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

Published citation:
Adams K, and Cook A. (2015). Using robots in "Hands-on" academic activities: a case study examining speech-generating device use and required skills. Disability and Rehabilitation: Assistive Technology. Published Online Dec 8, 2014. doi: 10.3109/17483107.2014.986224

Using robots in "Hands-on" academic activities: A case study examining speech generating device use and required skills

Kim Adams [a,b] and Al Cook [a]

[a] Faculty of Rehabilitation Medicine, University of Alberta, Edmonton, Alberta, Canada
[b] Glenrose Rehabilitation Hospital, Edmonton, Alberta, Canada

Keywords: Complex communication needs (CCN), Augmentative and alternative communication (AAC), Speech generating device (SGD), assistive robots, object manipulation, educational activities, mathematics

Acknowledgements: We kindly acknowledge Elaine Holtham at Aroga in Vancouver, B.C., for the loan of a Vanguard for investigator use during the study. We would also like to thank Julie Yantha for her contribution to implementation of the math and social studies activities and the I Can Centre for Assistive Technology team for their advice and assistance.

Abstract

Purpose A 12 year old girl, Emily, with complex communication needs and severe physical limitations, controlled a Lego robot from a speech generating device (SGD) to do various 'hands-on' academic activities. Emily's teacher and assistive technology (AT) team thought that controlling a robot would motivate Emily to 'use her SGD more'.

Method A descriptive case study was used because the integration of communication and manipulation technologies is not yet understood. Target activities and goals were chosen by Emily's teacher and AT team. Emily performed several manipulative math activities and engaged in an 'acting' activity aimed at increasing her message length. The competency skills needed to control a robot from the SGD were examined, as well as stakeholder satisfaction with the robot system.

Results Emily generated up to 0.4 communication events and 7 robot commands per minute in the activities. Her length of utterance was usually one-word long, but she generated two- and three-word utterances during some activities. Observations of Emily informed a framework to describe the competency skills needed to use SGDs to control robots. Emily and her teacher expressed satisfaction with robot use.

Conclusion Robot use could motivate students to build SGD operational skills and learn educational concepts.

Use of robots in 'hands-on' academic activities: A case study examining the skills required to use a speech generating device to control a robot

1.0 Background

Current teaching practices call for students to have inquiry-based learning opportunities through hands-on activities and to communicate what they have learned [1-3]. This hands-on, enactive approach has many benefits: it increases student motivation and engagement (e.g. [4]), improves student understanding while they use concrete examples and 'verbalize to internalize' [5, p 145]; and teachers can ascertain student's level of understanding as students ask for help or talk aloud [6].

Children with complex communication needs (CCN) who also experience severe physical limitations may find it difficult to actively engage in hands-on activities, and might be excluded or take a passive role [7,8]. Physical limitations can affect the motor control required for accurate pointing, grasping, and manipulating physical objects [9] and children's only choice may be to watch others doing the manipulation for them. Children with CCN may use augmentative and alternative communication (AAC) methods such as speech generating devices (SGDs) to direct the manipulation of objects by telling a classmate which objects to move [as in math in 7], or, they may use gestures such as pointing, head nods and shakes, or eye gaze to respond to options presented to them by a classmate or teacher. However, if children with disabilities have opportunities to themselves perform hands-on activities *and* communicate they are likely be more engaged in the activity, and the enriched experience may augment the learning realised.

Assistive robot systems can help children with physical limitations to manipulate objects in school-based activities. Movement commands can be stored and replayed, allowing the robot to repetitively perform actions to complete a task; new movement commands can be programmed as children move on to new topics. For example, assistive robots have been developed for: science lab activities such as bringing items closer for sensory inspection [10,11], putting a glass over a burning candle to extinguish it [12] or mixing solutions, planting seeds, and plugging in electrical wires to make a radio [13]; math activities such as drawing lines to match questions and answers on a worksheet [14]; and art activities such as pasting items onto an art collage [13]. In most of the studies cited here, the investigator examined the feasibility of using a robot to perform a task. The number of participants in the studies ranged from one to seven, and their ages ranged from seven to 29 years. Participants were described as having moderate to severe orthopeadic disabilities, arthrogryposis, muscular distrophy, and cerebral palsy. Interfaces with which children sent commands to control the robot included: a five-slot switch [10], three push buttons [12], two joysticks [13], and single switch scanning [14]. Most studies were qualitative observational trials; in cases where data were collected they represented: number of interactions, accuracy, response time [10], time to perform tasks, and number of external operator interventions required [13]. However, Howell, Martz, and Stanger [11] measured students' performance with respect to curriculum concepts; pre- and posttests were given on the five senses, but students performed so well on the pretest that there was no room to improve.

The high cost of robotic systems (e.g. $12,000 to $30,000) make them unaffordable for most people, so these studies are not easily replicated. More recent studies in the area of play have used inexpensive infrared controlled Lego Mindstorms robots. For example, children with cerebral palsy used Lego RCX robots in activities like knocking over blocks, bringing princesses to a ball, and delivering valentines to friends [15]. The children made the robot move by pressing one to four switches using various body parts, like the head, for example. Ljunglof et al. [16] developed a robot system using a Bluetooth controlled Lego NXT robot disguised as a bumble bee to draw shapes on the floor. Children with autism chose commands through a touch screen on a tablet computer, and the robot asked the children for more information before implementing a command.

None of these robot activities involved AAC during robotic manipulation tasks; although the robot communicated in the Ljunglof et al. [18] study, the child did not choose a response using AAC. The following observations in robotic play studies illustrate the importance of providing AAC during play activities. Children generally increased the number of vocalizations during and after robotic play interventions, possibly indicating a desire to comment [17]. In [15] the participant used an SGD, but it had to be removed so that she could use switches to control the robot. This led to the missed communication opportunities described in [18]. For example, on one occasion the participant appeared to be randomly controlling the robot and not following the prescribed play routine. When her mother interpreted the child's nonverbal communication for the investigators, it became evident that her behaviour was intentional and she was being innovative in her robot play. Had an SGD been available during the robot activity, she would have been able to communicate her intention.

Disengaging from manipulation activities in order to communicate or disengaging from communication in order to manipulate is undesirable, but Light and Drager [19] highlighted research that is beginning to address this issue in play activities. For example, for children who have no physical limitations, communication symbols have been integrated into the play area so children do not have to coordinate their attention between manipulating the play items and commenting via a separate AAC system [19].

For children who have more severe physical disabilities, a system is needed which provides both communication and manipulation from the same access interface (e.g., switches, eye tracking). This is possible through the infrared or BlueTooth output feature built into many SGDs.

Children have used SGDs to control infrared appliances and toys [20], and SGDs can also be used to control robots. Instead of pressing the small buttons on the toy or robot's remote control unit, children only need to select a cell on the display page of the SGD, and the SGD emulates the remote control unit. SGDs support many alternative access methods, thus, widening the potential number of robot functions available to the children. In the Lego RCX system above, four switches were needed to control four robot functions. If a child can only access one or two switches, but uses scanning on an SGD programmed with robot commands, he can access many more than one or two robot functions. The only limit is the grid size and number of display pages.

With a system such as this, a student with severe physical disabilities can be actively involved in educational manipulative activities using the robot and also communicate observations and the rationale for actions using his or her personal SGD language system and alternative access method. Perhaps this hands-on, enactive approach can provide the benefits of motivation, engagement, and achievement to these students.

The skills required to be a competent user of AAC have been described in terms of four competence domains: (1) linguistic—understanding and using symbols to communicate ideas and feelings, (2) operational—operating the AAC method accurately and efficiently, (3) social—using the tool effectively to communicate with others (discourse strategies, communicative functions, social relations), and (4) strategic—using strategies to minimize the limitations in the other domains [21]. Using an SGD to control a robot requires user skills to competently communicate with others as well as to control the robot. The nature of these skills has not been reported.

This paper presents a case study in which a 12 year old girl controlled a robot from an SGD in various academic activities. Prior to the study, her use of the SGD was limited but her teacher and assistive technology (AT) team thought that being able to control a robot would motivate her to use the SGD. The study aimed to:

(1) examine the participant's use of an SGD in various hands-on academic activities,

(2) determine the competency skills needed to use an SGD to control a robot in these activities, and

(3) establish if the participant and teacher were satisfied with the SGD-robot activities involved in the study.

2.0 Method

Critical factors involved in using SGDs with robots are not yet understood, and it is unclear what measures of success will be meaningful. Therefore, systematic and rigorous manipulation of an independent variable was not feasible at this stage of the research, so a descriptive case study design [22] was employed.

2.1 Participant

Emily (a pseudonym) was a 12 year old girl with spastic athetoid cerebral palsy which affected all four limbs leading to severe physical limitations in reaching and grasping. She had a manual wheelchair with a custom seating and positioning system. She did not propel the wheelchair independently. There were no issues with Emily's vision and hearing, as reported by her teacher. Emily has CCN and used a Vanguard[i] II SGD, with a Unity[ii] 45 Full vocabulary set (Version 4.06), which she had received seven months prior to the study. She accessed the communication symbols on the SGD with two-switch step row-column scanning with two Jelly Bean[iii] switches attached to her wheelchair headrest. Lateral bending of the neck to the left and right was previously established by her assistive technology (AT) team as the most reliable anatomic site for activation of the switches.

The AT team reported that Emily was a context-dependent communicator who infrequently used her SGD. Context-dependent communicators can reliably use words, signs, or pictures to represent a concept or meaning, but they are limited to particular contexts or partners [23]. Emily rarely initiated communication with the SGD but she would readily engage in conversation with nonverbal communication such as smiles, laughter, and head nods and shakes. In social conversation with familiar partners such as her AT team, her teachers, and her education assistant (EA), Emily typically generated utterances requiring only one selection on the SGD, for example, stored social comments such as 'HOW ARE YOU?' or responses one word in length such as 'mom'. When motivated, she sometimes composed two or three symbol messages (e.g. 'I go swimming'). The notation throughout the paper will represent stored phrases in capital letters and words, phrases, or sentences composed by Emily from her core vocabulary in lower case letters. Emily was unfamiliar with the Unity vocabulary on her device, and when requested to compose a sentence, she would spend several minutes searching for words and required cueing from her communication partner regarding the symbol pathways she must follow to locate them.

Emily was in an integrated grade six classroom (with students aged 11 to 13 years), but did not study the grade six curriculum. No formal testing was performed as part of this study, but Emily's teacher reported that psychological testing prior to the study indicated that Emily had mild to moderate intellectual impairment. The teacher's opinion was that the impairment was due to reduced opportunities for learning. An educational assistant (EA) provided academic and personal assistance to Emily and one other student. Emily performed individualized reading, writing, and math activities with her EA and group activities such as acting in drama class with her peers. Prior to receiving an SGD, Emily had no means for written communication, hence her skills were delayed. She wrote short sentences with assistance from her EA who provided sentence frames for copying. Her teacher reported that Emily understood counting numbers up to five, and was working on numbers up to 15. Emily's EA performed the manipulation required in math activities.

2.2 Materials

Two robots were built from the Lego RCX Mindstorms[iv] kit: a car-like robot and a robot arm (figure 1, a and b, respectively). The remote control unit that comes with Lego robots was used to train the Vanguard SGD to send the infrared signals required to control the robots. The instructions for controlling infrared appliances are included with SGD documentation, and controlling Lego robots is like training the SGD to control a TV. The car-like robot could be controlled by sending direct commands to individual motors (e.g. to go forward, backward, left, or right in approximately 10 centimeter steps). The robots could also be controlled by sending a command to start a prestored program. Robot programs allow users to perform complex tasks with a single command. The car-like robot programs used during the study were: (1) turn the robot in a circle in one direction, (2) turn the robot in another direction, (3) direct the robot to go forward for eight seconds, and (4) direct the robot to go backward for eight seconds. A robot arm program was used to shake and roll a die. If a program was sent two times in a row, it would not run, so a robot 'stop' infrared command was added to the commands stored in each robot program cell on the SGD page.

[Insert Figure 1 about here]

A new page was created on Emily's SGD with symbols for the robot commands and some prestored phrases (e.g. 'IT'S NOT WORKING', 'THIS IS BORING', 'YOUR TURN', 'DUMB MOVE') (figure 2). The page layout for robot commands was designed using concepts similar to pages with which Emily was already familiar. For example, mouse cursor movements bore a relationship to the required left, right, forward, and back movements of the robot. Other considerations included locating robot commands and vocabulary in cells that would yield the least potential for SGD selection errors. For example, the robot 'STOP' was placed in the upper left hand corner of the scanning array (the start position for the scan) and other robot commands were moved away from the first scan position of each row. A symbol to return to the core vocabulary was placed in the top right corner of the page to be consistent with its location on her other pages. The SGD robot commands page and her core vocabulary were available to Emily during all activities.

[Insert figure 2 about here]

Yellow and blue arms were added to the car-like robot to distinguish its left and right sides and corresponding colour coded symbols were added to the SGD robot page for turn 'this way' (toward the yellow arm) and 'that way' (toward the blue arm). It was expected that the colour coding would help Emily to base movements on the frame of reference of the robot, rather than on her own frame of reference. For example, when the robot was coming toward Emily, the left and right directions were the opposite of when the robot was moving away from her.

2.3 Procedure

The study took place at Emily's school. Target goals and desired hands-on academic activities were chosen in a discussion with Emily's teacher and AT team. Emily's teacher and the AT team wanted Emily to generally increase the use of her SGD. The teacher wanted Emily to have manipulative experiences with numbers, specifically in math, and the AT team wanted Emily to increase her message length. A specific linguistic competence goal to increase the length of utterances from one word to two, three, and four words was chosen and examined in the math and social studies activities described below.

Prior to starting the activities, Emily approved the planned activities, and was given a demonstration of how an SGD could send commands to a robot. In addition, a targeting test was performed to establish Emily's operational accuracy in selecting items on her SGD. This consisted of placing four target stickers on the screen of the SGD in specific cells of the display. Emily was then asked to move her cursor to those targets as accurately as possible. Reaching the cell with the target was recorded as a success, selecting an adjacent cell was an error. Accuracy was determined as the number of correct selections divided by the total number of targets.

There were 12 sessions over 14 weeks, all in a separate room from her classmates. All of the sessions were videotaped and involved author 1 of this paper and a research assistant (RA), a student in the Speech Language Pathology program. The activities shown in table 1 varied in length from 23 to 65 minutes.

[Insert table 1 about here]

In sessions 1 and 2, Emily learned to use each robot program. A felt-tip marker was attached to the car-like robot, with the colour chosen by Emily, and by controlling the robot she drew on a large piece of paper placed on top of a table. She used the ‘circle’ and ‘long line’ programs to draw a flower in session 1 and an X's and O's grid in session 2. The RA aided the drawing activity by picking up the robot and placing it at the required starting locations. To play the X's and O's game, Emily used the ‘circle’ program to make her O's and the RA placed the robot in her desired location on the X's and O's grid (chosen by Emily using eye gaze).

Several math activities were devised by author 1 and the RA, and Emily trialed them in sessions 3 to 10. Sessions 3 to 7 were structured as board games where Emily was expected to move her game piece, the car-like robot, the appropriate number of spaces along the board (an enlarged board game on paper, with spaces about 10 cm^2 in size, placed on the table). A felt-tip marker was attached to the robot so that the pathway taken as Emily moved the robot over the board game spaces could be recorded. Emily was told to stay within the borders of the game board and that accuracy was more important than speed.

In session 3, the RA read the body of the "Over in the Meadow" poem [24] and Emily was expected to produce a two word reply (e.g. ‘we swim’) before she could move the robot forward according to the number mentioned in the poem (e.g. two spaces for ‘fishes two’). In sessions 4 to 7, Emily rolled a die by sending a program command from the SGD to the robot arm, and then moved the car-like robot the number that came up on the die. The board-game pathways increased in complexity of shape, thus requiring her to use more robot direct-control commands as she progressed through the sessions; for the square pathway she used forward and left in the counter-clockwise direction, and forward and right in the clockwise direction; and for the zig zag and loop-shaped pathways she also had backwards available. Emily had an opponent in the games (the RA) and was encouraged to use appropriate game playing comments (e.g. ‘YOUR TURN’).

In sessions 8 and 9 Emily put together a square and rectangular puzzle, to work on shapes and orientation, requesting items, and counting. Each puzzle piece had either a line of beetles or worms going straight across the piece or turning a corner. Emily was expected to use her SGD to direct the RA to place the desired piece (‘beetle’ or ‘worm’) ‘on’ the car-like robot, and then drive the robot to the puzzle location on a table top. After spinning the robot to properly orient the piece for insertion, she was expected to direct the RA to take the piece 'off' so the RA could insert it.

The final math activity was a connect-the-numbered-dots drawing in session 10. A 12 dot pattern of a spider's web was drawn by the RA on a large piece of paper, which was placed on the table. Emily connected the numbered dots by driving the car-like robot, with the felt-tip marker attached, from one numbered dot to the next. She was asked to make comments about her drawing.

In sessions 11 and 12, Emily did a social studies activity. The AT team suggested that if

Emily could act out a story with the robot, it might motivate Emily to write a story herself, requiring her to make two or three words sentences. Students in Emily's social studies class were creating PowerPoint[v] presentations about ancient Greece, so Emily was allowed to act out a Greek myth in an alternate presentation format. ‘Theseus and the Minotaur’ was chosen since it had potential robot action such as manoeuvring through a labyrinth [25]. Emily was expected to write the story during social studies class using writing supports (e.g. modeling and sentence frames) with her EA and then act out the myth during the robot sessions. However, Emily's EA reported that Emily lost interest in composing the myth after only a few minutes of writing. In order to continue with the intended activity of acting out the myth, the story narration (the story background) was written by author 1 and uploaded into the notepad on Emily’s SGD, thus allowing Emily to read aloud the narration as she stepped through each line on the notepad. In the sessions she acted out the movements with the car-like robot as ‘Theseus’ and the robot arm as the ‘Minotaur’ and she made up utterances for the characters (e.g., greetings) and spoke them using the SGD. Small toys were used as other characters and props. A classmate shared a picture of the Minotaur which was used as the costume on the robot arm. A movie was produced by author 1 by videotaping Emily's narration, robot movements, and spoken utterances, and then editing the videos with Windows Movie Maker[vi]. Time periods when Emily was scanning to the robot commands or vocabulary were omitted from the final movie, resulting in a finished product five minutes in length.

Prompts regarding robot control from least to most support (e.g. ‘try it’, ‘you want to turn left,’ ‘you use the blue left arrow to turn left towards the blue arm’) were given to Emily by the RA as needed. To become familiar with the new prestored phrases on the SGD robot page, Emily selected each one prior to the activities to learn what it would say. In the activities, if Emily did not respond to a natural cue, then the RA prompted Emily by asking what she thought she could say in the situation. If Emily indicated that she did not know what to say, the RA suggested examples from which to choose. Cueing for core vocabulary was given as needed by the RA by looking up symbol pathways on PASS[vii] demonstration software for the Vanguard on a laptop computer.

After the study, Emily and her teacher were asked what they thought about using the robots in the activities. The interviews were unstructured and Emily responded using her SGD and the teacher responded via email.

2.4 Data collection and analysis

To examine the amount Emily used the SGD and the length of her messages, the communication and robot manipulation events in each activity were tracked, with her permission, using the SGDs built-in Language Activity Monitor[viii] (LAM). The LAM logs SGD output, listing every character, word, and prestored phrase spoken, and every robot infrared command sent by the SGD. Communication events were also tracked using Morae Usability Analysis software[ix] by importing session videos into Morae and then the RA coded them manually. This step served to confirm the communication entries in the log and determine if some were caused by mis-selections. Communications regarding choosing the marker pen colour was excluded from analysis since they were not part of all activities. The communication rate was calculated as all communication output (word, prestored phrase, and repetition) divided by session length. The robot manipulation rate was calculated as all robot infrared program and direct control commands divided by session length. The SGD communication rate was graphed per session, and also versus infrared commands rate. Visual analysis of the graphs was used to examine (1) how much communication output was made by the participant in each activity, and (2) how the amount of robot manipulation performed in the activity related to the amount of participant communication.

The type of utterance was also coded from the videos (e.g. a prestored phrase from the SGD robot page or SGD language set, a letter or number character, or an utterance of one or more words composed using the core vocabulary). Whether Emily's utterance was independent or cued from the RA was also noted.

Emily's accuracy at controlling the robot was calculated from photographs of the board games after Emily completed each game. Using the ImageJ[x] program, the trace left by the felt tip marker was digitized. The AT team had proposed that if Emily stayed within the borders 75% of the time, then they would believe that Emily intended to follow the board game. Thus, accuracy was calculated as the length travelled by the robot inside the board game borders divided by the total pathway length.

All videos were observed by author 1 to identify the skills Emily demonstrated while using the SGD to control the robot. As a starting point, interactions were coded using Light's communication competence domains (e.g. linguistic, operational, social, and strategic) [21], and themes were extracted from the emerging codes. Finally, the poststudy interview responses were examined for indications of satisfaction. NVivo software was used to aid the analyses.

3.0 Results

3.1 SGD use

Emily's target selection accuracy on her SGD was 50% in trial 1 and 100% in trial 2. Figure 3a shows the rate of SGD communication output per session and figure 3b shows the rate of SGD communication output versus rate of robot infrared commands output. Figure 3b was divided into quadrants with lines arbitrarily chosen visually. The horizontal line separates low/high communication rates and the vertical line separates low/high infrared output rates. The activities in the upper-left quadrant had comparatively high communication output and low robot manipulation, those in the lower-left had low communication output and low robot manipulation, and those in the lower-right had low communication output and high robot manipulation.

[Insert figure 3 about here]

The count of types of utterances Emily made in the activities is shown in table 2. In the drawing and board game activities she generally used only the prestored phrases on the SGD robot page and other utterances that counted as one 'word' in length. For instance, she used the robot command 'STOP' in a communicative way in session 5, made a one-word comment about the activity in session 6, and said 'I'M SORRY' and 'oops' when she drove the robot over the RA's game piece in the board game in session 7. Emily used letters to shorten the length of time to compose utterances, for example, instead of spelling out the name of the player who should go first in session 7, she said the first letter of the name. In the puzzle activity, Emily began by requesting pieces by saying 'beetle' or 'worm', but since it required so many switch hits to find those words, the RA suggested that she use 'b' and 'w' instead. Though it was expected that Emily would generate two-word utterances to request a piece and help from the RA, she only said one, 'b off'. This was because she learned to use the strategy that 'on' was implied when the robot was near the pickup location, and the piece to take 'off' was implied when she stopped the robot at her chosen location on the puzzle. Thus, the puzzle activity resulted in many 'b' and 'w' utterances, and Emily gazing intently at the RA to perform the implied 'on' or 'off' function. In the dot-to-dot activity Emily generated one-word comments about what the drawings looked like ('sun' and 'octopus'), but was motivated to compose a longer sentence to request to do a second dot-to-dot drawing ('Let's again').

[Insert table 2 about here]

Emily made the most (two-words or more) utterances in the board game pathway that was structured around a word game, and in the myth. In the word game in session 3 Emily composed four two-word sentences: ‘I jump’, ‘we run’, ‘we sing’, and ‘we swim’. The only other two-word utterance in the board games was in session 6 when she said ‘I win’. Emily used prestored social phrases, one-word, and multiple word compositions for Theseus' script in the myth. In session 11 she said ‘WHAT'S UP?’ (greeting his father, the king), ‘I want to going’ (offering to go to the labyrinth in place of a boy), and ‘I will win’ (indicating that he would kill the Minotaur). Emily also composed some utterances that indicated she may not have completely understood the story. For example, when Theseus met Crete's king (an antagonist) she said, ‘hi’ and ‘IT'S NICE TO MEET YOU’. Also, when the king's daughter said she would tell Theseus the secret of how to escape the labyrinth, but only if he married her, Emily said ‘maybe’ (but changed it to ‘okay’ after being prompted by the RA that Theseus needed the secret). In session 12, Emily's script was all appropriate: ‘Let's get going’, ‘Let’s go home’, ‘I won’ (after killing the Minotaur), and ‘I feel sad’ (after Theseus' father jumped into the sea because he erroneously thought Theseus was dead). She also independently added her own ending to the story: Theseus asked ‘You marry me’ to one of the girl characters, who responded ‘Yes’.

Emily said numbers in four of the activities, all requiring prompting from the RA. She counted items in session 6 (the number of potential game pieces for the RA, i.e., five), session 9 (the number of pieces in the square and rectangle puzzles, i.e., eight and ten), and session 11 (the number of boys and girls who would be sent to the Minotaur, i.e., seven). In session 10, she once said the number that would come next in the dot-to-dot drawing, e.g., two.

Emily independently located the prestored phrases on the SGD robot control page and SGD social comments. She also independently located letters, numbers, and the single words that she used from her core vocabulary. She composed the multiple word utterances 'I feel sad' and 'you marry me' independently, but for most sentences she needed cueing for each word (or part of a word). For example, she could start a sentence with a pronoun but could not locate the verb. For 'I want to go', she needed cueing for which connector word to use, where to locate it, and how to end the verb (she first said, 'going').

3.2 User skills themes

Themes 1–4 regarding the skills needed to use an SGD to control a robot emerged from observations of Emily's efforts to control the robot, and are described below with examples.

1. Extending from Light's AAC linguistic competency domain [21], the robot operator must understand and use the symbols on the SGD in order to control the robot's movement as intended. Emily readily understood the symbolic mapping of the arrows for direct control of the robot, including the colour coded turn commands; she used them appropriately to orient the robot as needed. She chose the correct symbols to run the programs that turn the car-like robot in a circle and to roll the dice with the robot arm, but she had difficulty with programs 4 and 5 that instruct the robot to move forward or backward, respectively, for eight seconds. She sent too many of these commands in a row, resulting in the robot overshooting the target.

2. Extending from Light's AAC operational competency domain [21], the user must be able to operate the robot accurately and efficiently. Emily's pathway accuracy results (shown in table 2) fit this operational competency theme. The accuracy of Emily's first square pathway was only 68%, but that was attributed to a robot limitation (because it made wide turns). When the turn commands were modified so that one wheel went forward while the other went backward, making tighter turns, Emily's accuracy was 88% or higher on subsequent pathways (square, zig-zag, and loop-shaped). Emily's control of the car-like robot and robot arm was sufficient to accomplish all

of the other activities.

3. Extending from Light's AAC social competency domain [21], the robot operator must be able to interact with others using robot actions. Emily was able to use the SGD to control the robot and interact in many ways with the RA—drawing, playing a board game, making a puzzle, and acting out a story. Emily also demonstrated social skills because she had access to the robot. She demonstrated her sense of humor when she drew circles around every number on the spider's web dot-to-dot drawing after the RA joked that an accidental circle looked like a flattened bug. She independently ensured that her robot characters were face-to-face with other characters when she was about to speak to them in the myth, despite the fact that she never had the opportunity to independently orient her manual wheelchair for face-to-face conversation.

4. Extending from Light's AAC strategic competency domain [21], the robot operator must determine the correct time to switch between robot and communication modes and choose the most efficient methods to accomplish tasks. Emily did not spontaneously switch between communication and robot control modes. She tended to stay in the robot control mode until an utterance was expected from her. However, Emily did learn some strategies for the most efficient methods to accomplish tasks. For example, she learned that pressing and holding her switch when selecting the direct forward command (e.g. forward one step) resulted in continuous robot movement. She used the 'STOP' infrared command on the SGD robot page (which said 'stop' as auditory feedback) rather than going to the word in her core vocabulary. Emily also demonstrated strategic preferences during the activities. For example, she preferred to use the robot arm to roll the die rather than using the random number generator on the SGD. Conversely, she preferred to play X's and O's on the SGD rather than drawing out the grid and making the O's with the robot.

3.3 Satisfaction

Emily was an enthusiastic partner in all robot activities and was always motivated to keep working toward the completion of an activity. When asked specifically what she thought of doing the activities with the robots, she responded with positive statements (e.g. ‘awesome’ or ‘THIS IS FUN’). The teacher was also positive about Emily's involvement in the study. She noted that the robots allowed Emily to link with the curriculum and with other students using unique, motivating, and fun technology. The reported that Emily’s attention was sustained for a long time and Emily had opportunities to make decisions, use her thinking skills, and improve her head switch control of her communication device. The teacher reported that Emily's classmates were enthusiastic about the movie when it was shown in social studies class; one classmate said ‘I wish I did that with my robot’ (referring to his robot programming in science class).

4.0 Discussion

Emily appeared motivated to accomplish math and social studies activities using an SGD to control a robot. She participated eagerly in the activities, and asked that some activities be repeated, e.g. ‘Let's again’ in the dot-to-dot drawing. The teacher noted that Emily’s attention was sustained in sessions of 60 minutes, for instance, while she was moving the robot and making up appropriate utterances to act out the Greek myth. This contrasts with Emily’s loss of interest after a few minutes of writing the myth with her EA. Increased participant engagement is consistent with previous robot studies [26].

Figure 3 shows how much Emily ‘used her device’ during the activities; her communication rate varied from 0 to 0.38 events per minute and her infrared output rate varied from 1.9 to 7 events per minute. The maximum infrared output rate is about 15 times higher than her communication rate; this is logical because it took more time to search for and compose communication utterances than to move the robot. The high number of switch hits required for infrared output could have contributed to the improvement in Emily's head switch control identified by her teacher. It takes a great deal of practice using switches for scanning to develop expert skills [27]. This project suggests that controlling a robot could be a motivating activity to engage students in practice using their switches, potentially providing carry-over gains in access to AAC and computers.

Some of the math and social studies activities required more communication or manipulation than others. Figure 3b shows the manipulation (robot control) versus communication output trade-off. Emily made fewer word selections in more action-focused activities requiring more robot manipulation commands (e.g. dot-to-dot drawings and board games in the lower right quadrant of figure 3b), whereas Emily made more word selections in less manipulation-focused activities (e.g. puzzle and myth in the upper left quadrant of figure 3b). Higginbotham, Bisantz, et al. [28] found a similar task effect with SGD output being lower for tasks requiring more physical actions. They found that the communication rate was highest for a narrative task, lower for an instruction-giving task involving drawing on a map, and lowest for a cooperative puzzle building task. If robots are used to motivate students to build SGD skills, the manipulative task requirements should be taken into account so that the student can focus on the intended skill to be practiced: When the goal is operational (e.g. improved switch use) the activity could be following pathways or making dot-to-dot drawings. When the goal is linguistic (e.g. increasing the length of utterance in words) the activity could be acting out a story with the robot taking on roles.

Emily generated some utterances two or more words in length in some of the activities, e.g., ‘Let's again’ in the connect-the-dots drawing, in the word-based board game and the myth. Though she usually needed cueing to generate them, she was actively involved in the process. We hoped that Emily would independently achieve four-word utterances in these activities, as she sometimes demonstrated while chatting socially. However, social conversation was familiar to her, whereas these activities were new. Also, length of utterance tracking did not fully capture Emily's communication competence. To generate utterances of two to four-words, the core vocabulary had to be used and it took Emily a lot of time to scan to it with the switches. Emily used time-saving strategies which only counted as ‘one-word’ (prestored social and robot page phrases, letters). Telegraphic communication is actually a strategic communication competence skill used by independent communicators [21].

The themes that emerged from observing Emily use the robot were logical extensions of Light's AAC competence domains [21]. Light's AAC domains have been used practically in clinical environments for assessing user skills and setting goals [29]. This robot skills framework based on linguistic, operational, social and strategic domains could potentially be used by researchers and clinicians to categorize and focus on specific goals if using a robot in activities. This study showed that robot use may be beneficial for motivation to increase length of utterance (linguistic domain), improving access method operational skills (operational domain), and providing students a method additional to communication to interact socially (social domain).

The SGD system design might have caused Emily to experience limitations in her robot skills. For example, the symbols used for the robot program buttons could have influenced Emily's ‘linguistic’ understanding. A segmented arrow pictorial symbol was used to represent programs 4 and 5 for moving the robot forward for eight seconds. The program functions may have been understood sooner by Emily if the symbol was something that portrayed a long distance more intuitively for Emily. In addition, the symbol to switch to the core vocabulary was located at the top-right corner of the robot control page, far from the top-left start position of the scan. Although it was placed there to be consistent with her other pages, it probably limited her ‘strategic’ competence to switch between robot use and core vocabulary. This could be addressed by moving the symbol closer to the initial scan position or by making robot commands available on the main SGD page.

The comments reported above from Emily and her teacher indicated that they were satisfied with the SGD-robot activities involved in the study. Though not measured, the activities elicited social validation from Emily's classmates, as indicated by the positive comments regarding her Greek myth presentation. This study addressed Emily's link with the curriculum but it would also be important to study how children who have CCN and physical limitations can use robotic systems alongside their classmates in performing ‘hands-on’ group activities.

Because this was a case study, the results might not be the same for other students. Causality cannot be inferred because no baseline data were collected. The fact that Emily learned the robot commands at the same time as she performed the board game activity might have led her to focus more on robot control than on curriculum concepts and communication. Training on robot commands prior to commencing curriculum activities, would help to establish a student's operational skills and ensure activity expectations are appropriately set.

Strengths of this study are that the curriculum topic and goals were chosen by the teacher and AT team and the corresponding robot activities were directly relevant to those curriculum expectations. However, Emily's understanding of mathematical and social studies concepts was not evaluated in this study. She clearly understood the numbers one through six on a single die because she moved the correct number of positions in the board game; therefore, two dice should have been used to challenge her in a higher number range. Emily demonstrated excellent visuospatial skills orienting puzzle pieces in the puzzle task. Emily's inappropriate choices of utterances for the characters in ‘Theseus and the Minotaur’ illustrated that she might not have completely understood the story at first. A poststudy test of comprehension would have provided some information regarding Emily's grasp of the plot and meaning of the myth.

Future research should further develop robotic activities that focus on specific skills for students to practice (using the robot skills framework). Studies should go beyond feasibility testing to using robots as tools to learn educational concepts. For example, Emily's teacher insisted on Emily using robots to participate in mathematics activities, an area in which it is difficult to involve students with disabilities; this case study prompted the investigation of SGD control of a robot for developing and demonstrating math measurement concepts [30]. Measurement of student performance before and after robot supported activities will provide a yardstick for the educational value of assistive robot technology. Finally, the technical aspects of controlling the next generation of Lego robots from computer-based SGDs with Bluetooth output, should be further developed [31].

5.0 Conclusions

This case study demonstrated the benefits of using an SGD to control a simple low cost Lego robot. The participant, who had severe physical and communication limitations, used an SGD to control a robot to manipulate objects in academic activities tailored to her learning needs. The robot provided the motivation for the participant to use her SGD and expand her length of utterance, an important goal for children with severe physical limitations who rely on AAC.

Light's communication competence domains [21] were found to be useful for building a framework for robot control skills via SGDs. Evaluation of SGD use in the chosen activities revealed that activities must be chosen carefully if they are to be successful in developing certain skills, since some better supported operational skills versus linguistic skills. In addition, design of the SGD interface could influence the ease of use of the system. Further research and clinical practice in this area will help to build a body of evidence regarding robot use via SGDs and make progress towards children with disabilities having the benefits of integrated communication and manipulation academic activities like those experienced by students without disabilities.

Acknowledgments

To be completed after blind review.

Declaration of Interest statement

The authors report no declarations of interest.

References

[1] Van De Walle JA, Karp KS, Bay-Williams JM. Elementary and middle school mathematics: Teaching developmentally. Boston, MA: Allyn and Bacon; 2010.

[2] Fredericks AD. Much more social studies through children's literature: A collaborative approach. Through children's literature. Westport, CT: Greenwood Publishing Group; 2007.

[3] Gustafson B, MacDonald D, d'Entremont Y. Elementary science literature review. Edmonton, AB: Minister of Education, Alberta Education, Curriculum Branch 2007.Cited <files.eric.ed.gov/fulltext/ED502913.pdf>.

[4] Carbonneau KJ, Marley SC, Selig JP. A meta-analysis of the efficacy of teaching mathematics with concrete manipulatives. Journal of Educational Psychology 2013;105(2):380-400.

[5] Bley NS, Thornton CA. Accommodating special needs. In: Thornton CA, Bley NS, editors. Windows of opportunity: Mathematics for students with special needs Reston, VA: National Council of Teachers of Mathematics 1994. p 137-166.

[6] Ginsburg HP, Klein A, Starkey P. The development of children's mathematical thinking: Connecting research with practice. In: Siegel IE, Renninger KA, editors. Handbook of child psychology, volume 4, child psychology in practice. 5th ed. New York: John Wiley and Sons; 1998. p 401-476.

[7] Schlosser R, McGhie-Richmond D, Blackstien-Adler S, Mirenda P, Antonius K, Janzen P. Training a school team to integrate technology meaningfully into the curriculum: Effects on student participation. Journal of Special Education Technology 2000;15(1):31-44.

[8] Eriksson L, Welander J, Granlund M. Participation in everyday school activities for children with and without disabilities. Journal of Developmental and Physical Disabilities 2007;19(5):485-502.

[9] Wright M, Hunt L, Stanley O. Quantification of object manipulation in children with cerebral palsy. Pediatric Rehabilitation 2001;4:187-195.

[10] Howell R, Hay K. Software-based access and control of robotic manipulators for severely physically disabled students. Journal of Artificial Intelligence in Education 1989;1(1):53-72.

[11] Howell R, Martz S, Stanger CA. Classroom applications of educational robots for inclusive teams of students with and without disabilities. Technology and Disability 1996;5:139-150.

[12] Kwee H, Quaedackers J. Pocus project: Adapting the control of the manus manipulator for persons with cerebral palsy. ICORR '99: International Conference on Rehabilitation Robotics; 1999; Stanford, California. p 106-114.

[13] Eberhart SP, Osborne J, Rahman T. Classroom evaluation of the arlyn arm robotic workstation. Assistive Technology 2000;12:132-143.

[14] Smith J, Topping M. The introduction of a robotic aid to drawing into a school for physically handicapped children: A case study. British Journal of Occupational Therapy 1996;59(12):565-9

[15] Cook A, Adams K, Volden J, Harbottle N, Harbottle C. Using Lego robots to estimate cognitive ability in children who have severe physical disabilities. Disability and Rehabilitation: Assistive Technology 2011;6(4):338-46.

[16] Ljunglof P, Thunberg G, Claesson B, Olsson M, Mulenbock K, Larsson S. TRIK: A talking and drawing robot for children with communication disabilities. The 14th Biennial Conference of ISAAC - International Society for Augmentative and Alternative Communication 2010; Barcelona, Spain.

[17] Cook AM, Howery K, Gu J, Meng M. Robot enhanced interaction and learning for children with profound physical disabilities. Technology and Disability 2000;13(1):1-8.

[18] Cook AM, Adams KD, Harbottle N. Lego robot use by children with severe disabilities. CSUN Annual International Technology and Persons with Disabilities Conference; 2007; Los Angeles, California.

[19] Light JC, Drager KDR. Improving the design of augmentative and alternative technologies for young children. Assistive Technology 2002;14:17-32.

[20] Anderson A. Learning language using infrared toys. CSUN 18th Technology and Persons with Disabilities Conference; 2002; Los Angeles, California.

[21] Light JC. Definition of communicative competence. In: Light J, Beukelman DR, Reichle J, editors. Communicative competence for individuals who use AAC: From research to effective practice. Baltimore, MD: Paul H. Brookes Publishing Co.; 2003. p 3-40.

[22] Yin RK. Case study research: Design and methods. Thousand Oaks, CA: Sage; 2009.

[23] Dowden P, Cook A. Choosing effective selection techniques for beginning communicators. In: Reichle J, Beukelman D, Light J, editors. Implementing an augmentative communication system: Exemplary strategies for beginning communicators. Baltimore, MD: Paul H. Brookes Publishing Co; 2002.

[24] Wadsworth OA. Kit, fan, tot, and the rest of them. Boston: American Tract Society; 1870.

[25] Hamilton E. Mythology: Timeless tales of gods and heroes. New York, NY: Warner Books, Inc.; 1942.

[26] Cook AM, Adams K. The importance of play: AT for children with disabilities. In: Oishi MMK, Mitchell IM, Van der Loos HFM, editors. Design and use of assistive technology: Social, technical, ethical, and economic challenges. New York: Springer Science+Business Media; 2010. p 33-39.

[27] Cook AM, Polgar JM. Cook & Hussey's assistive technologies: Principles and practice.

Philadelphia, PA: Elsevier; 2008.

[28] Higginbotham DJ, Bisantz AM, Sunm M, Adams K, Yik F. The effect of context priming and task type on augmentative communication performance. AAC: Augmentative and Alternative Communication 2009;25(1):19-31.

[29] Clarke V, Schneider H. Interaact framework: Dynamic AAC goals planning guide. Pittsburgh, PA: DynaVox Mayer-Johnson 2008.Cited November 27, 2009 <http://ca.dynavoxtech.com/training/toolkit/details.aspx?id=32>.

[30] Adams K, Cook A. Access to hands-on mathematics measurement activities using robots controlled via speech generating devices: Three case studies. Disability and Rehabilitation: Assistive Technology 2014;9(4):286-298.

[31] Chung Y, Simpson R. The development of a robot controlled by speech generating devices for children. RESNA Conference; 2011; Toronto, ON

Figure 1

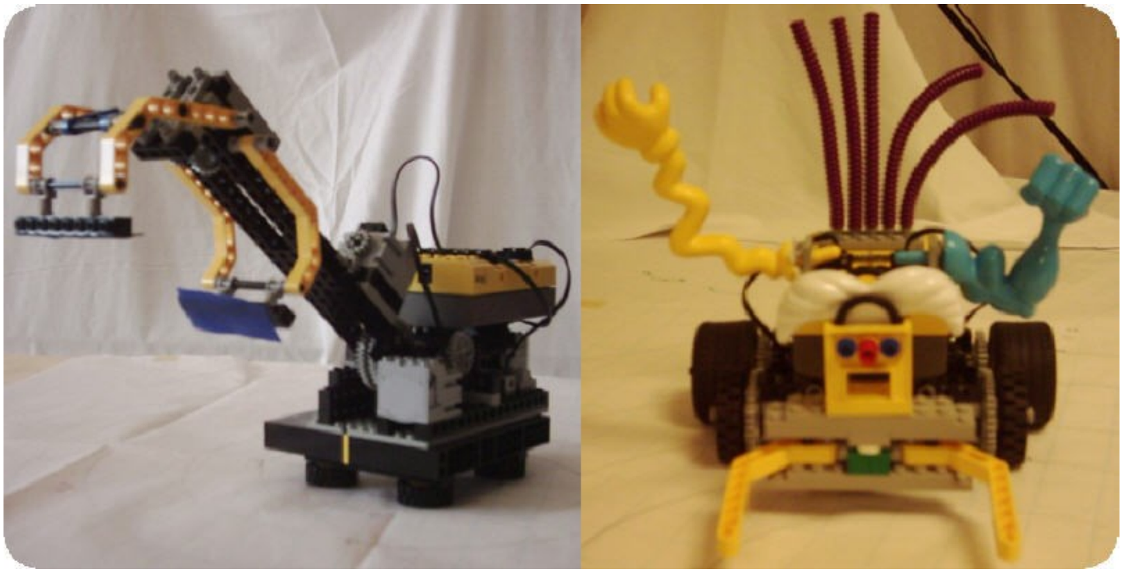


Figure 2

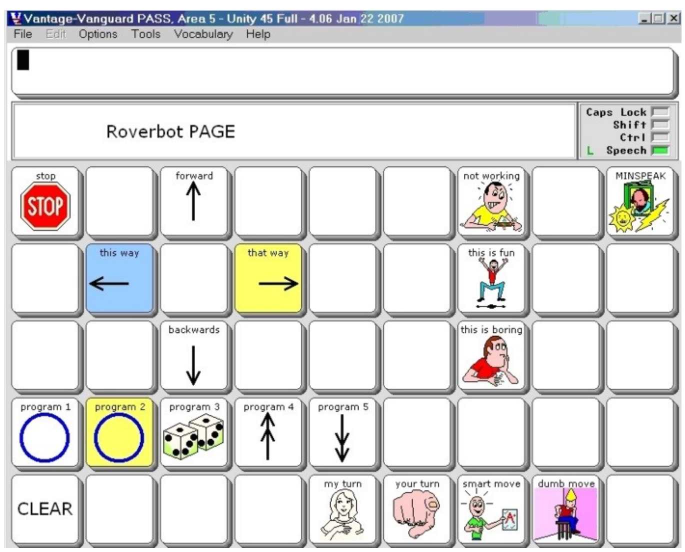


Figure 3

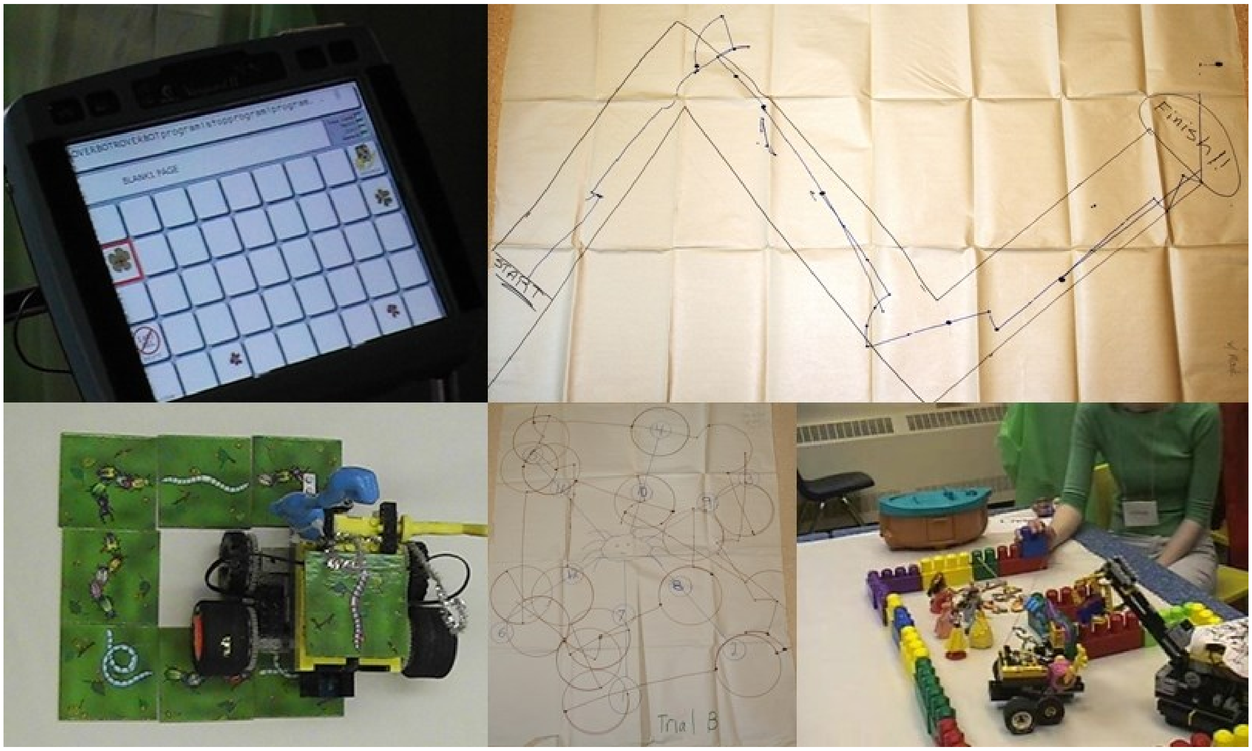
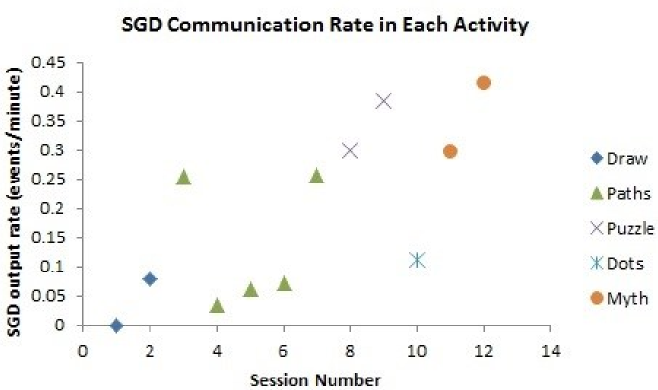


Figure 4



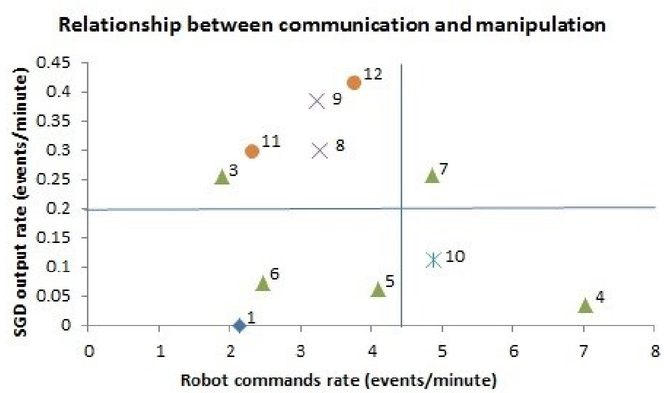


Table 1: Activities performed in each session. Time is in minutes.

Session #	**Activity**	**Time (min.)**	**Description**
1	Drawing	23	A flower (2 times)
2		25	X's and O's grid and then play game
3	Board Game Pathways	43	Straight shape as a word game
4		59	Square shape (2 times)
5		64	Long zig zag shape as a game (2 times)
6		28	Short zig zag shape as a game
7		62	Loop shape (φ) as a game (2 times)
8	Puzzle	50	Square shape
9		52	Rectangular shape
10	Dots	63	Connect numbered dot-to-dot of a spider web (2 times)
11	Acting the Greek myth	64	Part 1 - Moving the robot and saying the script
12		65	Part 2

Table 2: Number of occurrences of each type of utterance; numbers in the last column refer to accuracy (%) in the pathways

		Phrase location		Characters		Composed		
Session	**Activity**	**Robot page**	**SGD**	**Letter**	**Number**	**1 word**	**2+ words**	**Robot Accuracy (%)**
1	Drawing							
2	Drawing	2						
3	Pathways						4	Not measured
4	Pathways	2						68 clockwise(CW), 88 counter-CW
5	Pathways	3				1		88 trial 1, 96 trial 2
6	Pathways				2	1	1	90
7	Pathways	12	1	2		1		90 trial 1, 93 trial 2
8	Puzzle			4		9	1	
9	Puzzle	1		4	10	5		
10	Dots				1	3	1	
11	Myth		2		2	3	2	

12	1	5	

3-48 Corbett Hall – University of Alberta Edmonton, AB
Ph: (780) 492-8954 Fx: (780) 492-1696 Email: atlab@ualberta.ca

---

[i] Vantage is a trademark of Prentke Romich Company, http://www.prentrom.com/

[ii] Unity is a trademark of Semantic Compaction Systems, http://www.minspeak.com/

[iii] Jelly Bean is a trademark of Ablenet, Inc., http://www.ablenetinc.com/

[iv] Lego Mindstorms is a trademark of the Lego Group, http://www.lego.com/

[v] PowerPoint is a trademark of Microsoft Corporation, http://www.microsoft.com

[vi] Windows Movie Maker is a trademark of Microsoft Corporation, http://www.microsoft.com

[vii] PASS software is a trademark of Prentke Romich Company, http://www.prentrom.com

[viii] Language Activity Monitor (LAM) is a trademark of Prentke Romich Company, http://www.prentrom.com/

[ix] Morae is a trademark of TechSmith Corporation, http://www.techsmith.com/

[x] ImageJ is not subject to copyright protection and is in the public domain, National Institute of Health, http://rsb.info.nih.gov/ij/