced self-image, they will learn to interact socially, and they will learn that they can have an impact on other people and objects that they encounter. They will be active agents in their world rather than passive observers of it. The skillful implementation of assistive robotic systems by teachers and other practitioners can contribute significantly to this improvement in awareness, functional skills, and orientation by children with severe developmental disabilities.

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