Assistive Technology Lab
3-59 Corbett Hall – University of Alberta Edmonton, AB T6G 2G4
Ph: (780) 492-5422 Fx: (780) 492-1696 Email: atlab@ualberta.ca

Alberta Health Services

Published citation:

Adams, K. D., Alvarez, L., & Rios-Rincon, A. M. (In press). Robotic systems for augmentative manipulation to promote cognitive development, play, and education. In A. Cook & P. Encarnação (Eds.), Principles and Practice of Rehabilitation Robots. Novato, CA: CRC Press.

Robotic systems for augmentative manipulation to promote cognitive development, play, and education

Contributors: Kim Adams, Liliana Alvarez, Adriana Rios
Acknowledgements: Javier Castellanos and Maria Gomez

Learning objectives

Upon completing this chapter the reader will be able to:
1. Discuss the importance of manipulation in child development and the potential of robotic systems to enable augmentative manipulation for children with motor impairments.
2. Apply an assistive technology model for using assistive robotic systems in cognitive assessment, play and or education.
3. List the purposes for which different types of robotic systems are currently used for augmentative manipulation in the literature, pertaining to cognitive development, play and learning for children with motor impairments.
4. Describe evidence that supports the use of robotic systems for augmentative manipulation for the assessment and/or development of cognitive skills, play, and learning.

Case studies

Three case studies of children with motor impairments will be used to examine these learning objectives.

Case study 1: Joseph - cognitive assessment need

Joseph is a 4-year-old boy with Pelizaeus Merzbacher disease (PMD). PMD is one of several rare diseases, commonly known as leukodystrophies, due to the disruption in growth and maintenance of the myelin sheath around the axons of a neuron (Kohlschütter & Florian 2011). Joseph has a special seating system in a manual wheelchair, but he does not propel the wheelchair himself. In addition to having spasticity, Joseph has nystagmus (rapid involuntary movements of the eyes). He is non-verbal, and the extent to which his cognitive skills are compromised remains undetermined. His parents are convinced he understands and knows more than what his paediatrician believes, as they can see him interact with them via non-verbal communication, such as smiling. His occupational therapist (OT) has found it difficult to locate an age-appropriate cognitive test that can provide some insight into Joseph's cognitive skills. For the most part, age-appropriate cognitive tests require the child to respond verbally (e.g. answering a question) or motorically (e.g. by creating a tower of blocks). Thus, none allow Joseph to demonstrate what he knows. The OT continues to explore ways for Joseph to demonstrate his cognitive skills, and work on improving them.

Case study 2: Juan - play need

Juan is a 6-year-old boy with spastic athetoid cerebral palsy which affects all four limbs, resulting in severe physical limitations in reaching and grasping. He has a paediatric manual wheelchair with a positioning system. He is not able to propel the wheelchair by himself so his mother usually pushes his wheelchair. There are no issues with Juan's vision or hearing as reported by his family and therapists. Juan recognizes and can say a few colors and shapes, and a few familiar animals and objects. He is not able to read or write. He is able to follow three-step directions. Juan has limited spoken language, so he tries to communicate in other ways using nonverbal communication such as laughter, head nods and shakes, and words and phrases to express himself; however, sometimes people around, even his mother, find it difficult to understand what he is saying.

Juan lives in a low-income country and his family belongs to a low social economic strata. Juan lives with his mother, his aunt, three cousins (an 11-year-old boy, a 9-year-old girl, and an 11-month-old boy), and his grandparents on the second floor of a two-storey house. He attends a rehabilitation institution every morning where he receives physiotherapy, occupational therapy, speech language pathology, and special education services. Juan does not yet attend school, but his mother is looking for one.

Juan's favourite activities are watching movies and listening to music; his favourite place for playing is sitting in his wheelchair. His least favourite activity is grasping toys, as reported by his mother. When Juan plays with his mother she reads him story books and cuddles him; if the play involves toys it is she who chooses the toys to play with. She tends to decide how to play with those toys and to initiate play themes.

Case study 3: Julia - education need

Julia is a 10 year old girl with spinal muscular atrophy which affects all four limbs leading to severe physical limitations in reaching and grasping. She has a power wheelchair with a custom seating and positioning system. She controls her wheelchair using a joystick located at her right hand. Her desk is customized with a slot for her joystick, so she can drive up to the desk. There are no issues with Julia's vision and hearing, as reported by her teacher. Julia is verbal. She uses an iPad mini™ attached to her wheelchair and positioned directly in front of her using a Modhose iPad Adjustable Cradle™ mounting system. Julia moves her right finger supported by her left hand to access the iPad. She cannot press hard enough to engage the home button, but she can press the iPad screen, as long as it is positioned within her range of motion.

Julia is in an integrated grade four classroom, and studies the same curriculum as her classmates. An educational assistant provides academic and personal assistance to Julia and other students in the classroom. Julia's education assistant or the other students in class perform most manipulation required in the school activities. Julia's teacher would like Julia to have hands-on experience manipulating the objects the other students are using to make arrays in order to practice the concept of multiplication.

Principles

Independent manipulation is instrumental for children's cognitive development and it enables participation in play and academic activities. It also provides a way for demonstrating acquired skills, which is important since, typically, new opportunities for cognitive development will be available only if adults acknowledge that previous milestones were reached.

Cognitive Development

Children develop cognitive, perceptual and social skills through motor experience (Flanagan, Bowman, and Johansson 2006; McCarty, Clifton, and Collard 2001). Object manipulation, a critical aspect of motor experience, enables the child to acquire the skills required for learning, emergence of symbols, referential communication and the understanding of relations between objects (Affolter 2004; Bates 1979; Greenfield 1991; McCarty, Clifton, and Collard 2001; Piaget 1954).

Emerging before locomotion, object manipulation is the first means through which the human infant acts on the world. For the first nine months of their life, human infants rely solely on manipulation for independent interaction with the world (Vauclair 1984). Object manipulation also serves as indication that early milestones of cognitive and perceptual development have been reached (Lockman 2005; Vauclair 1984). Through object manipulation, a child progressively starts to relate to objects, explore their properties, and discover how objects can be used to achieve a goal (i.e. tool use, a landmark cognitive skill in infancy) (Lockman 2000). For example, 18 month old children can choose which hand to use and how to change their grasp when self-feeding, if the spoon is placed in an awkward orientation inside a bowl (Keen 2011; McCarty, Clifton and Collard 1999). The use of objects as tools extends the capability of the child and enhances his interactions (St Amant and Horton 2008). Thus, tool use has been studied from several cognitive theory approaches. Among these theories, perhaps one of the most influential in the field of child development research is Piaget's (1950) genetic epistemology. Piaget's observations of children's behaviours led to the definition of four stages of cognitive development that have been used to further explore and understand cognition in children (Solaz-Portolésa and Sanjoséb 2008). According to Piaget, the relation between motor experience and cognitive development starts with the sensorimotor stage (Piaget and Inhelder 1969). The sensorimotor stage takes place during the first two years of life and is critical for the achievement of cognitive milestones such as object permanence and means-end analysis. During the first two years, the child actively manipulates objects, explores them individually and sequentially, and finally realizes that one object can be used as a means to reach the other (Piaget 1954). For example, a child can use a stick (McCarty, Clifton, and Chollard 2001) or a string (Chen 1997) to retrieve an object out of reach. Other approaches and contributions to the study of cognitive development differ in how and to what extent they emphasize the influence of cultural and social interactions on development (e.g. Vygotsky, 1978). However, there is wide spread agreement regarding the critical role of motor experience on the cognitive development of children.
Because of the strong relationship between motor skills and cognitive development, early studies suggest that a lack of motor experience can result in cognitive and perceptual delays (Bertenthal and Campos 1987). The assessment of cognitive skills throughout childhood relies heavily on the

child's motor and verbal skills as avenues for demonstrating or explaining concepts, or engaging in problem solving. Thus, children with physical disabilities can lose opportunities to demonstrate their skills or learn and develop new ones.

Much as powered mobility provides children with physical disabilities with opportunities for independent mobility, robots with adapted interfaces can provide children with motor impairments with opportunities for independent manipulation of objects (Alvarez, Cook, and Darrah 2016). Children with disabilities can accomplish manipulative tasks through the use of robots because robots compensate for their functional limitations by decreasing the motor demand of the task (Alvarez 2014). Given that the motor requirements to control the robot can be minimal and can be adapted to a wide range of possible anatomical control sites (Poletz, Encarnação, Adams, and Cook 2010), robots can be used as a tool to explore the cognitive skills of children with disabilities. Through robots, children with severe motor impairments can demonstrate what they know, and can further benefit from independent interaction with objects (Alvarez, Cook, and Darrah, 2016).

Play

Play is one of the occupations of human beings (American Occupational Therapy Association 2014). While work and activities of daily living are defined and labelled by external social conventions, play is defined only by the player's perception (Bundy 1993). This means that an activity is play if the individual's feelings are related to pleasure, flexibility, spontaneity, intrinsic motivation, choice, challenge, internal control and creativity (Blanche 2008; Skard and Bundy 2008). Parham (2008) reviewed the characteristics of play and proposed that the most common features that have been reported in the literature for play are: 1) intrinsic motivation; 2) process oriented, because play emphasizes the process rather than the product; 3) free choice, because the player is free to choose to play; 4) enjoyment and pleasure; 5) active engagement, because the player is active; and 6) non-instrumental, or not "serious", which is related to the pretend element of play. During play children learn about the properties of objects and how to interact with objects and people (Reilly 1974). Play where the child interacts with people is called social play (Coplan, Rubin, and Findlay 2006), and play where the child interacts with objects is called object play (Gowen, et al. 1992). Both types of play interactions have important benefits for children's development, which occurs in a natural way. Play follows three stages of development driven by cognitive development: **functional** play, **pretend** or **symbolic** play, and **games with rules** (Piaget, 1951). Functional play is the type of play where a child uses the objects according to the function designed for them and as they would be used in reality (e.g. a ball is used as a ball) (Barton 2010). Pretend play, or symbolic play, is a cognitive play skill of representing knowledge, experience and objects symbolically (Stagnitti and Unsworth 2004). In pretend play the child uses an object as if it was a different object (e.g. using a block as if it was a car) (Barton 2010). Games with rules involve more structured play, play activities having rules that need to be followed by each player. Thus, at this stage, play also takes on a social aspect (Piaget, 1951).

Play is an ideal way for children to discover the world through practice with different objects and experiences (Ferland 2005). In fact, innovative problem solving occurs during play (Sutton-Smith 2001). However, children with motor limitations, for example children with cerebral palsy (CP), have difficulties engaging in play (Blanche 2008; Missiuna and Pollock 1991) especially play with objects. Due to their physical limitations, children with CP have constraints in engaging in pretend play (Pfeifer et al. 2011), object play (Gowen et al. 1992), and expressing

playfulness (Chang et al. 2014; Harkness and Bundy 2001). Children with CP and their families spend more time in activities related to self-care (including rehabilitation) than do typically developing children. This reduces time for family play routines (Brodin 2005; Hinojosa and Kramer 2008; Missiuna and Pollock 1991). With few opportunities for practicing and testing their skills, children can develop a learned helplessness; that is, children assume that they are unable to perform a task by themselves even though they have the required physical abilities (Harkness and Bundy 2001). All of these situations delay not only the child's play and development, but also future overall functioning (Missiuna and Pollock 1991).

The need for interventions focused on promoting play in children with motor impairments has been widely stated (Blanche 2008; Chang et al. 2014; Ferland 2005; Missiuna and Pollock 1991; Pfeifer et al. 2011; Rios et al. 2016). Scholars agree that intervention should improve the play experience in a child's life and involve the child's family (Blanche 2008; Brodin 2005; Ferland 2005; Hinojosa and Kramer 2008; Rios et al. 2016). Promoting engagement in free play in children with motor impairment may impact children's overall functioning. Playfulness is an indicator of self-determined behaviors for children with CP with limited self-mobility. Children who are self-determined present behaviors oriented towards meeting personal life goals; these behaviors include identifying desires, actively pursuing interests, making decisions, and solving problems (Chang et al. 2014). This suggests that increasing playfulness may improve children's ability to find creative strategies to make choices, and to solve problems (Chang et al. 2014), which in turn can improve their future functioning in home, community, school, and work contexts.

Education

Education programs of study, for instance in mathematics (Van De Walle, Karp, and Bay-Williams 2010) or science (McCarthy 2005), emphasize the integration of hands-on activities while communicating about concepts. Learning and retention can be improved when actively participating in direct purposeful experiences as opposed to watching demonstrations (Petress 2008). Being actively engaged in classroom activities contributes to children's motivation to learn (Schunk, Meece, and Pintrich 2012).

Children who have physical impairments often cannot engage in academic activities due to limitations in pointing, grasping, or holding the manipulative objects used in the lessons (Eriksson, Welander, and Granlund 2007). Unfortunately, children with physical disabilities may miss the hands-on component of learning, or they may observe their classmates or an educational assistant perform the steps involving manipulation of objects. Increasing the active component of the learning experience for children with disabilities by providing access to manipulation and communication should have a large impact on a child's education.

There is some assistive technology for manipulation in the classroom, for example, a child can use a switch connected to a battery interrupter (Mistrett and Goetz n.d.) to activate electric scissors while a non-disabled student cuts out pictures for an art project. However, these simple tools cannot provide help to involve students with disabilities once school activities become more sophisticated. Children can direct others to do parts of the activities, for example telling a classmate which objects to measure (Schlosser et al. 2000). However, it can take a long time to give instructions. There are specialized computer programs for students with disabilities to practice language arts and mathematics concepts, for instance, Intellitools distributed by Mayer

Johnson[1]. These tools, when available in a classroom, can be very useful to actively engage in learning concepts. However, because they are screen-based, these activities do not give access to the physical world, and many early learning lessons use real-world physical objects in experiments.

Robots as augmentative manipulation tools can be beneficial for children with physical disabilities to interact with the same objects as their peers in the classroom. Children with severe disabilities have used robots as a tool to do various learning activities (described below), and robots have been found to be more motivating than single switch appliances or computer programs (Cook et al. 2005; Howell, Martz and Stanger 1996; Plaisant et al. 2000). Developing robots that can be used for augmentative manipulation in education activities can contribute to the hands-on learning of children with physical impairments. Effect of others on children's exploration, play and learning

The lack of meaningful opportunities for exploration and manipulation may be impacted by the perceptions of clinicians, parents and teachers who limit the number and type of opportunities they afford to the child. Parents of children with physical disabilities often perceive their child as seeking more adult approval and help, being less motivated and preferring very easy and familiar tasks (Blanche 2008; Jennings and MacTurk 1995). This can have an effect on exploration experiences of children, for example, mothers may encourage less exploration by their children with disabilities than mothers of typically developing children with the same cognitive capacity (Jennings and MacTurk 1995).

Parents of children with disabilities have no clear role in children's play (Brodin 2005); that is, parents do not know clearly whether they should take play as an opportunity for training their child in specific needed skills, or whether play should be an opportunity for enjoyment that they should facilitate (Brodin 2005). Generally, caregivers and playmates dominate the play so that children with CP become more a spectator of other's play rather than an active player (Blanche 2008; Brodin 2005). This was seen in a study where mothers of children with severe CP generally decided what to play and how to play when playing with their children (Rios et al. 2016).

Low expectations of teachers can prevent children from thriving in the classroom. Adults who had speech and physical impairments were critical of the special education they received, saying the expectations were not high enough (McNaughton, Light and Arnold 2002). Several studies have shown that teachers' perception of the abilities of children with disabilities has increased after seeing children's skills when they use robots in playful or academic activities (Cook et al. 2000).

Requirements for robotic systems as augmentative manipulation assistive technologies for cognitive development, play, and education

Robots can be used as augmentative manipulation systems due to their capability for picking, placing and exploring objects (Tejima 2000). Among the assistive technologies available for

[1] http://www.mayer-johnson.com/intellitools-classroom-suite-v-4

manipulation for cognitive assessment, play and academic activities, robots are flexible in interactions with the environment; they can do more than one repetitive action, and they can manipulate three-dimensional objects in the real world (Cook et al. 2000; Cook et al. 2002). However, using the robot as a tool is not the same as manipulating objects with one's hand. Action mediated by a tool can add additional cognitive demands to the task (Keen 2011) that, in the case of augmentative manipulation, can result in poor robot operational competence, which can be confused with poor performance on the task. For example, to perform the robot mediated tasks in Poletz et al. (2010), children need to understand that pressing the switch causes the robot to move in a certain way or that when using two or more switches the robot can move in sequences that gives the child more control over the step by step movement of the robot (Cook et al. 2005; Poletz et al. 2010). Thus, robots may decrease the motor demand while at the same time increase the task's cognitive complexity. It is critical to understand the additional cognitive and perceptual demands that the use of the robot imposes on the child. On one hand, this can guide the selection and adaptation of human-robot interface. On the other hand, robot characteristics and programming can be adapted to match the needs and skills of the child as well as the task and goals.

A theoretical approach to the assessment and quantification of the complexity of children using the robot as a tool, rather than directly manipulating an object with their arm and hand, has been explored in (Alvarez, Adams and Cook 2016). The complexity number hypothesis, first proposed by Van Leeuwen, Smitsman and Van Leeuwen (1994) for common tools, was used to assess the complexity of a robot mediated task performed by an infant with a disability; and this was compared with the demands encountered by a typically developing infant when using a common tool. Through this approach, the authors established that, from a cognitive and perceptual perspective, there is an increase in complexity of robot-mediated activities over that of simple tools. Far from discouraging the use of robots by young children with disabilities, the complexity of robotic augmentative manipulation systems further supports the fact that by the very interaction with robots, children with physical disabilities can display and develop cognitive skills.

A survey of commercially available robots from $250 to $500 was compiled and compared to desirable characteristics of robots for cognitive development, play, and education of children with disabilities (Cook, Encarnação, and Adams 2010). Characteristics included being flexible, robust, safe, easy to use and learn, portable, aesthetically pleasing, reasonably priced, an appropriate human-robot-interface, and provision of various levels of control. Their cost, bulkiness, and non-playful appearance, eliminate assistive robotic manipulators like the ones described in Chapter 3 as candidates for the applications considered here. The review in (Cook, Encarnação, and Adams 2010) revealed no commercially available robots that were entirely suitable for use by children with disabilities, but the Lego Mindstorms or the Fischertechnik Robot Explorer™ were found to be appropriate as long as the needed adaptations for an interface to accept children's alternate physical abilities were made.

Critical factors involved in the use of the robots by children to support play have been identified in (Besio 2008): factors related to play (functions of play, types of play); factors related to the individual according to the International Classification of Functioning - Children and Youth Version (ICF-CY); factors related to the context according to the ICF-CY; factors related to technology and robotics (approach to technology development, usability, quality of life and characteristics for autonomous and safe play); and factors related to methodology. Usability considerations (accessibility, universal design, and innovation) and functional aspects of the

technology (communication and social interaction, manipulation and mobility) are discussed (Besio, 2008). Usability of assistive robots is a major concern (Tsun et al. 2015), especially when considering their use by children who have physical impairments, and perhaps concomitant cognitive impairments or delays. Children's success in understanding the use of a robot depends on the flexibility of the robotic system, not only in terms of the degrees of freedom but also related to the capacity of the robotic system to be adjusted to different levels of cognitive demands and motor impairments for the child.
The human-robot interface (cf. Chapter 2) should accommodate the abilities of the child with disabilities. A complete review of the many different ways to access assistive technology, along with a framework for control interface decision making, is presented in (Cook and Polgar 2015). Many of the typical interfaces to assistive technology (e.g. keyboards, joysticks, head gimbals, eye gaze, voice control or switches) can also be used to control robots. For children with severe disabilities, finding as many avenues of input as possible, may be beneficial. However, these additional input channels need to be balanced with keeping the methods of control intuitive. Another issue is that the interfaces can be cognitive demanding. For instance, using **scanning** with switches requires monitoring the options being presented to the user, correctly selecting the desired option, as well as monitoring the robot. Eye tracking requires children to divert attention from the robot in order to make selections on a computer screen. Another factor to consider is how multiple activities might need to be controlled from the same interface. Controlling the robot from an **augmentative communication device** is one example of using the same interface for multiple purposes (Adams and Cook 2016a). There are other combinations that may be needed (e.g., electronic aids to daily living, wheelchair, mobile robot, and/or robot arm).
Similar to any other assistive technology, considerations above should be framed in a model that encompasses the user, the activity to be performed, the technology, the context of use, and the dynamic interactions between these (cf. the HAAT model described in Chapter 1). Depending on the complexity of the situation, a team of individuals may be involved in designing, developing, and implementing a robotic intervention. The knowledge and skills of different professionals may be beneficial in assessing needs and abilities of the children, demands in the environments, cognitive, play or educational goals, and related activities. Occupational therapists, physical therapists, speech language pathologists, rehabilitation engineers, psychologists, and teachers are potential team members. At the centre of the team should be the child and his/her parents, as they are the experts in the personal factors that will influence functioning of the system, for instance, what motivates them, preferences, and what is feasible in their environment.

Critical review of the technology available

Stationary and mobile robots have been used by children with disabilities in play and education. For instance, the CRS A465 (Figure 7-1) is a stationary industrial robotic arm approximately the same size as an adult human arm. It is able to 1) rotate about its base, 2) flex and extend at the elbow and shoulder, 3) extend, flex, supinate, and pronate at the wrist, and 4) open and close a gripper. Children operated a CRS robot through three switches to perform play activities (Cook et al. 2000). A Minimover 5 robotic arm, about half adult human scale, was used to bring a cookie closer, and was controlled by a switch (Cook, Liu, and Hoseit 1990) (that system is now available as the educational robot, Microbot Teachmover, Figure 7-2). Lego Mindstorms robots can be configured into "robotic arms" made of Lego pieces with a base, an upper arm, a forearm, and a gripper (Figure 7-3). This type of robot was used by a participant to drop, lift, and release a variety of small toys (Schulmeister et al. 2006). A robot arm was assembled from basic components and controlled by voice to pick up blocks and put them into shapes of letters (Lee 2013). Another type of robot, assembled from basic components, is a 3DOF (degrees-of-freedom) Cartesian configuration robot with a special gripper for grasping and inserting Lego bricks on a play area, also made of Lego bricks (Kronreif et al. 2007). The first version of this PlayROB system was called the 3DOF Robot system (Prazak et al. 2004). The PlayROB was controlled through a joystick, keyboard, pointing, and sip-puff input devices.

*** Insert Figure 7-1 about here ***

*** Insert Figure 7-2 about here ***

*** Insert Figure 7-3 about here ***

The most common mobile robots that have been used in play and education are Lego Mindstorms robots, which are made of Lego pieces and that can be configured like a car with wheels, sometimes with a gripper (Figure 7-4). These robots have been used in studies for the manipulation of small toys such as dolls, balls, toy cars, and wood blocks using a gripper or a scoop during semi-structured and free-play activities (Encarnação et al. 2014; Poletz et al. 2010; Rios et al. 2016; Schulmeister et al. 2006). Adaptations were necessary for children to operate the robots, such as the design of an infrared remote control adapted for single switch control of the Lego Mindstorms RCX robots (Poletz et al. 2010; Rios et al. 2016), or the use of a Don Johnston switch interface® connected to a computer with a program for controlling Lego Mindstorms NXT robots by BlueTooth (Adams, Ríos, Becerra, and Esquivel 2015; Adams et al. 2016). Computer-based augmentative communication software has been used to send commands to a program to control Lego NXT robots, via trackball and eye gaze (Encarnação et al. 2016). Another method to control the robots, which did not need customized hardware or software, was to train infrared commands for the RCX robot into a communication device (Adams and Cook 2014; 2016a). With this method, children used two switches in scan mode to select robot commands from their device display. A benefit of using communication devices and computers to control robots is that the same access method that children are used to for accessing the communication device or computer can be used to control the robot. Also, when children are severely impaired, they do not have many anatomical sites with which to control technology. Controlling a robot through a communication device or computer gives children access to robot movements and the other functions of the device or computer. A motivation for using a commercial Lego robot is that teachers, therapists and parents can easily acquire, build and program them, thus potentially leading to increased opportunities for play and academic activities.

*** Insert Figure 7-4 about here ***

Two low-cost robots are being developed in Brazil for grasping objects or drawing (Ferasoli-Filho et al. 2012). Directional control of the mobile robots is done by tilting the head, read by an accelerometer, and the gripper (or pen) is activated by muscle, read by an electromyography sensor. Robots like this are still in the development stage, but would be an important contribution for use in under resourced areas.

Programming the robots requires varying levels of technical expertise. The Lego Mindstorms software is easy to use, but can only be used to download programs to the robot to run autonomously. To control the robot in teleoperation mode, some technical programming is needed, and some researchers have made their software available (e.g., http://uarpie.anditec.pt/images/docs/user_manual_iamcat.zip and http://www.rehabresearch.ualberta.ca/assistivetechnology/resources/tools/). The programming

community sometimes makes available useful programs for common platforms, like the Lego robot, but they are not consistently available (for a list see (Adams and David 2013a)). Some robot projects have been designed with the long term goal of having an easy to use programming interface for parents and teachers (Ferasoli-Filho et al. 2012). Most robots used in studies with children with physical impairments have required programming skills to translate input from the user to movements of the robot (e.g., Microsoft Robotics Developer Studio in (Encarnação et al. 2016), Labview in (Adams et al. 2015), or microprocessor programming in (Lee 2013)).
None of the mentioned robots are commercially available as a package ready to be used by children with motor impairments. All of the robotic systems used to promote play and education in children with motor impairments are level seven or lower according to the Technology Readiness Scale (Department of Energy U.S. 2009). Some of them are prototypes that were completely developed by researchers and used in laboratory settings or real contexts such as schools or rehabilitation centers. This is the case of the robot arm (Lee, 2013), and PlayRob robotic systems (Klein et al. 2011; Kronreif et al. 2007; Marti and Iacono 2011; Prazak et al. 2004). These robotic systems demand the presence of a person with special training to deal with technical issues which constrains their use in family play routines or in educational settings. Other researchers have used and adapted some commercially available robotic systems such as the CRS A465 robotic arm (Cook et al. 2000) and the Lego Mindstorms robots (Adams and Cook 2014; Rios et al. 2016; Schulmeister et al. 2006;) in order to be used by children with motor impairments. The adaptations have been focused on the control interfaces. Most robotic systems have been used in laboratory environments or real contexts such as school or home, and the whole system is not yet available to be used in the real context by the end users, or there is only one prototype that needs to be adjusted for its use by the research team. The Lego Mindstorms robots are the only ones tested in children's homes and operated by children's families (Rios et al 2016).

Critical review of available utilization protocols

Utilization protocols to assess cognitive skills

The performance of children with disabilities when executing robot mediated play activities designed to elicit particular cognitive skills can be compared to the performance of typically developing children executing the same activities to provide a proxy measure for cognitive development. In (Encarnação et al. 2014; Poletz et al. 2010) typically developing and children with neuromotor disabilities at the age of three, four, and five years old were exposed to four tasks designed to challenge cause and effect, inhibition, laterality and sequencing skills. For each task, children were presented with a specific goal:

1) Cause and effect: children were asked to use the robot to knock over a tower of blocks. In order to successfully complete the task children needed to understand that pressing the switch caused the robot to move forward towards the blocks.

2) Inhibition: Children were asked to move the robot forward (as in the previous task) and stop at a specific point in the path to pick up a block. In order to successfully complete the task, children needed to understand that releasing, and thus inhibiting the pressing action that was previously successful, was required.

3A) Laterality: In this task, children were presented with the robot, facing forward, but located midway between two towers of blocks placed at the right and left sides. In addition, children now had three switches instead of one as in the previous tasks. Children were asked to select a tower to knock over, thus they needed to select the correct switch to make the robot turn and face the chosen tower.

3B) Sequencing: Complementary to task 3A, children needed to press the forward (middle) switch to complete the sequence by which they could knock over the selected tower.

Other robot mediated activities may be designed to elicit different cognitive skills. Piagetian tasks are often used to gain insight into children's cognitive skills through the child's verbal and/or motor responses. One example is a conservation task in which children are shown two identical containers filled with the same amount of liquid. After agreeing that they have the same amount, children are shown how the contents of one container are poured into a taller one. Children are then asked whether the containers have the same amount of liquid. Children who cannot yet conserve (typically under the age of 5) will answer no, and will identify the taller container as having more liquid. Piaget's conservation task is considered an important cognitive milestone, by which children demonstrate that they have reached the cognitive skills that allow them to discern amount from height, and focus on the content rather than the shape of the container. A child with physical and speech impairments may have difficulties in expressing his answer. A switch controlled robot can be used by the child to choose between the different answers by driving the robot towards the location his choice is positioned.

When designing activities to challenge different cognitive skills, it is important to keep in mind that they should be perceived by children as playful activities. In fact, if the activities are meaningless and unappealing to children they may underperform and fail to reveal their true cognitive development. Often the same activity is not engaging for all children and different activities requiring the same cognitive skills should be prepared to meet each child's preferences. For example, holding down a switch to drive a robot forward to knock over a stack of blocks, to take a flower to a princess, or to feed an animal, all require an understanding of cause and effect and a particular child might prefer one play activity over the others.

Robot training protocol

As mentioned above, indirect manipulation of objects by controlling a robot is not the same as direct manipulation using one's own hands. In studies where the task was too rigid or too challenging or the interface was too complicated, children had problems understanding how to operate the robot and became passive, frustrated, and uninterested (Besio, Carnesecchi, and Converti 2013; Kronreif et al. 2007; Marti and Iacono 2011; Prazak et al. 2004). Researchers have found that a training and practice period is necessary for children to understand how to operate the robot (Adams et al. 2014; Cook et al. 2000; Rios et al. 2016). This helps to ensure that children will have the operational skills to control the robot to do the activities. This way the teacher knows if the child is having trouble doing a play or academic task, it is likely due to not understanding the concept, not from not knowing how to control the robot. A protocol for training is available at (Adams and Encarnação 2011). The protocol is based on the basic cognitive robot skills above (Encarnação, et al. 2014; Poletz et al. 2010), and adds tasks with more complexity, like navigating a slalom course. It includes tests to track the child's progress at using the robot including the speed and accuracy of using the access method alone, and the speed and accuracy of using the access method to control the robot. For a discussion on the use of this protocol with nine children with neuromotor disabilities please refer to (Encarnação et al. 2016).

A framework to describe the competency skills needed to use communication devices to control robots has been proposed (Adams and Cook 2016a). It is based on the competency domains proposed by Light (1989) for using augmentative communication devices: linguistic, operational, social, and strategic competence. In the communication device-robot framework, linguistic competence is knowing what the robot commands will do (e.g. the difference between direct motor control and running a program from a button), operational competence is knowing how to activate the robot commands, social competence is using the robot to interact with others, and strategic competence is knowing when to switch between robot control and communication mode. This framework may also be useful for controlling robots from other types of devices that do not have communication output.

Utilization protocols to promote access to play

Researchers have designed structured and semi-structured play activities to be performed by children using robots. Structured activities have included, exploration and cooperative play with an adult. For instance, children were encouraged to hit three switches (using their heads, hands, or legs) in a specific order to perform three sequential tasks: pouring out dry macaroni from a glass, digging up objects, and dumping them into a tub with dry macaroni. The design of the activity promoted interaction and turn taking between the child and the researcher (Cook et al. 2000; Cook et al. 2002). Other researchers designed tasks to be performed by a child using a Lego Mindstorms mobile robot and robotic arm through switches. Tasks included: activating a song and dance program, making the mobile robot move forward in order to knock over a tower of blocks, dropping a variety of toys, lifting a toy into sight and, rotating the arm closer to the child followed by opening a gripper to release a toy. A prompt hierarchy was developed in case the child did not actively engage in the play activity that went from visual prompting (gesture) to full physical and verbal prompting (i.e. researcher hand over child's hand) (Schulmeister et al. 2006). Other researchers have had a different approach in which the robotic play activities are free-play oriented instead of structured play activities. Children who used the PlayROB were encouraged to freely explore the robot using it to build any structure they wanted with Lego bricks (Kronreif et al. 2007). However, in a second phase of the study, researchers oriented the activity towards a structured play activity. That could be because some participants did not understand the relationship between using the input device and the robot's actions during the free-play phase; thus, researchers felt they needed to train those children through structured activities (Kronreif et al. 2007; Prazak et al. 2004). Rios et al. (2016) designed a study in which mother-child dyads were encouraged to engage in free play with a Lego robot and the child's own toys. A resource manual was developed to support parents to use robots to promote learning in their children with disabilities though play activities at home. The robot activities are based on the cognitive skills required for operating a robot mentioned above, and encourage free play, too. The booklet is available at http://www.rehabresearch.ualberta.ca/assistivetechnology/resources/tools/

Utilization protocols to promote access to education

The most recent review of educational robots located was performed over 10 years ago (Howell 2005). The review presented a historical perspective covering early work from the 1980's which led to present day robots for activities of daily living. There were only two robots for augmentative manipulation in education activities mentioned in the review, and none of those systems is presently available (Harwin, Ginige, and Jackson 1986; Howell and Hay 1989; Howell, Martz, and Stanger 1996). From 1986 to 2000 there was some very good progress made in the area of robots in education (Eberhart, Osborne, and Rahman 2000; Harwin, Ginige, and Jackson 1988; Howell and Hay 1989; Howell, Martz, and Stanger 1996; Kwee and Quaedackers 1999; Smith and Topping 1996). The body of work was impressive in many ways. First, robot use moved out of the laboratory into classrooms and was tested with actual students, though primarily case studies with 1 to 7 participants. Children with various physical impairments, including arthrogryposis, and muscular dystrophy, and cerebral palsy (the most common) tried the systems. Second, some of the stationary robot arms used had very sophisticated vision systems and built-in intelligence (Harwin, Ginige, and Jackson 1988). Third, the researchers had accommodated severe physical abilities with a wide array of access methods, including switches (Howell and Hay 1989; Kwee and Quaedackers 1999; Smith and Topping 1996) and some systems were flexible enough to accommodate multiple methods since they were computer-based (Harwin, Ginige, and Jackson 1988; Howell 2005). Trouble using the access methods was a common concern (Howell and Hay 1989). Finally, the researchers undertook a number of varied academic tasks, most commonly science lab activities (Eberhart, Osborne, and Rahman 2000; Howell and Hay 1989) including sensory inspection (Howell, Martz, and Stanger 1996) and extinguishing a candle (Kwee and Quaedackers 1999). Other activities included drawing on worksheets to match questions and answers (Smith and Topping 1996) and sorting objects, picking and placing objects, and manipulating the discs for the Tower of Hanoi puzzle (Harwin, Ginige, and Jackson 1988). Unfortunately, the development of robots for manipulation of educational objects lost its momentum, and there has been very little research and development in the area lately.

The literature regarding the use of robots for augmentative manipulation by children with physical impairments in academic activities since 2005 is scarce, with only seven studies located. In these recent studies, several robot mediated educational activities have been performed, showing the flexibility of robots as tools for augmentative manipulation in the classroom. For example, to learn the English letters, children said a letter out-loud, and if pronounced correctly, a robot would build the letter in a typesetting plate and the letter would also be displayed on a computer screen (Lee 2013). The authors found that the ideal age where children were old enough to understand the system, but not too old to be bored, was 3 and 4 years old.

Being able to control a robot from a communication device to act out a story was motivating for a participant to increase her length of utterance (Adams and Cook 2016a). Often children who use augmentative communication systems make very short utterances, sometimes one word long. A car-like robot, and a robot arm were "dressed-up" like characters in the story, and the participant moved the robots and spoke their lines.

To write a simple robot program, a participant moved the computer cursor and selected commands in the Robolab program via her communication device (Adams and Cook 2013). The communication device was connected to the computer via a USB cable, and operated in mouse emulation mode.

Various mathematics activities have been accomplished using a robot (Adams and Cook 2016a). Building simple puzzles was done by having a puzzle piece placed on top of a mobile robot. The participant then drove the robot to the location where the piece should go and spun the robot into the correct orientation (a helper was needed to insert the piece into the puzzle). A mobile robot was moved along a "board game" while counting spaces. Another numeracy activity was drawing lines between ascending numbers on an enlarged numbered connect-the-dots picture using a marking pen attached to the back of a mobile robot.

A series of studies were performed where students did mathematics measurement activities: comparing and sorting objects by length (Adams and Cook 2014), measuring the length of objects using non-standard units, like paperclips, and then comparing lengths based on the numerical measurement (Adams and Cook 2016b), and measuring using standard centimetre units (Adams, David, and Helmbold 2016; Adams and David 2013a). Information about programs to control the robots, instructions for doing the mathematics measurement activities and building NXT and EV3 robots and attachments are available through (Adams and David 2013b) and on-line at http://www.rehabresearch.ualberta.ca/assistivetechnology/resources/tools/. Simple adaptations were made to the mobile robot to enable the activities, for instance, attaching a ruler to the side of the robot. A method to do a task analysis of the activity and assign parts of the task to the robot, an environmental adaptation, or a helper is available in (Adams 2011). Several robot mediated Language, Mathematics, and Science and Social Studies activities have been proposed in (Encarnação et al. 2016). In this study children with neuromotor disabilities used an integrated augmentative manipulation and communication assistive technologies (IAMCAT) system where a Lego Mindstorms NXT robot was controlled through the computer-based GRID 2 communication software. Many activities were performed including drawing lines to connect answers, putting story illustrations or letters or sequences into order, carrying labels for matching words and letters or illustrations or numbers, or to label parts of pictures, following pathways on a map, measuring width with non-standard units, or carrying a certain number of items for working with numbers. Instructions, GRID samples, and activities can be found at http://uarpie.anditec.pt/images/docs/user_manual_iamcat.zip

Review of user studies, outcomes, clinical evidence

Cognitive assessment

Outcomes of Cognitive Assessment Studies

Several studies have shown that children with disabilities are able to use a robotic system as a tool for augmentative manipulation. In (Cook, Liu, and Hoseit 1990) children as young as 7 to 9 months old were able to use an industrial robotic manipulator to bring a cookie closer. Such a finding is consistent with the typical development literature, in which at approximately 9 months children can use objects as tools to retrieve other objects (Claxton, McCarty, and Keen, 2009). Cook, Howery, Gu, and Meng (2000) report that children that were unable to directly manipulate objects in their environment, were able to use a robotic arm to handle and manipulate objects in a playful scenario. Besides tool use, robot mediated activities have proved to be a means to demonstrate other cognitive skills such as cause and effect, inhibition, laterality, and sequencing (Encarnação et al. 2014; Poletz et al. 2010), problem solving and spatial reasoning (Cook et al. 2007; Cook et al. 2011), or conservation (Mainela-Arnold et al. 2006). These studies showed that cognitive skills revealed by robot use were correlated with the children's developmental age, in line with cognitive development literature. This validates the use of robot mediated activities as a proxy measure of cognitive development through the comparison of the performance of children with disabilities executing the tasks with that of typically developing children. These studies have also provided the first set of normative data in this regard.

Case Study 1 continued: Joseph's cognitive assessment need

Joseph's OT considers using a robot-adapted version of the conservation task mentioned above to gain insight into Joseph current cognitive skills. His OT first considers the human component, as per the HAAT model (cf. Chapter 1). Due to his physical disability, Joseph cannot talk or manipulate objects independently, which limits his ability to make a selection. His nystagmus prevents him from using visual fixation as a reliable response. The OT carefully analyzes the activity and its demands. In order to participate in the conservation task, Joseph requires a means through which he can reliably and independently express his choice. In addition, his OT wonders whether the limited opportunities afforded to Joseph to independently interact with objects would have limited his ability to develop the cognitive skills required to succeed in the task in the first place. Thus, a gap exists between Joseph's current skills and the demands of the activity, which restricts his participation in the conservation task. The OT concludes that a robotic system for augmentative manipulation could bridge that gap. The OT proceeds to set-up the Microbot Teachmover (as in Figure 7-2), adapted for switch control. The OT places two switches, one to each side of Joseph's headrest, as she has identified this to be the best site of motor control for Joseph. One switch causes the robot to reach for the container on the left and the other to the container on the right. The OT sets-up the conservation task and programs the robot to reach towards the container after a switch selection is made. First, Joseph demonstrated that he understood the concept of laterality, by performing the cognitive utilization protocol that requires him to knock over stacks of blocks (described above). After he demonstrated that he could use the appropriate switch to make choices on his left or right side, Joseph was presented with the conservation task. When asked to make a selection, he was able to press the left or right switch to turn the robot towards the response he believed to be the correct one. This provided the OT and parents with unprecedented insight into Joseph's specific cognitive skills and unveiled further potential. Further, after the assessment, the robot could be used as an intervention strategy to help Joseph engage in activities that would increase his understanding of volume, like pouring water into different sized containers. Experiences like these could ultimately improve the mental representations that lead to fully developed conservation skills.

Play

Outcomes of Play Studies

The literature regarding the use of robots to promote play in children with disabilities is scarce. In many studies play is approached as an activity that promotes or assists the assessment of other skills in the child, such as cognitive development; or play is approached as a motivator during research or therapeutic sessions. This is the case of the robotic applications to assess cognitive skills described in the previous section. Under these two approaches, the play activities were structured and goal oriented, where the research team specified the target that the child had to accomplish. Besides the small number of studies that have used robots to promote semi-structured activities or free play, the number of participants in each study was also small (between one and ten participants, in the last case all typically developing children). Participants' age ranged from 3 to 11 years of age. The fact that children younger than 3 years of age were not participants in the studies may be due to the skills required to operate a robot, at least using two switches or more. This can be cognitively demanding for children younger than four years of age (Poletz et al. 2010). From a theoretical point of view, an individual experiences pleasure and enjoyment while doing an activity only when there is a balance or a good match between the individual's skills and the challenges of a task (Csikszentmihalyi 2008). Thus, children younger than four years of age may not express play behaviors when operating a robot since their cognitive skills may be too low to understand the relationship between the control interface and the robot's movements.

Using robots to promote play in children with motor impairment has been focused mainly on children with a diagnosis of cerebral palsy, including children with quadriplegia and hemiplegia. This may be due to cerebral palsy being the most common childhood neurodisability (Eliasson et al. 2006). Other diagnoses related to motor impairments were children with general developmental delay and transverse spinal cord syndrome (Klein, et al. 2011; Prazak et al. 2004). Some studies included children with diagnoses related to cognitive functions such as global cognitive disability (Kronreif et al. 2007), tuberous sclerosis, and attention deficit hyperactive disorder along with children with motor impairments (Marti and Iacono, 2011).

Outcomes reported in these studies have consistently been the observation of behaviors such as enjoyment, pleasure, curiosity, active engagement, spontaneity, teasing and sense of control, all related to play, which occur when children interact with the robot that they are able to operate (Besio, Carnesecchi, and Converti 2013; Cook et al. 2000; Kronreif et al. 2007; Marti and Iacono 2011). Children improve their performance in operating the robot as they practice during play, needing fewer prompts, making fewer errors, and performing the task faster, but they need practice to carry out the most complex tasks (Besio, Carnesecchi, and Converti 2013; Cook et al. 2000; Kronreif et al. 2007; Schulmeister et al. 2006). Other outcomes have been an increase in child's attention span, frequency of smiles and vocalizations, and an improvement in the participant's memory (Schulmeister et al. 2006). Rios and colleagues explored the effects of a robot on mother-child interaction finding that when children used the robot to access play, mothers tended to decrease their directiveness, allowing the children to be more independent and active during the play interaction (Rios 2014).

Robots have the potential to improve not only children's playfulness and play performance, but also the quality of support of the able-bodied playmates who became more enabling during play. Rios and colleagues explored the use of robots at children's homes in family play routines involving their mothers (Rios et al. 2016). The Lego Mindstorms RCX with an adapted remote control was used by children. The results revealed that the levels of playfulness of all the children, measured using the Test of Playfulness (Bundy 2010), showed a statistically significant increase and the play performance, measured through the Canadian Occupational Therapy Measure (COPM) (Law et al. 1998), showed a clinically significant improvement according to the COPM manual criteria when the children played with the robot (Rios et al. 2016). The mothers' tendency to direct the play of the child was reduced when the children had access to the robot to play (Rios et al. 2014). Adams and colleagues investigated the type of play (no play, functional, and pretend) expressed by typically developing children while playing in two conditions: with and without a robot (Adams et al. 2016). A coding system according to Barton's taxonomy of pretend play (Barton 2010) was developed and implemented to code the different levels of play (no play, functional play, and pretend play). The results revealed that the scenarios elicited play at the expected developmental levels for the no-robot condition, but not for the robot condition. It was also found that children presented a higher percentage of pretend play without the robot than with the robot for both conventional toys and unstructured materials. Researchers hope to use these results to use the robotic scenarios as a proxy of play development in children with motor impairment (Adams et al. 2016).

Case Study 2 continued: Juan's play need solution

Juan had the physical ability to activate four Jelly bean switches, so these were utilized to operate a Lego Mindstorms RCX car-like vehicle. The switches were plugged into an adapted remote control, based on the original commercial Lego remote control with switch jacks wired to the remote control circuit board (as in Figure 7-4). The forward switch was located close to Juan's forearm. A right turn switch was attached to the wheelchair's right-hand side using a mounted arm and a left turn switch was attached to the wheelchair's left-hand side, both of them to be hit using Juan's head movements. A backwards switch was located on an adapted foot-rest attached to the wheelchair to be activated by Juan's left foot. Juan had four training sessions in the use of the switches to make the robot move and carry objects. Once he was able to operate the robot, Juan and his mother were encouraged to play together. During the robotic sessions he made many vocalizations, trying to tell his mom about what he was doing and what he required from her in order to do what he wanted with the robot and the toys. He explored what to do with the robots and his toys and showed great creativity; for example, he asked his mother to put a toy car on top of the robot that was about five times bigger than the robot; initially his mother refused to do it, but he insisted. When Juan's mother placed the toy on the robot, the robot was able to carry it for a short distance. Thus, the child showed that he was able to explore an object's physical property (weight) while playing with the robot. He also asked his mother to build a pile of plastic donuts so he could hit the pile with the robot to make them fall down. Then he modified the activity and asked his mother to put the pile of donuts on top of the robot. He designed different strategies to make the donuts fall down; for example, making the robot hit the board edge and making the robot oscillate (forward and backward) in order to destabilize the pile of toy donuts. During the robotic sessions Juan used the robot as a tool that supported his independence and participation during free play. Compared to sessions without the robot, he was more responsive, more active, and less compliant in following his mother's lead; he provided ideas for the play activity and was able to lead the play.

Education

Outcomes of education studies

As mentioned above, a literature search revealed only seven recent user studies reporting the use of robots for augmentative manipulation by children with physical impairments for academic activities. The sample sizes in these studies with children with disabilities are very small, with two studies being case studies (Adams and Cook 2013; 2016a), three being a series of case studies (Adams and Cook 2014; 2016b; Adams, David, and Helmbold 2016), and one study having nine participants (Encarnação et al. 2016). The age of the case study participants was between 10 and 14 years, and the study with 9 participants worked with young children, 3 to 6 years old. The studies have included children with cerebral palsy (Adams and Cook 2013; Encarnação et al. 2016), traumatic brain injury, and global development delay (Encarnação et al. 2016). In addition, 20 participants without disabilities two to five years old have used an augmentative manipulation robot to test the system before planned trials with children with disabilities (Lee 2013).

Determining the outcomes to track in order to evaluate the benefits of robot intervention is in the exploratory stages, and studies have included many varied outcomes. One outcome is children's engagement in the robotic system (Lee 2013), or satisfaction with the robot compared to other ways of doing activities, for example, measuring with the robot compared to watching a teacher do the measuring (Adams and Cook 2014; Adams and Cook 2016b; Adams, David and Helmbold 2016). In general, children have preferred to do the manipulation themselves with the robot, except when measuring long objects which took a long time.

Another outcome studied was children's skill of using the robot or access method to perform activities. The robot competency skills framework described above (Adams and Cook 2016a) can be used to frame these outcomes. For instance, robot operational skill was tracked as the amount of distance a robot "game piece" travelled outside the board-game pathway compared to the distance within the board-game pathway (Adams and Cook 2016a). In another study, the operational skill of using the scanning access method to control the cursor to do robot programming was tracked. In this case poor operational control resulted in a number of unwanted cursor movements and long task times (Adams and Cook 2013). Linguistic competency using the communication device voice output was tracked in a study where the participant used her communication device to move the robot and say the lines for the characters in the story; the participant generated utterances two- and three-words long, which were longer than her usual one word utterances in normal conversation (Adams and Cook 2016a).

Participation in the curriculum is another outcome. For example, the "run" command from the Lego robot remote control was trained into a participant's communication device, allowing her to run the robot programs of the other students in a science class where students were learning to program Lego robots (Adams and Cook 2013). In this way the participant had a central role in the classroom as she tested her classmates' robot programs. In (Encarnação et al. 2016) all the children in the class did the same activity, but the children with disabilities did the activity with the integrated augmentative manipulation and communication robotic system. Participation in the above studies was alongside other students in the classroom. Participation in the curriculum can also be done in one-on-one sessions. For example, in the study reported in (Adams and Cook 2013), programming of the participant's own car-like mobile robot was performed in pull out sessions due to the level of support needed by the student to do the required tasks. Likewise, gaining experience performing hands-on mathematics activities, including puzzles, number games, connect-the-numbered dots pictures was done in one-on-one sessions (Adams and Cook 2016a).

Robot use has enabled teachers to evaluate children's understanding against the standard curriculum rubrics. Success or failure of saying an English letter appropriately was observed when children used a robot (Lee 2013). In addition, teachers have assessed student's mathematical procedures and concepts in (Adams and Cook 2014; 2016b), and discovered gaps in student's knowledge, which the student's teaching team attributed to the students not previously having "hands-on" experience in the activities.

Teacher opinion of robot system use is another outcome studied. Stakeholders have indicated that robots in the classroom have a role, with obvious benefits to the children with disabilities and the class, but they are leery of required technical support, even with the simple Lego robot (Adams and Cook 2014; Encarnação et al. 2016). In one study, teachers thought that using the robot was the most effective way for the students to show what they know compared to other methods of manipulating objects in class, i.e., observing a teacher doing manipulation and responding to her questions, or telling the teacher using their communication devices how to manipulate the objects (Adams, David, Helmbold 2016). The teachers in the classrooms in (Encarnação et al. 2016) thought that robot system was useful, and had a positive impact on children with disabilities and the classmates and other teachers. However, they found it difficult to manage the extra time required by children with disabilities to complete the activities. In

(Adams and Cook 2016b), teachers felt that some measuring activities were too complex for the children to perform (e.g., measuring a curved surface).

Case study 3 continued: Julia's education need

The intended mathematics activity for Julia was to practice with multiplication by making arrays representing statements, for instance, there are four ducks on the pond, each with two feet, how many feet in total are there? Other students in the class placed 1" (2.54cm) square blocks into tightly packed arrays with the required rows and columns and then counted them. Julia has the physical ability to point to and lightly press items on a touch screen, as long as it is positioned within her reach. Since she already had the iPad mini mounted on her wheelchair, options to control a robot through the iPad mini were explored. Lego provides a free download Robot Commander app to control the Lego NXT and EV3 robots. Only the Lego EV3 is controllable from the iPad products. Julia trialed one of the built-in Robot Commander interfaces, to control the EV3 and gripper. Several adaptations to the robot, environment, and the app were needed. For instance, rather than using a gripper, which made the blocks shift at an angle when it closed, a scoop built to the size of the blocks was used (Figure 7-5). Grid paper was placed in a box so that Julia could push the blocks up to the edge of the box in order to line them up. Julia had trouble using the joystick in the Robot Commander interface to control the robot because a little movement of the joystick off of straight ahead caused a large turn of the robot. The app allows one to make their own interfaces, so another one was made with a slider that controlled a motor. The left and right motors for the robot wheels were given the same signal (by making a wire that split one signal to two), thus, only straight forward and backward were possible. The activity was accomplished by Julia, with a little assistance from a helper. After placing a block, Julia would request another and ask for the robot to be repositioned one column over, so she could proceed to place the next block. Julia reported that she preferred using the robot over using a screen-based app on her iPad to do the arrays. The teacher expressed that she was confident in assessing Julia's understanding of the multiplication concept when Julia used the robot to manipulate the blocks into arrays.

*** Insert Figure 7-5 about here ***

Future directions

Available research has shown that robot use by children with physical impairments has the potential for many positive outcomes, but further studies are needed to examine the benefits and challenges of using robots for cognitive development, play and educational activities. Current evidence is mostly based on case studies where children used the robotic systems for a short period of time in relatively artificial conditions (in a lab or at school but with a research team present). Thus, the level of clinical evidence about the effects of robotics interventions on developmental outcomes in cognitive development, play and education is low. In the area of assistive technology, single case research designs (which when carefully designed provide higher evidence than case studies) are recommended, and appropriate due to the heterogeneity of the population, and the individualized interventions required (Ottenbacher and Hinderer 2001). There is the need to conduct single case research design studies for longer periods of time in a natural setting (home, classroom, and community) to raise the levels of evidence about the effects of the robotic systems.

Other areas of play and education should be examined. For instance, the use of augmentative manipulation robotic systems has been shown to have positive effects on mother-child interaction during free play (Rios et al. 2016). Further research should focus on the effects of robotic interventions on other interactions such as a child with motor impairments with other family members (for example fathers, siblings, and cousin) and peers with and without disabilities during free-play activities. In the area of education, experimental results relating to the expected outcomes in the programs of study that are taught in the schools will truly align with what is actually happening in the classroom. Assessment instruments that evaluate outcomes of the interventions should be created.

Studies should be widely disseminated, and translated into easily accessible resources in order to increase awareness among stakeholders such as parents, therapists, educators, researchers, and funding agencies of potential benefits (Cooper et al. 1999; Tejada et al. 2007). Resources and databases for parents and therapists that integrate robotic play should be created and evaluated. More resources for teachers who integrate the robotic tools directly with curriculum materials are needed (Cooper et al. 1999; Tejada et al. 2007).

Technical development is needed to develop appropriate, robust, easy to use assistive robots for children with physical impairments. The only robots used in studies with children that are presently commercially available are the Lego robots and though they are inexpensive, safe and flexible, they have limitations. They are fragile and require frequent minor adjustments, they have limited payloads, and limited environmental sensing and navigation capabilities may limit the degree of autonomy that can be achieved (Cook, Encarnação, and Adams 2010).

Standard robot control software is needed to enable the use of the same program across robotic systems (Howell, Martz, and Stanger 1996). The open source Robotics Operating System (ROS) has gained some ground in the last few years, and could be a useful tool for programmers. However, if robots are to be useful at home, hospitals and in the classroom, the user interface must be very simple. Another approach is to have a wide range of applications for a common robotic platform (Cooper et al. 1999). When an appropriate robot is commercially available, it enables researchers to build technology and strategies with it; this is the situation with the Manus robotic arm which evolved over decades to become the iArm (Brose et al. 2010) (cf. Chapter 3).

Guidelines for reproducing or emulating previously utilized prototypes could increase effort into researching and developing assistive robotics for children. A template has been proposed for facilitating the understanding of the various interdependent hardware and software components of a typical assistive robot for children with cognitive disabilities (Tsun et al. 2015). The authors give a concrete example of how it was used in development of a robotic system for children, but no evidence of other researchers using it was found. Though not specifically proposed for development of augmentative manipulation systems, the basic concepts could be applied.

There are various interfaces that can be used to interact with assistive technologies, but the control interfaces most commonly used in the robot studies above were switches followed by touch screens, motion detection, and joysticks. The lower cost and availability of innovative controls should be pursued such as eye tracking or brain computer interfaces. Recent innovations in intelligent techniques to switch between items to be controlled with very few input signals could be beneficial, for instance to switch between robot controls and augmentative communication software or between forward movement of a robot and turns (Pilarski et al. 2012).

Many recent technological developments can potentially facilitate children's functioning in tasks. For example, now that vision systems have gone down in cost, they could be beneficial tools for detecting objects of interest in the environment, so the robot can autonomously interact with them. In addition, the human technology interface can be made to better reflect the environmental situation (e.g., detecting if objects are hard or soft). With the robotic systems available today the user is able to experience picking and placing objects. But the interfaces do not provide the sensation of feeling different textures or allow children to move an object in order to be able to see it from different perspectives and explore all its features, children do not feel the different weights of different objects, or to freely explore the object. The activities performed have been structured, mainly because of the technical limitations of the robotic systems. Independent exploration is important for cognitive and perceptual development. There are tactile sensors available, which require some sort of additional device to relay the information to the body, for instance, a pad attached to the upper arm. Kinesthetic touch information can be fed back to the user through the robotic interface, providing a richer manipulative experience, and could require less time to set up the system (Atashzar et al. 2016; Jafari, Adams, and Tavakoli 2015).

In addition, as children get more proficient using the robots with experience it is important that they continue to be challenged to take on as much of the task as appropriate. The level of autonomy of the robotics system could adapt automatically to the users capabilities by using machine learning capabilities.

Ten years ago Howell (2005) predicted that it will take years to develop an easy-to-use, cost-effective, and reliable assistive robot for home and classroom use, and once developed, it will take more time to develop appropriate activities. The need is still present, as there have been recent calls to develop appropriate robots for children with disabilities (Cook, Encarnação, and Adams 2010). Significant advances have been made in robotics for activities of daily living (Brose et al. 2010) and robots for seniors (Broadbent, Stafford, and MacDonald 2009) (cf. chapters 3 and 10) as far as commercializing systems, addressing safety and usability concerns. Hopefully this momentum will carry into the development of robotics for children with physical disabilities to manipulate play and learning objects, because the benefits to children could be significant.

Study questions

1. List the HAAT components for each case study.
2. Discuss the impact of motor skills on the cognitive development of young children.
3. Based on Joseph’s case, design an activity in which Joseph could use a robot to demonstrate his cognitive skills (assessment).
4. Based on your response to question 4, adapt the activity demands so that Joseph can use the robot to further develop that skill (intervention).
5. What are the most common features of play as an occupation?
6. Define these types of play: functional play, pretend play, and object play.
7. How does physical impairment affect children’s engagement in play alone and with others?

8. Explain why promoting play in children with motor impairment is important for their functioning.
9. Based on Juan’s case, design an activity in which Juan could use a robot to engage in play with family members.
10. How does physical impairment affect children’s engagement in education?
11. Based on Julia's case, design an activity in which Julia could use a robot to do an addition problem or a division problem.
12. What are some features that have made Lego Mindstorms robotic systems feasible to use in children’s real educational contexts?
13. Name some factors that should be addressed in order to facilitate the adoption of robots in homes and schools.
14. What are some new technologies that may be beneficial for children using robots for cognitive assessment, play or education?

References

Adams, Kimberley. “Access to math activities for children with disabilities by controlling Lego robots via augmentative and alternative communication devices.” Doctoral Dissertation, Faculty of Rehabilitation Medicine, University of Alberta., 2011.

Adams, K., and A. Cook. "Programming and Controlling Robots Using Scanning on a Speech Generating Communication Device: A Case Study." *Technology and Disability* 25 (2013): 275–86.

Adams, Kim, and Albert Cook. "Access to Hands-on Mathematics Measurement Activities Using Robots Controlled Via Speech Generating Devices: Three Case Studies." *Disability and Rehabilitation: Assistive Technology* 9, no. 4 (2014): 286-98.

Adams, K. and A. Cook. "Using Robots in “Hands-on” Academic Activities: A Case Study Examining Speech-Generating Device Use and Required Skills." *Disability and Rehabilitation: Assistive Technology* no 11 (2016a): 433-443.

Adams, K., and A. Cook. "Performing Mathematics Activities with Non-Standard Units of Measurement Using Robots Controlled Via Speech Generating Devices: Three Case Studies." *Disability and Rehabilitation: Assistive Technology* Early Online (2016b): 1-13.

Adams, K., and P. Encarnação. "A Training Protocol for Controlling Lego Robots via Speech Generating Devices". In: G.J. Gelderblom, M. Soede, L. Adriaens, and K. Miesenberger (eds.), Everyday Technology for Independence and Care - AAATE 2011, *Assistive Technology Research Series*, vol. 29, Netherlands: IOS Press, (2011):517-525.

Adams, Kim, and Bonnie-Lynn David. "Methods of Manipulation for Children with Severe Disabilities to Do Hands-on Math Activities: Robot, Directing, Guiding." *Presentation at the RESNA Conference*. Bellevue, WA, 2013a.

Adams, K., and Bonnie-Lynn David. "Making Hands-on Activities for Everyone: Math and the Lego Mindstorms Robot." Edmonton, Alberta: Alberta Teacher's Association Library 2013b.

Adams, K., Bonnie-Lynn David, and Bruce Helmbold. "Making Messages + Taking Measurements: Leveraging Speech Generating Devices to Manage Mathematics Activities with Lego Mindstorm™ Robots." *AAC: Augmentative and Alternative Communication, Manuscript submitted for review* (2016).

Adams, K., A. Ríos, L. Becerra, and P. Esquivel. "Using robots to access play at different developmental levels for children with severe disabilities: a pilot study." *Presentation at the RESNA Conference*. Denver, CO, 2015.

Adams, K., A. Rios Rincon, L Becerra, Javier Castanellos, Maria Gomez, A.M. Cook, and P Encarnação. "An Exploratory Study of Children's Pretend Play When Using a Switch-Controlled Assistive Robot to Manipulate Toys." *British Journal of Occupational Therapy (BJOT), Special Issue on Assistive Technology Manuscript submitted for review* (2016).

Affolter, F. "From Action to Interaction as Primary Root for Development." In *Movement and Action in Learning and Development: Clinical Implications for Pervasive Developmental Disorders*, by I. Stockman. 169-99. San Diego: Elsevier, 2004.

Alvarez, L. "A Robot Journey into Developmental Pathways: Exploring Cognitive Skills of Young Children with Motor Impairments". Doctoral Dissertation, Faculty of Rehabilitation Medicine, University of Alberta, 2014.

Alvarez, L., A. Cook, and J. Darrah. "Grasping the Opportunity for Augmentative Manipulation." *Manuscript submitted for review* (2016).

Alvarez, L., K. Adams, and A. Cook. "Quantifying the Complexity of Using Robots as Augmentative Manipulation Tools: An Affordances Perspective." *Manuscript submitted for review* (2016).

American Occupational Therapy Association. "Occupational therapy practice framework: Domain and process (3rd ed.)." *The American Journal of Occupational Therapy 68*, no. Supplement 1 (2014): s1-s48.

Atashzar, F., N. Jafari, M. Shahbazi, H. Janz, M. Tavakoli, Rajni Patel, and K. Adams. "Telerobotics-Assisted Platform for Enhancing Interaction with Physical Environments Designed for People Living with Cerebral Palsy. *Journal of Medical and Rehabilitation Robotics*, no. Special Issue on Rehabilitation Robotics (2016).

Barton, E. "Development of a taxonomy of pretend play for children with disabilities." *Infants and young*, (2010): 247-261.

Bates, E. "The Biology of Symbols: Some Concluding Thoughts." *In The Emergence of Symbols: Cognition and Communication in Infancy*, by E. Bates, L. Benigni, I. Bretherton, L. Camaioni and V. Volterra. 315-70. New York: Academic Press, 1979.

Bertenthal, B. I., and J. J. Campos. "New Directions in the Study of Early Experience." *Child development 58*, no. 3 (1987): 560-7.

Besio, S., F. Caprino, and E. Laudanna. “Profiling Robot-Mediated Play for Children with Disabilities through ICF-CY: The Example of the European Project IROMEC.” Paper presented at the 11th international conference on Computers Helping People with Special Needs - ICCHP '0. Linz, Austria, July 9-11, 2008.
Besio, S., M. Carnesecchi, and R.M. Converti. "Prompt-fading Strategies in Robot Mediated Play Sessions." Edited by P Encarnação, L Azevedo, GJ Gelderblom, A Newell and N-E Mathiassen. *Assistive technology: from research to practice*. Vilamoura, Algarve, Portugal: IOS Press BV, (2013): 143-149.
Blanche, E.I. "Play in Children with cerebral palsy: Doing with-Not doing to." *In Play in Occupational Therapy for Children*, by Diane Parham and Linda Fazio, 375-393. St. Louis: Mosby Elsevier, 2008.
Broadbent, E., R. Stafford, and B. MacDonald. "Acceptance of Healthcare Robots for the Older Population: Review and Future Directions." *International Journal of Social Robotics 1*, no. 4 (2009): 319-30.
Brodin, J. "Diversity of aspects on play in children with profound multiple disabilities." *Early Child Development and Care 175*, no. 7 and 8 (2005): 635-646.
Brose, Steven W. , Douglas J. Weber, Ben A. Salatin, Garret G. Grindle, Hongwu Wang, Juan J. Vazquez, and Rory A. Cooper. "The Role of Assistive Robotics in the Lives of Persons with Disability." *American Journal of Physical Medicine & Rehabilitation 89*, no. 6 (2010): 509-21.
Bundy, A. "Assessment of play and leisure: Delineation of the problem." *American Journal of Occupational Therapy 47*, no. 3 (1993): 217-222.
Bundy, A. “Test of playfulness (ToP)” Version 4.2 Manual revised 11/10. Lindcombe: Unpublished document, 2010.
Chang, H.-J., L.A. Chiarello, R.J. Palisano, M.N. Orlin, A. Bundy, and E.J. Gracely. "The determinants of self-determined behaviors of young children with cerebral palsy." *Research in Developmental Disabilities 35* (2014): 99–109.
Chen, Z., R. P. Sanchez, and T. Campbell. "From Beyond to within Their Grasp: The Rudiments of Analogical Problem Solving." *Developmental psychology 33*, no. 5 (1997): 790-801.
Claxton, Laura J., Michael E. McCarty, and Rachel Keen. "Self-Directed Action Affects Planning in Tool-Use Tasks with Toddlers." *Infant behavior and development 32*, no. 2 (2009): 230-3.
Cook, A., K. Adams, N. Harbottle, and C. Harbottle. "Using Lego Robots to Estimate Cognitive Ability in Children Who Have Severe Disabilities." *RERC State of the Science Conference and Coleman Institute Annual Conference*, Broomfield, CO, 2007.
Cook, Albert M., Kim Adams, Joanne Volden, Norma Harbottle, and Cheryl Harbottle. "Using Lego Robots to Estimate Cognitive Ability in Children Who Have Severe Physical Disabilities." *Disability and rehabilitation. Assistive technology 6*, no. 4 (2011): 338-46.
Cook, Albert M., Brenda Bentz, Norma Harbottle, Cheryl Lynch, and Brad Miller. "School-Based Use of a Robotic Arm System by Children with Disabilities." *IEEE transactions on neural systems and rehabilitation engineering 13*, no. 4 (2005): 452-60.
Cook, A., P. Encarnação, and K. Adams. "Robots: Assistive Technologies for Play, Learning and Cognitive Development." *Technology and Disability 22*, no. 3 (2010): 127-45.
Cook, A., K. Howery, J. Gu, and M. Meng. "Robot Enhanced Interaction and Learning for Children with Profound Physical Disabilities." *Technology and Disability 13*, no. 1 (2000): 1-8.
Cook, A. M., K. M. Liu, and P. Hoseit. "Robotic Arm Use by Very Young Children." *Assistive technology: the official journal of RESNA 2*, no. 2 (1990): 51-57.

Cook, A., M. Q.-H Meng, J. J. Gu, and K. Howery. "Development of a robotic device for facilitating learning by children who have severe disabilities." *IEEE Transactions on Neural Systems and Rehabilitation Engineering 10*, no. 3 (2002): 178-187.
Cook, A., and J. M. Polgar. *Assistive Technologies: Principles and Practices*. Philadelphia: EDI - 4th: Elsevier Inc., 2015.
Cooper, Martyn, David Keating, William Harwin, and Kerstin Dautenhahn. "Robots in the Classroom-Tools for Accessible Education." *In AAATE Conference, The 5th European Conference for the Advancement of Assistive Technology*, Dusseldorf, Germany, 1999.
Coplan, R., Rubin, K. and Findlay, L. Social and nonsocial play. *In Play from birth to twelve: Contexts, perspectives, and meaning,* edited by D. Fromberg, and D. Bergen, 75-86. New York: Garland, 2006.
Csikszentmihalyi, M. *Flow the psychology of optimal experience*. New York: Harper Perenial, 2008.
Department of Energy U.S. *Technology Readiness Assessment Guide*. Washington, DC: Office of Management, 2009.
Eberhart, Silvio P., Joseph Osborne, and Tariq Rahman. "Classroom Evaluation of the Arlyn Arm Robotic Workstation." *Assistive Technology 12* (2000): 132-43.
Eliasson, A.C., S.L. Krumlinde, B. Rösblad. E. Beckung, M. Arner, A.M. Öhrvall, P. Rosenbaum. "The Manual Ability Classification System (MACS) for children with cerebral palsy: scale development and evidence of validity and reliability." *Developmental Medicine and Child Neurology 48* (2006): 549-554.
Encarnação P., L. Alvarez, A. Rios, C. Maya, K. Adams, and A. Cook. "Using virtual robot mediated play activities to assess cognitive skills", *Disability and Rehabilitation: Assistive Technology*, 9(3), (2014): 231-241
Encarnação, P., T. Leite, C. Nunes, M. Nunes da Ponte, K. Adams, A. Cook, A. Caiado, et al. "Using Assistive Robots to Promote Inclusive Education." *Disability and Rehabilitation: Assistive Technology* Early Online (2016): 1-12.
Eriksson, Lilly, Jonas Welander, and Mats Granlund. "Participation in Everyday School Activities for Children with and without Disabilities." *Journal of Developmental and Physical Disabilities*, 19 (2007): 485–502.
Ferasoli-Filho, Humberto, Marco Antônio Corbucci Caldeira, René Pegoraro, Silas Franco dos Reis Alves, Carlos Valadão, and Teodiano Freire Bastos-Filho. "Use of Myoelectric Signals to Command Mobile Entertainment Robot by Disabled Children: Design and Control Architecture." *Paper presented at the Biosignals and Biorobotics Conference (BRC)*, 2012.
Ferland, F. *The Ludic Model:Play, Children with Physical Disabilities and Occupational Therapy?*. 2nd ed. Translated by Phyllis Aronoff and Howard Scott. Ottawa, Ontario: CAOT publications ACE, 2005.
Flanagan, J. Randall, Miles C. Bowman, and Roland S. Johansson. "Control Strategies in Object Manipulation Tasks." *Current opinion in neurobiology 16*, no. 6 (2006): 650-9.
Greenfield, P. "Language, Tools and Brain: The Ontogeny and Phylogeny of Hierarchically Organized Sequential Behavior." *Behavioral and Brain Sciences 14*, no. 4 (1991): 531-51.
Gowen, J.W., N. Jonhson-Martin, B. Davis Goldman, and B. Hussey. "Object play and exploration in children with and without disabilities: A longitudinal study." *American Journal of Mental Retardation 97* (1992): 21-38.
Harkness, L., and A. Bundy. "The test of playfulness and children with physical disabilities." *The Occupational Therapy Journal of Research 21*, no. 2 (2001): 73-89.

Harwin, William, A. Ginige, and R. Jackson. "A Potential Application in Early Education and a Possible Role for a Vision System in a Workstation Based Robotic Aid for Physically Disabled." *Interactive robotic aids-one option for independent living: An international perspective 37* (1986): 18-23.
Harwin, W., Ginige, A. and R.Jackson. "A Robot Workstation for Use in Education of the Physically Handicapped." *IEEE Transactions on Biomedical Engineering 35*, no. 2 (1988): 127-31.
Hinojosa, J., and P. Kramer. "Integrating children with disabilities into family play." *In Play in Occupational Therapy for Children*, by D. Parham and L. Fazio, 321-334. St. Louis: Mosby Elsevier, 2008.
Howell, Richard. "Robotic Devices as Assistive and Educational Tools for Persons with Disabilities." *In Handbook of Special Education Technology Research and Practice*, edited by Dave Edyburn, Kyle Higgins and Randall Boone. 849-62. Whitefish Bay, WI Knowledge by Design, 2005.
Howell, Richard, and K. Hay. "Software-Based Access and Control of Robotic Manipulators for Severely Physically Disabled Students." *Journal of Artificial Intelligence in Education 1*, no. 1 (1989): 53-72.
Howell, Richard, Stacy Martz, and Carol A. Stanger. "Classroom Applications of Educational Robots for Inclusive Teams of Students with and without Disabilities." *Technology and Disability 5* (1996): 139-50.
Jafari, N., K. Adams, and M. Tavakoli. "Haptic Telerobotics: Application to Assistive Technology for Children with Disabilities." *Paper presented at the Rehabilitation Engineering and Assistive Technology Society of North America (RESNA) Annual Conference*, Denver, Colorado, 2015.
Jennings, K., and R. MacTurk. "The Motivational Characteristics of Infants and Children Physical and Sensory Impairments." *In Mastery Motivation: Origins, Conceptualization and Applications*, by R. Macturk and G. Morgan. 201-20. New Jersey: Ablex Publishing Corporation, 1995.
Keen, K. "The Development of Problem Solving in Young Children: A Critical Cognitive Skill." *Annual review of psychology 62* (2011): 1-21.
Klein, T, G.J. Gelderblom, L. de Witte, and S. Vanstipelen. "Evaluation of Short Term Effects of the IROMEC robotic toy for children with developmental disabilities." *IEEE International Conference on Rehabilitation Robotics*. ETH Zurich Science City, Switzerland, 2011.
Kohlschütter, Alfried, and Florian Eichler. "Childhood Leukodystrophies: A Clinical Perspective." *Expert review of neurotherapeutics 11*, no. 10 (2011): 1485-96.
Kronreif, Gernot, M. Kornfeld, B. Prazac, S. Mina, and M. Fürst. "Robot assistance in playful environment - user trials and results." *IEEE International Conference on Robotics and Automation*. Roma, Italy:, (2007): 2898-2903.
Kwee, H., and J. Quaedackers. "Pocus Project: Adapting the Control of the Manus Manipulator for Persons with Cerebral Palsy." *Paper presented at the ICORR '99: International Conference on Rehabilitation Robotics*, Stanford, California, 1999.
Law, M., S. Baptiste, A. Carswell, M.A. McColl, H. Polatajko, and N. Pollock. *The Canadian Occupational Performance Measure*. 3rd ed. Ottawa: CAOT Publications ACE, 1998.
Lee, Hou Tsan. "Voice Controlled Typesetting Robot of Alphabets for Children Learning." *Journal of Information Technology and Application in Education 2*, no. 1 (2013).

Light, J. "Toward a Definition of Communicative Competence for Individuals Using Augmentative and Alternative Communication Systems." *AAC Augmentative and Alternative Communication 5*, no. 2 (1989): 137-44.
Lockman, J. J. "A Perception-Action Perspective on Tool Use Development." *Child development 71*, no. 1 (2000): 137-44.
Lockman, J. J. "Tool Use from a Perception–Action Perspective: Developmental and Evolutionary Considerations." In *Stone Knapping: The Necessary Conditions for a Uniquely Hominid Behaviour*. Eds. V. Roux and B. Bril. Cambridge UK, 2005.
Mainela-Arnold, Elina, Julia L. Evans, and Martha W. Alibali. "Understanding Conservation Delays in Children with Specific Language Impairment: Task Representations Revealed in Speech and Gesture." *Journal of speech, language, and hearing research: JSLHR 49*, no. 6 (2006): 1267-79.
Marti, P., and I. Iacono. "Learning through Play with a Robot Companion." Edited by G.J. Gelderblom et al. Assistive Technology Research Series (IOS Press) 29 (2011): 526 - 533.
McCarthy, Cheryl B. "Effects of Thematic-Based, Hands-on Science Teaching Versus a Textbook Approach for Students with Disabilities." *Journal of Research in Science Teaching 42*, no. 3 (2005): 245-63.
McCarty, M. E., R. K. Clifton, and R. R. Collard. "Problem Solving in Infancy: The Emergence of an Action Plan." *Developmental psychology 35*, no. 4 (1999): 1091-1101.
McCarty, M. E., R. K. Clifton, and R. Chollard. "The Beginnings of Tool Use by Infants and Toddlers”." *Infancy 2*, no. 2 (2001): 233-56.
McNaughton, David, Janice Light, and Kara B. Arnold. "'Getting Your Wheel in the Door': Successful Full-Time Employment Experiences of Individuals with Cerebral Palsy Who Use Augmentative and Alternative Communication." *AAC Augmentative and Alternative Communication* 18 (2002): 59-76.
Mistrett, Susan, and Amy Goetz. "Playing with Switches." Center for Assistive Technology, University at Buffalo. http://letsplay.buffalo.edu/products/switches.doc (accessed April 27, 2016).
Missiuna, C., and N. Pollock. "Play deprivation in children with physical disabilities: The role of the occupational therapist in preventing secondary disability." *American Journal of Occupational Therapy 45*, no. 10 (1991): 882-888.
Ottenbacher, K. J., and S. R. Hinderer. "Evidence-Based Practice: Methods to Evaluate Individual Patient Improvement." *Am J Phys Med Rehabil 80*, no. 10 (Oct 2001): 786-96.
Parham, L. “Play in Occupational therapy.” In *Play in Occupational Therapy for Children*, edited by L. Parham, and L. Fazio, 3-39. St. Louis: Mosby Elsevier, 2008.
Petress, Ken. "What is meant by 'active learning?'" *Education* 128, no. 4 (2008): 566.
Pfeifer, L.I., A.M. Pacciulio, C.A. Dos Santos, and J.L., Stagnitti, K.E. Dos santos. "Pretend play of children with cerebral palsy." *Physical and Occupational Therapy in Pediatrics 31*, no. 4 (2011): 390-402.
Piaget, J. *Play, Dreams and Imitation*. New York: Norton, 1951.
Piaget, J. The Psychology of Intelligence. London: Taylor and Francis, 1950.
Piaget, J. The Construction of Reality in the Child. Great Britain: Routledhe, 1954.
Piaget, J., and B. Inhelder. The Psychology of the Child. New York: Basic Books, 1969.
Pilarski, Patrick M., Michael R. Dawson, Thomas Degris, Jason P. Carey, and Richard S. Sutton. "Dynamic Switching and Real-Time Machine Learning for Improved Human Control of

Assistive Biomedical Robots." *Paper presented at* 2012 4th IEEE RAS and EMBS International Conference on the Biomedical Robotics and Biomechatronics (BioRob), Rome, Italy, 2012.
Plaisant, Catherine, et al. "A Storytelling Robot for Pediatric Rehabilitation." *Paper presented at the ASSETS'00*, Arlington, Virginia, 2000.
Poletz, L., P. Encarnação, K. Adams, and A. Cook. "Robot Skills and Cognitive Performance of Preschool Children". *Technology and Disability 22* (2010): 117-26.
Prazak, B., G. Kronreif, A. Hochgatterer, and M. Fürts. "A toy robot for physically disabled children." *Technology and Disability 16* (2004): 131-136.
Reilly, M. *Play as exploratory learning: studies of curiosity behavior*. Beverly Hills: Sage, 1974.
Rios Rincon, A.M. "Playfulness in children with severe cerebral palsy when using a robot." PhD dissertation, Edmonton: University of Alberta, 2014.
Rios, A., K. Adams, J. Magill-Evans, and A Cook. "Playfulness in children with severe cerebral palsy when using a robot." *Physical and Occupational Therapy in Pediatrics* (2016): Published online 13 Nov 2015.
Ruff, H. A., C. McCarton, D. Kurtzberg, and H. G. Vaughan. "Preterm Infants' Manipulative Exploration of Objects." *Child development 55*, no. 4 (1984): 1166-73.
Ruffman, Ted, Lance Slade, Juan Carlos Sandino, and Amanda Fletcher. "Are a-Not-B Errors Caused by a Belief About Object Location?" *Child development 76*, no. 1 (2005): 122-36.
Schlosser, Ralf, Donna McGhie-Richmond, Susie Blackstien-Adler, Pat Mirenda, Kim Antonius, and Paul Janzen. "Training a School Team to Integrate Technology Meaningfully into the Curriculum: Effects on Student Participation." *Journal of Special Education Technology 15*, no. 1 (2000): 31-44.
Schunk, Dale H., J.R. Meece, and P.R. Pintrich. Motivation in education: Theory, research, and applications. Toronto, ON: Pearson Higher Ed., 2012.
Schulmeister, J., C. Wiberg, K. Adams, N. Harbottle, and A. Cook. "Robot assisted play for children with disabilities." Paper presented at RESNA Conference, Atlanta, GA*,* 2006.
Skard, G., and A. Bundy. "Test of Playfulness." *In Play in occupational therapy for children*, by L. Diane Parham and Linda S. Fazio, 71-93. St, Louis: Mosby Elsevier, 2008.
Smith, J., and M. Topping. "The Introduction of a Robotic Aid to Drawing into a School for Physically Handicapped Children: A Case Study." *British Journal of Occupational Therapy 59*, no. 12 (1996): 565-9
Solaz-Portolésa, J. J., and V. Sanjoséb. "Piagetian and Neo-Piagetian Variables in Science Problem Solving: Directions for Practice." *Ciências & Cognição 13* (2008): 192-200.
St Amant, R., and T. E. and Horton. "Revisiting the Definition of Animal Tool Use." *Animal behavior 75* (2008): 1199-208.
Stagnitti, K., and C. Unsworth. "The test–retest reliability of the Child-Initiated Pretend Play Assessment." *American Journal of Occupational Therapy 58* (2004): 93–99.
Sutton-Smith, B. The ambiguity of play. London: Harvard University Press, 2001.
Tejada, S., N. Traft, M. Hutson, H. Bufford, M. Dooner, J. Hanson, and G. Mauer et al.,"Educational Robots: Three Models for the Research of Learning Theories and Human-Robot Interaction." *AAAI workshop WS,* Boston 2007
Tejima, N. "Rehabilitation Robotics: A Review." *Advanced Robotics 14*, no. 7 (2000): 551-64.
Tsun, Mark Tee Kit, Lau Bee Theng, Hudyjaya Siswoyo Jo, and Patrick Then Hang Hui. "Robotics for Assisting Children with Physical and Cognitive Disabilities." *In Assistive Technologies for Physical and Cognitive Disabilities*, edited by Lau Bee Theng.. Hershey, PA: Medical Information Science Reference/IGI Global, (2015): 78-120

Van De Walle, John A., Karen S. Karp, and Jennifer M. Bay-Williams. *Elementary and Middle School Mathematics: Teaching Developmentally.* 7th ed. Boston, MA: Allyn and Bacon, 2010.
Van Leeuwen, L., A. Smitsman, and C., and Van Leeuwen. "Affordances, Perceptual Complexity, and the Development of Tool Use." *Journal of Experimental Psychology 20*, no. 1 (1994): 174-91.
Vauclair, J. "Phylogenetic Approach to Object Manipulation in Human and Ape Infants”." *Human development 27* (1984): 321-28.
Vygotsky, L. "Interaction between Learning and Development." *In Readings on the Development of Children*. 29-36. New York: W. H Freeman and company. Original work published in Vygotsky, L.S., Mind and Society. Cambridge, MA: Harvard University Press (1978): 79-91.

Figures

Figure 7-1. A CRS A465, a stationary industrial robotic arm. In the figure, a prosthetic hand is used as a gripper to hold a cup. The robot can be made to dig the cup in the macaroni and collect toys that are buried in the macaroni.

Figure 7-2. A Microbot Teachemover, a half-human size robotic arm with six degrees of freedom. The robot is poised to move to its right to pick up a block and place it on top of the pile of blocks.

Figure 7-3. A Lego Mindstorms RCX robot configured into a robotic arm. In the figure, the robot is being used to pick up differently shaped objects to put into a bin.

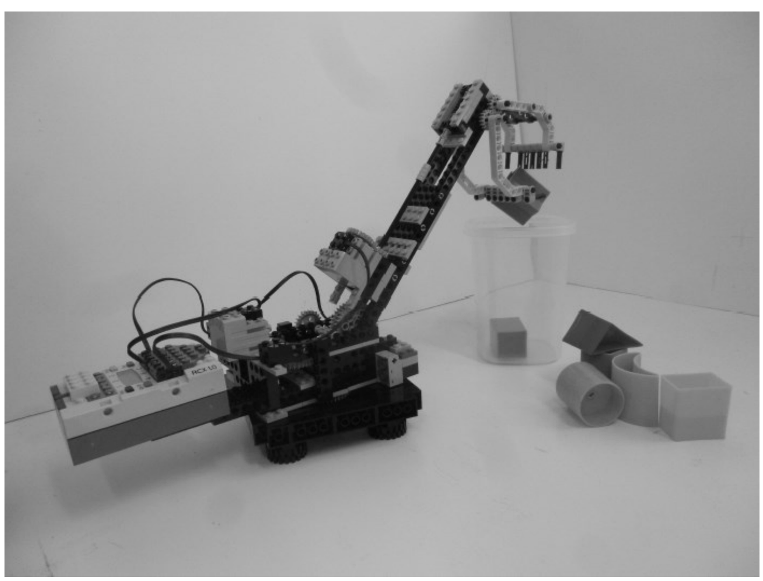

Figure 7-4. A Lego Mindstorms RCX robot configured into a mobile car-like robot. A scoop in front of the robot is being used to move play objects around the play area. A helper can place objects on top of the robot. An adapted remote controller (on the left of the picture) has the same functionality as the original Lego remote control, but allows switches to be plugged in to it. The push button switches (on the right of the picture) perform forward (with the symbol of the eyes), left and right, and backwards robot movements.

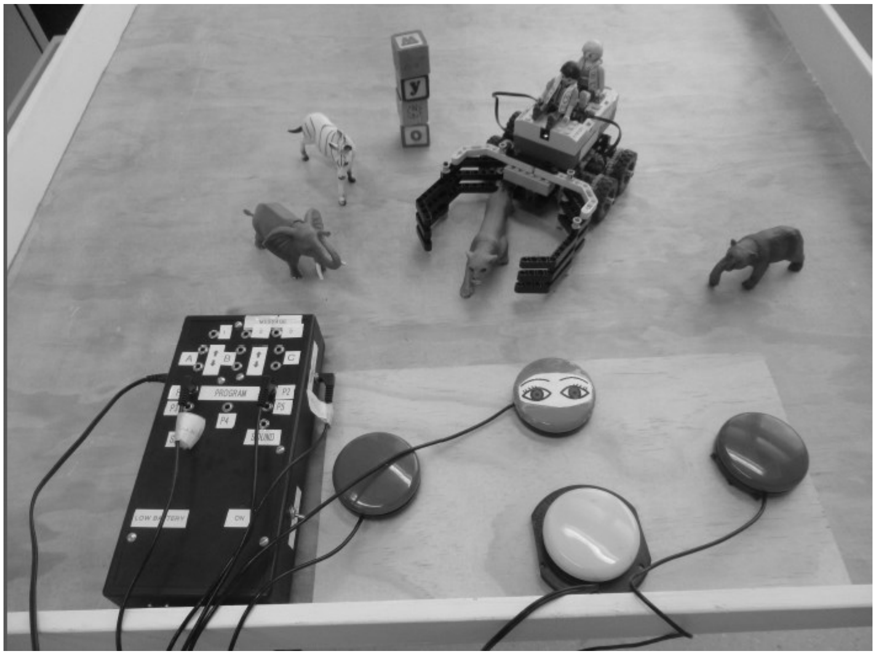

Figure 7-5. A Lego Mindstorms EV3 robot used by Julia to put blocks into arrays in order to study multiplication. The scoop in the front of the robot was designed so the blocks would fit without spinning. The array of 2 rows with 3 objects in each row represents the multiplication equation 3 * 2 = 6.