Robots and Children with Disabilities: Facilitating play, learning and cognitive development

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Introduction

During typical development children learn cognitive, social, motor and linguistic skills through manipulation of objects, often in the context of play. Because of motor limitations manipulation of objects may be difficult, and the quality of play and learning of skills may be compromised (Musselwhite, 1986). Demonstrated success with robot tasks could be an alternative way for children to demonstrate their understanding of cognitive concepts. Use of the robot can also help to track changes in cognitive development by the child, and may contribute to improved cognitive understanding (Cook et al., 2008).

Robots have been used successfully to allow children to participate in school-based tasks that would otherwise be closed to them. A prototype interactive robotic device was used by two groups of children, four in pre-school (2 to 4 years old) and five in elementary school (5 to 9 years old), all having moderate to severe physical impairments, and five also with cognitive delays (Karlan, et al,1988). Kwee, et al. (1998, 2000) adapted the Manus arm for use by children with cerebral palsy (CP) by altering both the physical control of the robot and the cognitive tasks required for control. The robot was used for various pick and place academic activities with six participants, 7 to 29 years old, all of whom had CP. The Handy 1 Robot, originally designed as a feeding aid, was adapted for use in a drawing task to allow children to complete assignments in class alongside peers with minimal assistance (Smith and topping, 1996). A specially designed robot for access to science lab activities was trialed with seven students aged 9 to 11 years who had physical disabilities (Howell and Hay, 1989). Access to the science and art curricula for students, aged 10 to 18 years, who had arthrogryposis, muscular dystrophy, and CP was evaluated with a multi-purpose workstation called the ArlynArm (Eberhart et al., 2000).

Robotic Systems

A robot is defined as “An automatically controlled, reprogrammable, multipurpose, manipulator programmable in three or more axes, which may be either fixed in place or mobile for use in industrial automation applications." (International standard ISO 8373). Robots can be used with children who have disabilities in one of two ways. First, the robot can be trained to carry out a movement and the child merely replays the movement by hitting a switch. Examples of playback robot control that we will discuss in following sections include: using a Mini-mover robot to evaluate tool use by infants, using a Rhino robot to develop sequencing skills and using a Lego roverbot for drawing and other tasks.

The second type of robot use is to allow the child to have direct control over the robot movements. For a car or other vehicle this involves turning (left/right) and movement (go/stop) using multiple switches. For a robotic arm the child controls three dimensional movements (up/down, rotate left/right, grip open/close). In all cases the controlled functions are allocated between robot and child. The three robots used in our work are shown in Figure 1.

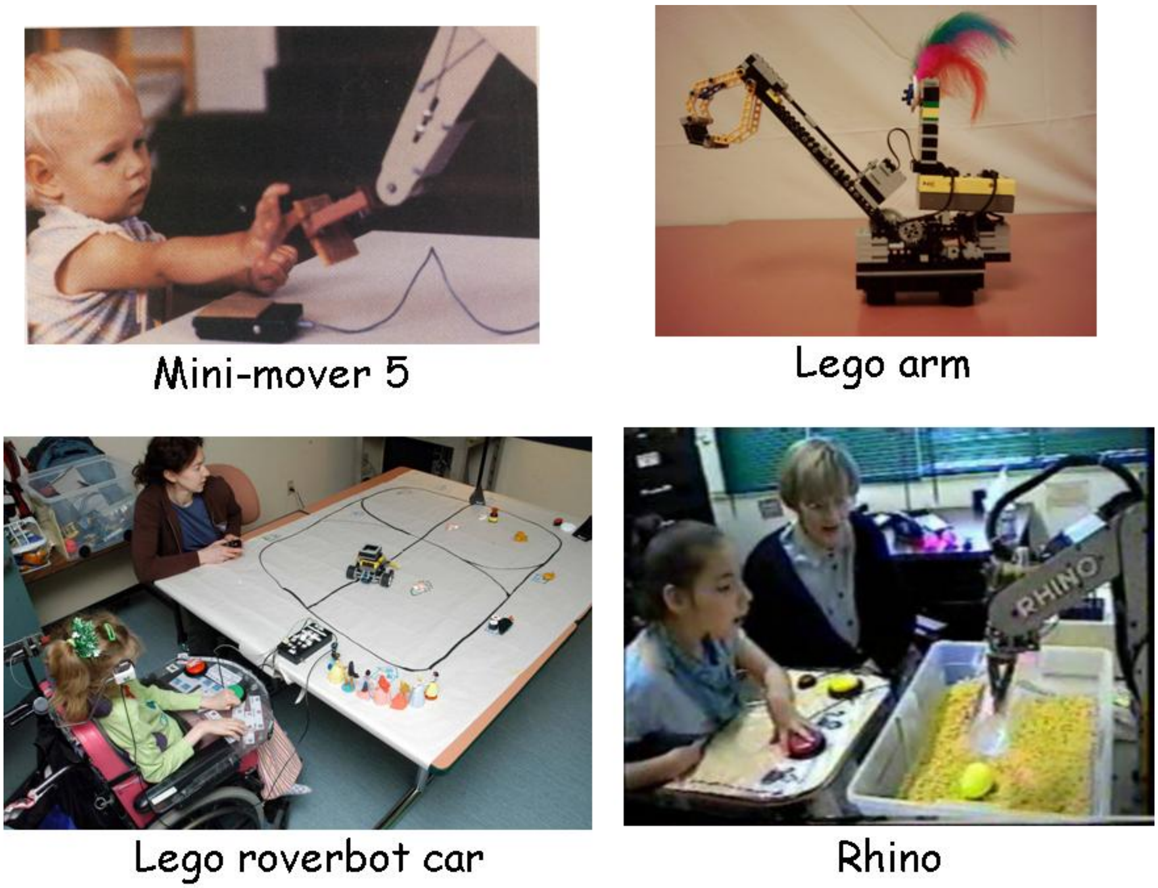

Figure 1 robots used in studies with children who have disabilities

Tool Use by Infants via Minimover

The MiniMover robot arm (figure 10 was used with young children aged 6-18 months in a direct control task in one dimension. The robot arm held a cracker. When the child pressed a switch the arm moved it closer, and when the child released the switch the arm stopped moving. Reaching for the cracker and then pressing the switch when cracker was out of range was taken to mean the child was using the robot as a tool to bring the cracker closer. This conclusion was also supported by observed behaviors such as point of visual regard (e.g., looking at the arm, then looking at the switch, then pressing the switch, then looking back at the arm expecting it to move) and affect (smiling, crying, laughing) during task (Cook et al, 1988).

Participants were typically developing children and children with disabilities in a pre-school setting. An infant development scale (Bayley Developmental Scale) was used to asses the cognitive age of the children. All typically developing children whose age was greater than eight months used the robot arm as a tool and younger children did not. All children with disabilities who had a cognitive age greater than eight months also used the arm as tool.

Sequencing Task via Rhino Robot

The Rhino robot, shown in figure 1, is a six degree of freedom arm designed for educational applications. We used it in a three task sequence (Cook et al, 2005). Each step of the sequence used a single switch. The first switch controlled the first task, which was to dump macaroni from a glass. The second task was to do two steps: (1) dig an object out of the macaroni, and (2) dump the macaroni and object using a separate switch for each step. The third task consisted of a three step procedure for the child: (1) press a 3rd switch to position robot arm for digging (using up to 8 steps), (2) dig an object out of the macaroni, and (3) dump the macaroni and object using a separate switch for each action of the arm.

Twelve children with severe physical disabilities participated in the study. All of them had experience using single switches to operate toys and to access computer games. None were able to engage in container play independently or with another child or adult without some adaptation. For many of the children consistent switch access was generally not established. Their cognitive and language skills were not possible to assess. The ages were from 5-10 years old.

There were two study objectives:

1. To evaluate how children with severe physical disabilities can physically control a robotic arm to engage in functional play tasks,
2. To determine the impact of the use of a robotic arm on children's behavior and social and academic performance

In order to evaluate Objective #1, Goal Attainment Scaling (GAS) (Kiresuk, et al., 1994) was used. Five levels are assigned: expected result (value=0), two better (+1,+2) & two worse (-1,-2) performance levels. A numeric T-score was calculated to determine changes in performance:

$$T = 50 + 10 \cdot \frac{\sum_{i=1}^{n} g_i}{\sqrt{n - R \cdot n + R \cdot n^2}}$$

Where:

T = 50 is the expected outcome
g_i = goal rating score (-2 to +2) for the i^{th} goal
n = number of scales
R = 30 (a constant reflecting the estimated inter-correlation for scores on multiple goals)

Examples of GAS Scales are shown in Figure 2.

Score	Scale #1: Play	Scale #2: Interaction	Scale #3 : Binary operation
-2	Unresponsive	Task #1 w/ assist	Does not initiate
-1	Plays if adult initiates	Tasks #1&2 w/ assist	Initiates doesn't terminate
0	Spont. Play w/adult	Three tasks W/assist	1 switch left, 1 right, auto stop
+1	Initiates play	2of3 tasks independent	1 switch left, 1 right, child stop
+2	Independent play	All three independent	2 switch L/R or forward /back, stop

Figure 2: Examples of GAS Scales

	Mean	Max	Min
Initial T	32.50	40.87	27.18
Final T	53.42	68.26	31.74
Difference	20.92	31.95	4.56
paired T	0.0009		

Figure 3: Summary data for Goal Attainment Scale ratings

Figure 3 shows the aggregated T scores for the twelve subjects. All twelve participants showed an improvement in performance for all the goals. Most of the participants also increased in other areas such as vocalizations and attention to tasks. Some of these effects carried over into the classroom.

To evaluate Objective #2 a set of open-ended questions were used with the teacher to provide insight into child's social and academic performance before and after using the robot. The primary themes form the teachers were:

- Children’s reactions to robot were very positive
- Robot tasks were more motivational (generated more interest and excitement) than single switch tasks with toys, appliances and computer-based activities
- Vocalizations increased during & after robot use

- Teachers initially thought that researchers had overestimated the skills of the children in selecting them for this project

At the end of the study, teachers were surprised at the level of accomplishment of the children, commenting:

- "Smiled and got excited when robot mentioned in class or at home."
- "[student] had more vocalizations in class, and was more interactive after robot use."
- "Robot gave [student] something to look forward to and become excited about."
- "[student's] confidence and interaction increased, he looked forward to the sessions."
- "[Student] used new symbols in class and interaction increased."
- "On the way to robot [student] anticipated what was going to happen; her ability to control robot increased [student's] self esteem."

This study is reported in more depth in Cook et al (2005).

Switch controlled Lego MindStorms Study

We used the Lego MindStorms robots shown in Figure 1 in a study that included both playback and direct robot control. The study question was:

> Can low cost robots provide a means by which children with severe disabilities can demonstrate cognitive understanding of cognitive concepts?

A group design was used with ten children ranging in age from 4 to 10. Their disabilities were primarily cerebral palsy and related motor conditions. The children had widely variable motor, cognitive and language abilities. All had complex communication needs and were non-speaking. The Lego Invention[1] "roverbot" vehicle and robotic arm were used.

The initial tasks were used to establish whether the child had an understanding of the switch operation of the robot. A single switch was used in the playback mode to activate pre-stored movements. Some example movements were: using one switch to make a robot dance, using one or two switches to draw circles or using two switches to knock over blocks. After establishing basic understanding, direct control was used to control the roverbot to turn (left/right) and move (go/stop) using four switches. For some children the switches were accessed with hand movement and for others it was a combination of hand and head movement. Based on analysis of cognitive skills for robot use a set of tasks was developed for the child to carry out. Each task required cognitive skills of varying levels of complexity, and they provided an alternative to standardized tests for evaluation of cognitive components of tasks. Using a comparison to robot use by typically developing children of varying ages (Forman, 1986), a set of cognitive skills required for robot use by typically developing children has been developed. The five skills assessed with typically developing children are: Causality, coordination of multiple variables, reflectivity, binary logic, and spatial relations.

This set provides a guide for comparison of performance by children with disabilities performing robot tasks to that of typically developing children of differing ages. Table 1

	Skill	**Definition for robot use**	**Age Considerations**[1] (typically developing children)	**Lego Robot Examples**
0	No interaction	Child displays no interest in the robot or its actions	NA	NA
1	Causality	Understanding the relationship between a switch and a resulting effect	<3 action is in switch, tried to use disconnected switches >4 yrs understood switch made robot move	Use switch to drive robot, knocking over blocks with robot, drawing circles on paper by holding a switch down and turning robot
2	Negation	An action can be negated by its opposite	4 yrs: begin to understand that switch release stops robot	Releasing switch to stop robot
3	Binary Logic	Two opposite effects such as on and not on	5-6 yrs: understood 2 switches with opposite effects.	2 switches turning robot right/left, or go and stop
4	Coordination of multiple variable Spatial concepts- multiple dimension	Movement in more than one dimension to meet a functional goal	age 5: Could fine tune a movement by reversing to compensate for overshoot, etc	Moving roverbot to a specific location in two dimensions
5	Symbolic Play	Make believe with real, miniature or imaginary props (Musselwhite, 1986)	6 yrs: Child ID action in robot not switch, planning of tasks is possible	Interactive play with pretense, i.e. serving at tea party, exchanging toys with friends , pretending to feed animals all using robot
6	Problem solving	Problem solving with a plan - not trial and error, Generation of multiple possible solutions	7 yrs. Designed robot and thought about coordinated effects, planning was possible, Can understand simple programs and debug	Changing strategies to solve a problem such as avoid an obstacle, Changing task to meet the child's own goal, simple programming

Table 1: Robot skills related to development of cognitive skills. (from Cook et al, 2008)

shows how the cognitive skills are related to robot tasks and how the skills progress as the typical child develops. This study is reported in more depth in Cook et al (2008).

Integrated AAC and Play

There is evidence that robotic play may help children acquire motor, cognitive, and social skills, and the goal of this study was to investigate the feasibility of integrating

[1] From Forman (1986)

spontaneous robotic play and communication. There were several limitations in previous Lego robotic play studies. First, children have to turn away from alternative and augmentative communication (AAC) devices in order to play. Another problem is that it can be difficult to find six switch access sites required for full robotic control for children with severe disabilities. The use of an AAC device opens up the possibility of alternative access strategies such as a touch screen, scanning, and manipulation of a cursor through head or eye pointing.

To investigate effective methods to integrate robotic play and communication, a testing platform was developed along with several integrated communication and robotic play interfaces. The following research questions were addressed:

- What is the best way to integrate language for communication and commands for the full range of robotic control for Lego roverbot and arm on the computer interface?
- Will children use the robot more frequently than directing someone else to play?
- Will children speak with the device more frequently when communication buttons are available to them on all pages?
    - At what age do children understand “playback” versus “direct control” of the robot?

A tablet computer (Sahara) installed with the ATCreator software (Madentec Ltd) and the RedRat two-way infrared controller (RedRat Ltd) for IR output was used for the study. Input from the user was via the touch screen of the computer. A set of user interface displays were developed to evaluate the research questions.

In order to get expert advice on how the interface should look and behave and make iterative design modifications based on their feedback, the interfaces underwent usability testing by five "expert" users (speech-language pathologist (AAC), rehabilitation engineer (computer access), psychologist (human factors) and psychologist (pediatrics)). A detailed heuristic evaluation was applied to the interfaces using a Usability Checklist that was based on the Xerox Heuristic Evaluation Tool. The checklist was completed independently by two investigators with consensus on subsequent interface modifications. Based on this evaluation the modified interface was evaluated with two groups of children. Six children without disabilities female age 3, male aged 3, female aged 5, male aged 5, male aged 7 and female aged 8. Three children with disabilities, two male aged 5, one female aged 5, all used a key guard to avoid mis-hits on the tablet computer touch screen.

The results showed that children prefer to do activities using the robot rather than directing another person to do it and that they will spontaneously talk using the AAC device during play. The platform provided a means to examine the best ways to present information (pages, links, symbols) for finger-pointing users, but requires testing with scanning users.

A 27 year old AAC user with complex communication needs, who uses an AAC device via direct keyboard access, summed up the situation for many children with complex communication needs: “This is my first actual time playing with stuff. [Before] I just watched my sister play [with] her toys.”

This study was valuable to explore AT usability testing procedures, to test automated data collection tools, and establish materials and methods. Limitations of the testing platform were that it was not populated with much vocabulary and it was unstable.

Lego Robot Control via an Augmentative Communication Device for Play and Educational Activities

An integrated communication and robotic control system was used by a child with disabilities to play games and do educational activities. The system incorporated the child's own AAC device (AAC) and access method, and infrared controlled Lego robots (see Figure 1). The purpose of this case study was to evaluate the feasibility of using an integrated communicative and robot control system to achieve educational goals. Goal attainment scaling (GAS) was used to measure progress towards goals[2].

The participant was a 12 year old girl who had cerebral palsy with severe physical and communication limitations. She used two switch step row-column scanning with one switch on each side of her head. The SGD was a Prentke Romich Vanguard, with Unity 45 Full vocabulary set. AAC pages were created for integrated communication and robot commands.

Several activities were used to develop skill in using the robot. The participant connected dot-to-dot drawings using a pen attached to the roverbot. She also followed a path with greater and greater complexity as she developed her skill at controlling the robot. The participant also used the robot to orient a puzzle piece for insertion by the research assistant. Educational goals were set in math and social studies classes.

The math goal score was scaled according to the numbers understood, and the social studies goal score was scaled according to the level of writing support required to write the narration of a Greek myth. The Greek myth Theseus and the Labyrinth was uploaded the to the participant's AAC. She then acted out the story by moving the roverbot (Theseus) and the robot arm (Minotaur) through their positions, while saying their lines using her AACvoice output. She and the research team created a movie. After showing the movie to her classmates, a classmate said: "I wish I did that with my robot".

The math GAS score did not increase because the goal was not reflective of her initial level of performance, and the social studies GAS score could not be measured as written. Although the participant's GAS scores did not increase, the robotic control system offered the participant a means for integrated communication and play. She also accessed educational materials and engaged in active learning of the curriculum content. Her teachers were pleased with the intervention, reporting that the participant demonstrated her abilities and connected with the curriculum and other students.

The participant achieved an increased operational goal score by demonstrating the required accuracy in the pathway tasks. The participant's communication goal to increase her length of utterance was not successful, likely due to lack of opportunity and supports and the tradeoff between operating the robot and communicating. The participant's teacher states that her work with the robot has improved skills with her SGD in daily communication

Conclusions

The use of robots gives the child a chance to demonstrate a range of cognitive skills and provides a versatile tool for presentation of tasks, problems and learning opportunities to the child. The robotic system can avoid the limitations of standardized test administration, such as verbal response or physical manipulation of objects. Integration of robot control and play activities also enhances participation and interest for the child. Finally, the use of AAC devices to control robots for play and academic activities is effective in increasing communicative interactions and enhancing motivation and interest by the student.

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