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Assistive technology for hands-on learning by children with physical disabilities

Perspectives or Theoretical Framework for the Research

Current elementary school mathematics pedagogy promotes the use of manipulatives for learning early concepts (Van De Walle, Karp, & Bay-Williams, 2010). Manipulatives can be concrete, such as beads or fingers; or virtual, such as interactive virtual representation of objects on a computer screen. While such approaches have long been shown to enhance students' achievement of specific mathematics outcomes (Carbonneau, Marley, & Selig 2013), students with severe physical disabilities are disadvantaged since their impairments limit participation. Indeed, there is evidence of lower participation (Eriksson, Welander, & Granlund, 2007) and lower performance (Jenks et al. 2007) in mathematics among children with physical disabilities compared to their typically developing peers.

Assistive technology (AT) can be used by students with disabilities to give access to learning materials and promote independence (Mumford & Chau, 2015). There are two AT strategies that have been studied with children with physical disabilities to manipulate objects: a) a Lego Mindstorms™ robot to move concrete objects (Adams & Cook, 2014), or b) a computer with virtual manipulatives programs (Stanger, Symington, Miller & Johns, 2000). Yet, there is limited understanding of the strategies that could lead to a positive learning outcomes for students and a lack of access to appropriate information and support for planning and assessment by teachers.

The use of manipulatives to aid conceptual understanding of mathematics provides a bridge from the concrete to the abstract (Marley & Carbonneau, 2014). Theories about AT's role in learning are not yet established (Edyburn, 2002), but there are several frameworks to evaluate the factors that influence outcomes in a student-AT-task interaction. The Student-Environment-Task-

Tool (SETT) framework (Zabala, 1995) is suggested for educational settings (Edyburn, 2002). The SETT components are: **S**tudent skills, abilities and preferences; **E**nvironmental facilitators or barriers; the expected **T**ask demands; and the AT **T**ool features required to bridge the gap between task demands and the student's abilities (Zabala, 1995). This framework guided the data collection and analysis in this study.

The long term outcome of this study is to enhance mathematics curriculum for children with physical disabilities. Through the documentation of experiences and assessment of strengths and limitations of the AT strategies, we will provide educational staff with practical information to implement mathematics learning activities. This study will begin to contribute to the scant literature on learning mathematics by children with severe physical disabilities.

Methods

The research question that guided this study was: "What is the performance of students with physical disabilities when they use the following strategies to learn mathematics concepts through manipulatives: a) observation of staff; b) robot control of concrete manipulatives, and; c) computer control of virtual manipulatives?"

Design: To examine our research question, we performed a mixed methods study (Creswell, 2003). A single case research design was performed to examine performance (Kazdin, 2011). This type of design has been used to study mathematics and manipulative use by children with cognitive impairment (Bouck, Satsangi, Doughty & Courtney, 2013). The independent variable was the type of assistive technology (the robot for concrete manipulatives or the computer for virtual manipulatives) and the dependent variable was performance. In the baseline the student did the lessons the way he would normally with the researcher (who was a teacher). The intervention alternated (as possible) between the robot and the computer with the first condition chosen

randomly. In addition, qualitative data was collected to obtain a rich description of the interactions (observations and interviews). Ethical approval was obtained from the university's human research ethics board.

Participants: Two students with physical disabilities have participated so far, and we are recruiting four more students. The participants were a 6-year-old boy and a 4-year-old boy. The pseudonyms Ethan and Dylan, respectively, will be used here. Ethan is in kindergarten and had a brain stem stroke about one year prior to the study, and was non-verbal. Dylan is in preschool and has cerebral palsy. Both participants have limited movement in their upper and lower limbs, such that they cannot hold or point to concrete manipulatives. Neither had visual impairments. Participants used the alternative access methods that had been recommended by their assistive technology team to control the robot or computer. Ethan used a HeadMouse to control the cursor on his communication device and a hand switch mounted on his wheelchair lap tray to do mouse clicks. Dylan used two head switches mounted on his wheelchair head rest.

Participants' teachers were interviewed to pick a mathematics concept goal. Ethan's mathematical concept goal was counting up to 10, and Dylan's mathematical concept goal was sorting objects. At the end of the study the participants and their mothers were interviewed.

Setting: Though the goal is to have sessions in schools, these sessions took place at a rehabilitation hospital. Participants' mothers were present during the sessions.

Materials: Mathematics activities to address the mathematical concept goal were chosen from "Maximizing Math K"(Campbell, Barteaux & Holden, 2007). Several activities were adapted for the robot and the computer, and were matched to be similar in mathematical concept addressed (see Fig 1). A Lego Mindstorms robot was used, and a gripper was added for grasping the concrete manipulatives, and a pointer was added for pointing to objects while counting them. The Lego

robot was controlled using a program written in MATLAB™. Ethan used his HeadMouse and switch and his communication device to send the required commands to the program to make the robot move. Ethan placed blocks with objects attached to the top of them onto a ten-frame, and counted objects using the pointer. Dylan's head switches were connected to the computer with the robot program using a Don Johnston Switch Interface™. Dylan sorted toys of different types, such as food and cars (Fig. 1, right), and cards with different images, such as superheroes and monsters.

For the virtual activities, Ethan's HeadMouse was connected directly to the computer, and again, Dylan's switches were connected to the computer through the switch interface. Ethan used the following free computer programs: Ten Frame[1], Ladybird Spots[2], Underwater Counting[3], Do You See My Seahorse[4], and Spider Count[5]. For Dylan, the virtual manipulatives were custom pages made using Grid 2™ software (Fig. 1, right).

Fig. 1. Dylan sorting concrete manipulatives (left) and virtual manipulatives (right).

Procedures: Prior to implementing the baseline and the intervention, each student's access method competencies were assessed (Adams & Cook, 2010). This test examines user accuracy and speed on the AT platform. Next, the participants learned to use the robot and the computer by performing

[1] Ten Frame: http://illuminations.nctm.org/activity.aspx?id=3565;
[2] Ladybird Spots: https://www.topmarks.co.uk/learning-to-count/ladybird-spots
[3] Underwater Counting: https://www.topmarks.co.uk/learning-to-count/underwater-counting
[4] Do You See My Seahorse: http://pbskids.org/catinthehat/games/do-you-see-my-seahorse [5]
Spider Count: https://www.turtlediary.com/game/spider-count.html.

tasks not related to the mathematical concepts, such as building towers or playing simple computer games, in order to expose the student to the different skills required to control the robot and the software.

Data Sources or Evidence for the Research

All sessions were video recorded. In order to collect each student's performance, percentage of correct problems solved out of 10 was tracked (as in Bouck, et al. 2013). Each data point was 10 mathematics problems. Sometimes, more than one data point happened in a session, and sometimes it took more than one session to collect a data point.

Daily field notes and observations were made documenting Student-Environment-Task

Tool factors (e.g., student alertness, distractions). Other data, which could be possible factors influencing outcomes when using assistive technology, were also tracked such as *efficiency* (time for the student to complete each mathematics problem), *effectiveness* (number of device related problems) per problem, and level of prompting required for the student to complete each problem. Analysis of this data is currently underway.

Results and Conclusions

Pre-existing abilities: Ethan and Dylan were accurate at using their access method, so it was expected that if they had problems performing the mathematics problems, it was because of their understanding of the mathematical concepts.

Training: Ethan was able to manipulate both the robot and the computer adequately. Dylan had problems controlling the robot and computer when sequencing was required (e.g turn the robot and then move straight, or move a highlight box on the computer to a choice and then select it). Therefore, all activities were simplified to only need a left or right switch hit to make a choice for sorting.

Baseline and Intervention: Ethan's and Dylan's percentage of correctly answered problems are shown in Fig.2. Note that the first four data points of Ethan's baseline involved significant guidance by the teacher. For the next three data points of the baseline, Ethan did the activities more independently by directing the teacher what to do. Two of Ethan's intervention activities involved counting without the use of the ten frame (data points number 5 and 10, respectively), and these activities were particularly challenging for him.

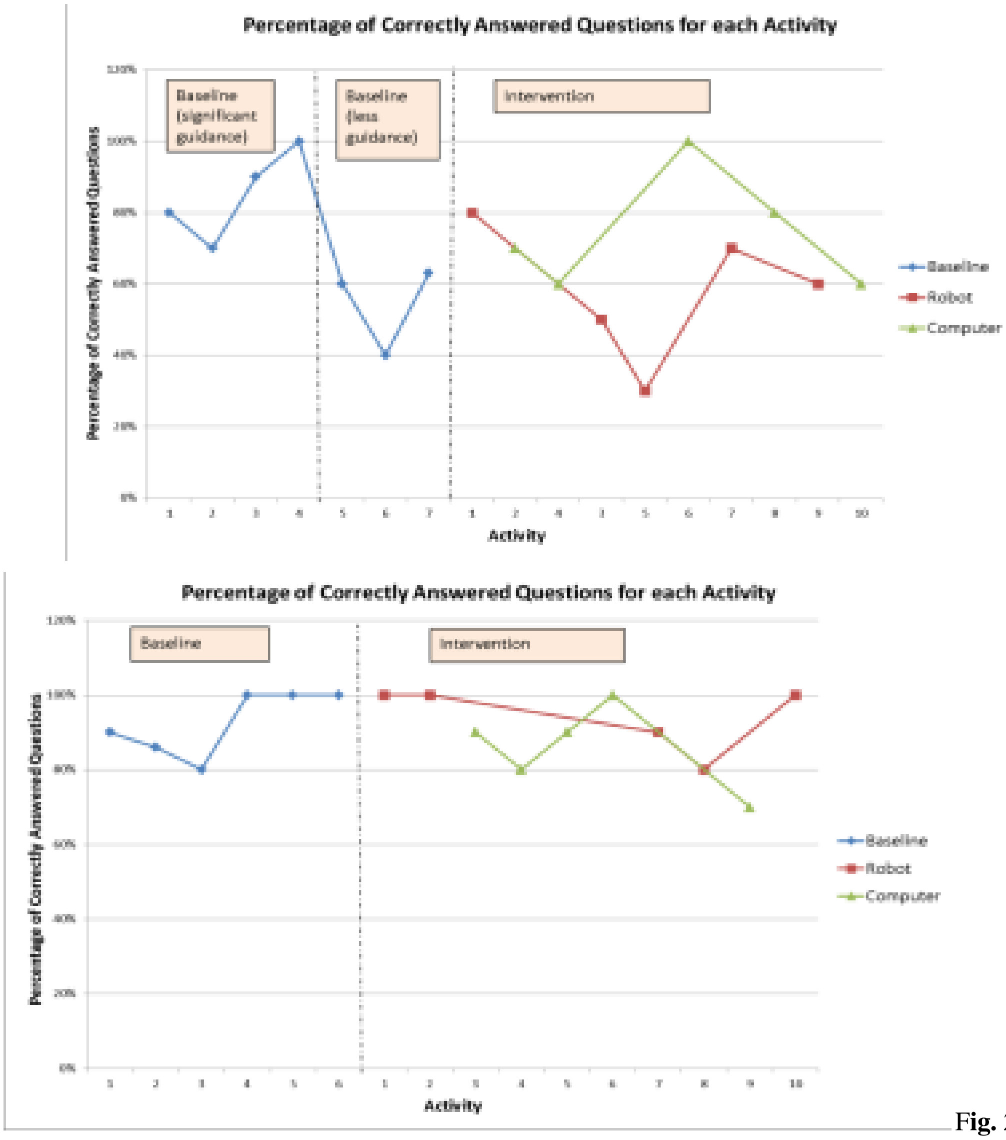

Fig. 2
Ethan’s (top) and Dylan’s (bottom) percentage of correctly answered problems

Because Dylan was achieving 100% consistently in baseline and early in the intervention, we changed the activity to sort on multiple dimensions in order to challenge him (e.g. on colour and/or shape) starting after activity 6. The final robot activity Dylan completed was purposefully intended to be fun and easy which accounts for the sudden jump to 100% for intervention data point 10.

Parent opinion: Both parents felt that their child improved their mathematics understanding and skills with both methods. Likewise, they could see their child's weaknesses, too. Both parents thought that using the robot was harder due to the extra steps (e.g., driving, looking at the objects and the robot) but they thought it was more interesting and motivating than the computer. The parents thought both strategies would be viable tools in the classroom and expressed desire to implement these strategies at home.

Conclusion: Results suggest that both forms of assistive technology were viable tools for the students to "show what they know" and solve mathematics problems relatively independently. Ethan's best performance occurred using the computer and his lowest performance occurred using the robot. One explanation for this finding with the computer is the ease of manipulation of the device, less effort, and less cognitive load. When he controlled the robot, he often got tired, requesting breaks frequently. Observations showed that Ethan developed a better sense of one-to one correspondence over the course of the study. Plus, he completed his mathematics problems with less prompting toward the end of the intervention.

Dylan's results do not show improvement over time, because the last activities were more difficult. We should have better assessed his sorting ability at the beginning of the study to prevent the ceiling effect that happened. But, using both AT strategies gave the researchers and his parent insight into his understanding of sorting.

Educational or Scientific Importance of the Research

Given that teachers need ways to assess understanding of students and student engagement is a critical factor in academic achievement (Christenson, Rschly, Whylie, 2012), using AT for children with physical disabilities to access mathematics activities is important. Each AT strategy (robot and computer) affords some opportunities for mathematics learning, while potentially limiting others. This study is investigating these in detail.

Equity as a collective professional responsibility

Mathematics is considered a particularly difficult subject in which to involve children with disabilities (Truelove, Holaway-Johnson, Leslie & Smith, 2007) and this has repercussions for lifelong learning and goal setting. Adults who have disabilities have found that limited skills in mathematics lead to restrictions in their daily living activities (managing money) and employment opportunities (Meyer & Loncke, 2008). Adults with cerebral palsy recognize education as a key to successful employment but criticize the education they received, citing low expectations on the part of the educators (McNaughton, Light & Arnold, 2002). Only 70% of Canadian parents report that they feel their children with disabilities are being challenged to their full potential in the school system (Statistics Canada, 2001). There is a need to investigate the tools for mathematics learning that will be both effective for students with physical disabilities and feasible for teacher implementation.

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