THE INFLUENCE OF CONTEXTUAL FACTORS ON ASSISTIVE TECHNOLOGY STRATEGIES FOR MATHEMATICS LEARNING IN STUDENTS WITH PHYSICAL IMPAIRMENTS

by

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ABSTRACT

Performance of students with physical impairments in mathematics are often limited because of the use of hands-on strategies using manipulatives (e.g., blocks or Cuisenaire rods) to learn early concepts. Two assistive technology (AT) strategies have been used by students to handle manipulatives, Lego Mindstorms robots and Information and Communication Technologies (ICTs). Students use alternative access methods to control a robot to move physical manipulatives, and ICTs to move on-screen simulations of manipulatives. However, the likelihood of abandonment of AT devices in the classroom is high; partly because contextual factors surrounding students have been ignored. This study attempted to explore the influence of contextual factors (personal and environmental) surrounding three students with physical impairments when they used the two AT strategies in mathematics lessons. The study used a qualitative approach in a holistic, multiple case study design. Data from observations, parents and teacher interviews, and participants' satisfaction surveys were collected. The observations were performed during a baseline phase where a research-assistant/teacher controlled the manipulatives for each student while they directed him and in an intervention phase where the students used the two AT strategies randomly to control the manipulatives. Findings showed that personal factors, such as engagement, severity of the impairment, and past experiences using AT influenced how the students used the AT devices during the lessons. Regarding environmental factors, the devices increased students' independence, were easy to use, and parents and school staff wanted to implement them in student learning. On the other hand, the students required more time to complete the lessons with the robot, and some virtual manipulatives were not compatible with the students' skills. Also, barriers such as individualized lessons, lack of technical knowledge, distractions in the environment, and funding issues, were reported.

PREFACE

This thesis is an original work by Paola Rocio Esquivel Ortiz, under the supervision of Professor Kim Adams. The research project, of which this thesis is a part, received research ethics from the University of Alberta Human Research Ethics Board, Project Name "Active engagement in mathematics for children with disabilities: a comparison of strategies for hands-on learning" No. Pro00059481, December 14, 2015.

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CHAPTER 1. INTRODUCTION

Current pedagogy promotes the inclusion of children who have disabilities, including those who have physical impairments, in educational settings (IDEA, 2004). In Canada, the Canadian Charter of the Rights of Persons with Disabilities (1982) recognizes the equal opportunity of students with disabilities to participate in academic activities. One of the most important academic disciplines in which to acquire life skills is mathematics because students learn fundamental skills, such as counting and arithmetic, which are necessary for daily life activities and the workplace (Butterworth, 2005). However, students with physical impairments tend to have a lower academic performance and limited participation in mathematics compared to their typically developing peers (Coleman, 2011).

Students with physical impairments may face challenges in the school system due to several factors, such as their physical limitations, concomitant disabilities (e.g. learning disability), or the influence of social factors (e.g. lack of school funding to provide learning materials) (Egilson & Traustadottir, 2009; Schenker, Coster, & Parush, 2005; Van Rooijen, Verhoeven, & Steenbergen, 2015; Van Rooijen, Verhoeven, & Steenbergen, 2011). In mathematics, the use of hands-on strategies to promote learning of early concepts may limit participation of these students because they may not be able to manipulate objects with their hands (Jenks, De Moor, & Van Lieshout, 2009). As a consequence, students with physical impairments may have a delay in the development of more complex mathematical abilities, such as multiplication and division (Van Rooijen et al., 2011).

To facilitate mathematics learning in children with physical impairments, assistive technology (AT) strategies have been implemented (Bouck & Flanagan, 2009; Coleman, 2011; Murchland & Parkyn, 2010). AT consists of “any item, piece of equipment or product system whether acquired commercially off the shelf, modified, or customized that is used to increase, maintain or improve functional capabilities of individuals with disabilities" (Public Law 108-364, 2004). With the use of AT, students with disabilities can perform activities that are normally not accessible to them, boosting their independence (Akpan & Beard, 2014). Likewise, these students can have better academic performance when they use AT in the classroom (Akpan & Beard, 2014).

Two AT strategies have been used with students with disabilities in mathematics for handling manipulatives. Manipulatives are hands-on practical objects, such as blocks, Cuisenaire rods, or strings of beads (Back, 2013). One of these AT strategies is Lego Mindstorms robots, which can be used to move physical manipulatives (Kim Adams & Cook, 2014b, 2014a; Encarnação et al., 2017). These robots are considered a portable low cost AT that allows children to interact with their physical environment. Lego robots are controlled via Bluetooth with software and children can access the software through different alternative access methods such as switches, eye gaze, and head control (Cook, Encarnaçao, & Adams, 2010). When children control a robot, they can push, pull, point, and carry objects by themselves (Cruz, Ríos, Rodríguez, Quiroga, & Bohórquez, 2017).

The other AT strategy is Information and Communication Technologies (ICTs), such as computer software programs, apps, and video games, which can be used to access virtual manipulatives (Burns, Kanive, & DeGrande, 2012; Cheung & Slavin, 2013; Nelson-Walker et al., 2013; Zhang, Trussell, Gallegos, & Asam, 2015). Virtual manipulatives are representations of two-and-three dimensional objects on a screen (Moyer, Bolyard, & Spikell, 2002). Students with disabilities can control ICTs through alternative access methods such as joysticks, trackballs, eye gaze, head control and switches (BECTA, 2000). There is some evidence for positive outcomes of these strategies in students with learning difficulties, including better performance and an increase of independence and motivation (Bouck, Satsangi, Doughty, & Courtney, 2014; Wilson, Majsterek, & Simmons, 1996). However, research about using ICTs for mathematics instruction of elementary students with physical impairments is still in its infancy.

Although AT has been widely used in educational settings, there is a high incidence of abandonment of AT strategies, partly due to a lack of consideration of contextual factors that surround students with physical impairments (Pape, Kim, & Weiner, 2002). The school staff and clinicians who recommend AT must not only consider the features and feasibility of the AT devices in the classroom but also contemplate the contextual factors that surround students. If these factors are taken into account, it might be possible to improve mathematics learning through AT in students with physical impairments (Egilson & Traustadottir, 2009; Söderström, 2016).

Huang, Sugden, and Beveridge (2009) highlighted the importance of considering the child-environment interaction to explore the effectiveness of an AT device in a school setting. Diverse personal factors such as student satisfaction and experience, and environmental factors, such as device characteristics should be assessed (Smith, 2000). Similarly, the opinions of parents and teachers, as well as the physical aspect of school and social interactions, must be evaluated to determine if technology can be suitable and have a positive influence in a child's performance (Huang et al., 2009).

1.1 Frameworks used in this study

The field of AT to support learning is young and does not offer well-developed theories, instead the field relies on conceptual frameworks (Edyburn, 2013). Conceptual frameworks can assist researchers to explain and understand the phenomenon being studied (Ngulube, Mathipa,

& Gumbo, 2015). In this thesis, I used three frameworks that focus on the relationship between the person, the environment, and the activity. The first one is the Person-Environment-Occupational Performance (PEOP), which is a well-known model widely used in my field of Occupational Therapy. This model serves as a framework to inform how the interaction between the person, the environment, and the occupation affects occupational performance. In this thesis the PEOP model was used to describe participants' occupational performance when they used AT strategies. The second framework is the Student-Environment-Tasks-Tools (SETT), which is used commonly in Alberta schools (Alberta Education, 2006). The SETT framework analyzes the student, the environment, and the tasks to implement AT in the classroom (Zabala, 2005). This framework was used in this thesis to design the instruments that were used to collect data. The third framework is the International Classification of Functioning, Disability, and Health (ICF). The ICF provides more specific terminology compared to the other two frameworks, elaborating on the person and the environment by including facilitators and barriers. The vocabulary that the ICF uses is a worldwide common language that can be applied in a school setting (WHO, 2013). The ICF framework was used in this study to structure the research questions and interpret the results according to personal and environmental factors that may affect the use of the AT strategies in mathematics activities.

1.1.1. Person-Environment-Occupational Performance Model (PEOP)

Christiansen and Baum developed the PEOP model in 1985 to demonstrate the dynamic nature of occupational performance. This model is depicted by four overlapping circles representing the interaction between the person, the environment, occupation and performance. At the centre is occupational performance and participation.

The person is defined as a being who interacts constantly with the environment to affect his occupational performance. The environment is the context in which occupational performance occurs. It includes socioeconomic, cultural, institutional, physical, and social aspects. The model points out that the environment cannot be put aside because it can enable or constrain behaviour, which in turn influences the environment. Occupation is considered as groups of tasks in which the person engages. Occupations are meaningful and necessary for living. Occupational performance is the complex interaction between the person, environment, and occupations that are purposeful for the person (Christiansen, Baum, & Bass, 2015).

AT is classified under the environment sphere and it can be considered as a facilitator or barrier influencing the occupational performance of the individual. The PEOP model puts aside the emphasis on technology, focusing on the person doing something in a context (Cook & Polgar, 2015). Dahlin, Iwarsson, and Sonn (2006) pointed out the need of integrating the PEOP relationship in the provision of AT, instead of considering technology as an isolated intervention. Few research studies involve all PEOP areas, especially in AT research (Dahlin et al., 2006).

1.1.2. SETT framework.

The AT decision-making process in the school setting is sometimes organized under the SETT framework (Zabala, 1995). SETT is an acronym for S (Student), E (Environment), T (Tasks), and T (Tools). Each letter symbol represents an area of consideration. Zabala (1995) states that in order to implement Tools (AT) successfully in the classroom and improve student achievement, teams must be aware of the needs, interests, and abilities of the Student, the characteristics of the Environment, and the Tasks required in the classroom.

In each area, important guiding questions are asked to support the AT decision-making (Zabala, Bowser, & Korsten, 2004):

The student: What specific skills does the student already have? The student's needs, current abilities, and interest must also be considered.

The environment: What are the attitudes of others in the environment? What is the physical layout? How much support is available from and to staff?

The tasks: Reflection questions can include: What activities will take place? How will the student participate with their peers?

The tools: The main question in this area is: What needs to be included when developing a system of AT tools for a student with these needs and abilities, doing these tasks in these environments?

The SETT Framework recognizes the relevance of collecting data through observations of the student doing activities in a natural context, interviews with people who share these environments with the student, and information about the student's needs and abilities. Zabala (2005) stated that even when the student's needs have been evaluated, if the environment is not considered, abandonment of the AT could be high.

1.1.3. International Classification of Functioning, Disability, and Health (ICF).

The International Classification of Functioning, Disability, and Health (ICF) was developed by the World Health Organization (WHO) and is used to describe the different contextual factors that can influence the level of participation of people with disabilities (WHO, 2007). The ICF describes an individual's functioning across domains of body structures, body functions, activities, and participation. These domains of functioning are influenced by the health condition and by personal and environmental factors; the latter two are called contextual factors. The model of the ICF is presented in Figure 1.

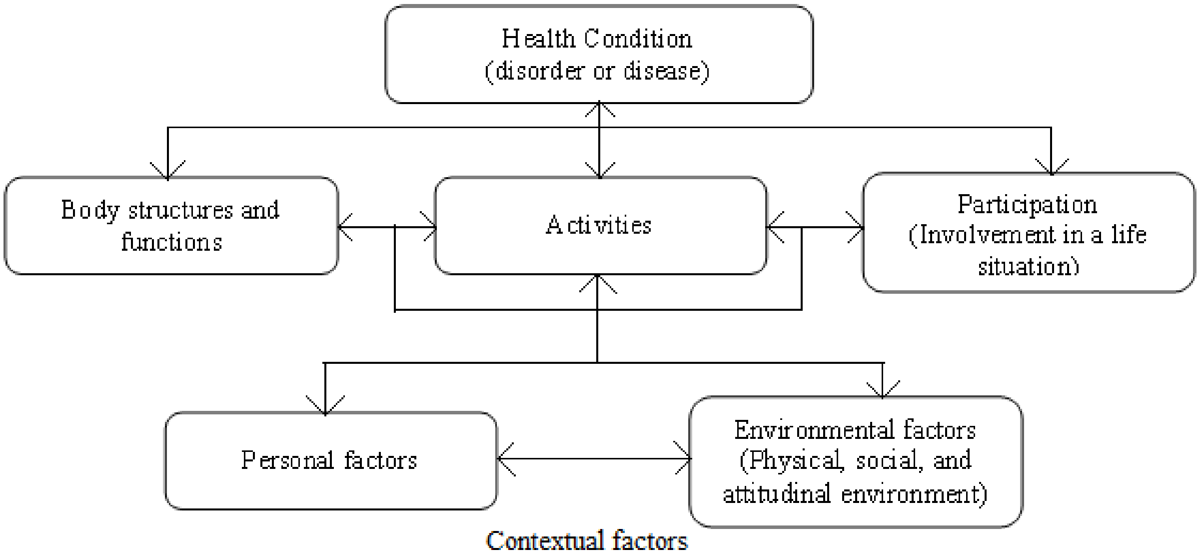


Figure 1. International Classification of Functioning, Disability, and Health (ICF) (Adapted from WHO, 2007).

According to the ICF, environmental factors are the physical, social, and attitudinal environment in which people live. Personal factors are internal factors such as age, gender, social background, past and current experience, and other factors that influence how an individual experiences disability (WHO, 2007). The ICF divides environmental factors into five domains: products and technology (also called AT); natural environment and human-made changes to the environment; support and relationships; attitudes; and services, systems, and policies. The ICF provides a schema for identifying facilitators and barriers in the environment that affect participation in people with disabilities (WHO, 2007).

The ICF applies the term "barriers" to any contextual factor that has a negative impact on an individual's functioning. Contextual factors might be a barrier for the implementation of AT. For instance a person's attitudes toward technology or a clinician's failure to consider a person's needs and preferences may prevent the successful use of AT (Hagglund & Heinemann, 2006). Other barriers in the use of AT could be lack of resources to purchase AT and lack of training to use AT. Furthermore, experience of previous failure with AT may be a negative personal factor (Hagglund & Heinemann, 2006).

1.2 Purpose of the study

The purpose of this study was to explore the influence of contextual factors surrounding students with physical limitations when they used two different AT strategies, Lego Mindstorms robots and ICT, for mathematics learning.

The research questions that guided this study were:

1) How do **personal factors** in students with physical impairments influence the use of two AT strategies, Lego Mindstorms robot and ICT, in mathematics learning?

2) How do **environmental facilitators** surrounding students with physical impairments influence the use of two AT strategies in mathematics learning?

3) How do **environmental barriers** surrounding students with physical impairments influence the use of the two different AT strategies in mathematics learning?

This study was done in conjunction with an overarching project that compared the performance of students with physical limitations when using the two AT strategies to learn mathematics concepts. In the overarching project, three case studies were conducted, and a mixed methods design was implemented. The quantitative part of the study evaluated participants' performance and level of prompting and assistance they needed when using the AT devices. The findings of this phase were published in a conference paper for the National Council of Teacher of Mathematics Annual Meeting and Exposition 2018 (Adams, McGarvey, David, Esquivel, & Morgan, 2018), and will be submitted as an article for the Journal of Special Education Technology

(Adams, Esquivel, Morgan, McGarvey, & David, n.d.). This thesis represents the qualitative part of the study. In this part, semi-structured interviews, observations, and participants' satisfaction surveys were implemented.

The research team in the overarching project was formed by my supervisor, who is a rehabilitation engineer, a special education teacher who specializes in AT, a mathematics education researcher, a research assistant, who had the role of teacher in the study (called research-assistant/teacher throughout this thesis), and myself. The research-assistant/teacher had a background in engineering and at the time of the study, was pursuing a Bachelor in Education (After-Degree). I am an Occupational Therapist and I have had experience working with children with disabilities in education. I participated in the recruitment of participants, preparation of materials, data collection, and data analysis in the overarching project. My primary responsibility was conducting observations and interviews.

CHAPTER 2. LITERATURE REVIEW

This chapter has three main parts, the first of which examines personal characteristics (physical, cognitive, and psychosocial) of children with physical impairments that could affect their performance in mathematics. The second part is a synthesis of the research about how AT has been used by children with disabilities in schools with an emphasis on robotics and ICTs in mathematics classrooms. The third part reviews related literature regarding the contextual factors surrounding children (personal and environmental factors) that may affect the use of AT in schools. The majority of the articles used were found in peer-reviewed educational research journals.

2.1. Characteristics of students with physical impairments in the mathematics classroom

Children with physical impairments present motor deficits that may affect their mathematics learning compared to typically developing peers. Students with cerebral palsy (Van Rooijen et al., 2015; Van Rooijen et al., 2011) or hemiplegia (Thevenot et al., 2014) may not be able to manipulate objects or use their fingers, and thus have a lack of motor experiences, which can lead to deficits in arithmetic skills (Van Rooijen et al., 2015; Van Rooijen et al., 2011). The use of fingers in mathematics tasks represents a visual representation system that helps children keep track of the items already counted. Thus, having difficulties using fingers in early numerical tasks, such as counting, could cause a delay with more complex mathematical tasks later (Thevenot et al., 2014).

Other physical characteristics can restrict performance and participation of students with physical impairments. For instance, children with speech language disorders may be unable to answer questions in the classroom or interact with their peers (Heller & Garrett, 2009). Also, fatigue is a crucial factor that affects students with physical impairments. These children may not be able to focus throughout a typical day at school due to fatigue (Heller & Garrett, 2009), interfering with their performance in subjects such as mathematics.

Significant cognitive limitations also affect the participation of students with physical impairments in regular classrooms. Schenker et al. (2005) analyzed participation and activity performance in children with cerebral palsy enrolled in regular schools. They stated that with increasing complexity of a child's impairment, their participation becomes more restricted, and the highest restricting factors are usually related to cognitive aspects, such as visuospatial limitations and learning disabilities (Schenker et al., 2005). Regarding visuospatial limitations, Arp & Fagard (2005) evaluated the causes for a lower subitizing skill (recognizing the numerosity of a small amount of items without counting) in children with cerebral palsy. The authors found that students with cerebral palsy tend to have a decrease in perception of the spatial relationship between elements.

Other specific cognitive skills can significantly affect mathematics learning in children with physical impairments. Jenks et al. (2009) investigated the arithmetic performance in children with cerebral palsy who were in special education or regular schools. Children with cerebral palsy in special education had deficits in executive functioning, and working memory. According to the authors, these children were more likely to develop arithmetic difficulties because of these deficits. Children with cerebral palsy in regular schools only had a deficit in handling visual and spatial information. Arp & Fagard (2005) found that children with cerebral palsy could have eye- hand coordination deficits that lead to limitations in understanding spatial relationships. Van Rooijen et al. (2015) pointed out that working memory deficit is a significant limitation for early numeracy performance of children with cerebral palsy (Van Rooijen et al., 2015).

Children with physical impairments may also face psychological problems that can affect their performance in schools. Nadeau & Tessier (2006) state that students with cerebral palsy are two to three times more likely to experience social difficulties in their relationships with typically developing peers. For instance, social adjustment, bullying, lack of friends, and peer rejection are social challenges that students with cerebral palsy may face in school. Heller & Garrett (2009) found that psychosocial factors such as poor motivation and depression can affect the learning process of students with cerebral palsy (Heller & Garret, 2009). Studies addressing psychosocial factors that specifically influence mathematics learning in children with physical impairments could not be found in the literature.

2.2 AT in schools for children with disabilities

Several articles have investigated the use of AT by students with disabilities to enhance learning. Gomez-Beleño & López-Muñoz (2016) described several AT devices that can be used in the classroom by children with cerebral palsy to facilitate access to manipulatives. The authors discussed low-tech AT, such as pen grippers and teacher-adapted materials (e.g. flashcards or wall-charts), and reviewed the use of moderate to high tech devices, such as speech-generating devices and computers. Speech-generating devices are communication devices with voice output and are used when children's natural speech is limited. These devices contribute to child's participation and interaction with peers and teaching staff (Blischak, Lombardino, & Dyson, 2003). Computers can be used for doing different school tasks, such as performing calculations, creating graphs, and navigating the internet (Gomez-Beleño & López-Muñoz, 2016). Students with physical impairments could use alternative access methods, such as joysticks and switches, to access AT in the school setting (Gomez-Beleño & López-Muñoz, 2016).

Akpan and Beard (2014), and Bouck and Flanagan (2009) discussed different AT devices as mathematics tools for all students with disabilities. Moderate to high tech AT in mathematics include MathPad Plus to do arithmetic directly on the computer, MathTalk to write mathematics through voice recognition, and calculators. Simulation games and software programs can also be used to provide mathematics lessons to students with disabilities (Akpan & Beard, 2014). Bouck & Flanagan (2009) identified in their literature review that anchored instruction (mathematics problems situated in real-life situations and presented via video) seems to be the strategy that has been investigated the most in mathematics research. However, according to some studies, students tended to decrease their computational scores after they were exposed to anchored instruction (Bouck & Flanagan, 2009).

2.2.1 Robotics

The use of robots by children with physical impairments to promote learning in educational activities has been investigated. Children with physical impairments, such as cerebral palsy, who could not normally manipulate objects with their hands, used robots in activities that involved manipulation of objects and exploration of the environment (Cook, Encarnaçao, & Adams, 2010). One robot these authors recommend is the low-cost Lego Mindstorms robot.

Some research studies have found advantages of using Lego Mindstorms robots with children with physical impairments during mathematics tasks. Adams & Cook (2014a, 2014b) evaluated the effectiveness of Lego robots controlled via speech-generating devices to improve participation of students with cerebral palsy in measurement activities. The participants used the robot to perform manipulative tasks in four measurement lessons regarding comparing, sorting, and ordering objects. The authors found that children could explain their understanding of mathematics concepts using the communication device, and demonstrate their understanding using the robot (Adams & Cook, 2014a). The increase of children's mathematics understanding over the course of the study was attributed to the opportunity to manipulate objects themselves by using the robot (Adams & Cook, 2014b). Teachers pointed out that they were more confident assessing student's understanding of mathematical concepts with the robot (Adams & Cook, 2014b). Also, they thought they could use the robot in other academic activities, and that the robot had an affordable cost (Adams & Cook, 2014a). Parents felt that the use of the robot helped to strengthen mathematical concepts in their children (Adams & Cook, 2014b). Finally, typically developing peers changed their perception by realizing that children with physical impairments could carry the same activities as them using the robot (Encarnação et al., 2017). The integration of the robot in the classroom can promote better interaction and collaboration between children with physical disabilities and their typically developing peers (Adams & Cook, 2014a).

The reviewed articles also pointed out some difficulties in using the robot in the classroom. For instance, teachers thought that training for them to support the student using the robot was necessary (Encarnação et al., 2017), and that the implementation of the robot in the classroom could be intimidating because it could need specialized technical support (Cruz et al., 2017). In addition, there were concerns that managing a group of students in general would be more difficult when the child with a disability is using the robot; thus, support from another adult would be required (Encarnação et al., 2017). Environmental factors, such as the space available in the classroom, also restrict robot use in classrooms. For instance, it could be difficult finding large tables on which to place the robot (so the students who are using wheelchairs can have the robot and the objects they are manipulating at eye level); thus, it might be necessary to adapt the activities to fit in a smaller space (Adams & Cook, 2014a).

2.2.2 ICTs

Multiple studies have investigated the effectiveness of using ICTs to improve mathematics learning in students with disabilities. Research on mathematics applications or math apps has shown diverse advantages of using these technologies. For instance, Zhang et al. (2015) used several math apps on an iPad with struggling fourth-grade students who had learning disabilities, dyslexia, autism or emotional disorders. The findings in this study showed that the apps improved students' performance in mathematics and reduced the achievement gap between struggling students and typical developing students. Furthermore, the apps allowed teachers to track student progress and weak areas, and promoted students' engagement to solve mathematics tasks (Zhang et al., 2015). Johnson (2013) implemented a survey to examine teachers' perceptions of the use of iPads for students with learning difficulties. Teachers had a positive perception of the utility of iPads in the classroom due to the familiarity and level of ease of use of this technology. In addition, the authors found that the greatest benefit of iPads, according to teachers, is the improvement of students' motivation to solve mathematics problems (Johnson, 2013).

Likewise, there are some benefits to implementing computer programs and video games in the mathematics classroom. Huang et al. (2012) implemented an Internet program for children with learning difficulties to work on addition and subtraction. Students who used the program had higher scores after the intervention than students who did not use the program. Moreover, students found that the program was easy to use, the mathematics questions were clearer on the computer than in a paper/pencil format, and the system was interesting and entertaining. Thus, they were willing to continue using the program for mathematics (Huang et al., 2012). Xin et al (2017) developed a web based computer program and compared the performance of students with learning difficulties in mathematics when using the program versus those following teacher instruction. The findings showed that the students who used the computer program improved more compared to the students who received teacher instruction. Also, there was a significant difference between the two groups in the post-intervention tests, favouring the computer program (Xin et al., 2017). Nelson-Walker et al. (2013) investigated the efficacy of a video game on a computer to improve number concepts in students with learning difficulties. The findings showed that students' scores increased in the post-test. However, the authors noted that the increase of the performance was not statistically significant because the study was only one week long and the videogame was intended to be a 12-week intervention. Students and teachers reported that the students were engaged in the mathematics problems and that the video game was easy to use (Nelson-Walker et al., 2013).

One study comparing the effectiveness of virtual manipulatives versus physical manipulatives in mathematics was conducted by Bouck, Satsangi, Doughty and Courtney (2014). These authors compared the accuracy and independence of students with autism spectrum disorder using virtual cubes in computer software versus physical cubes to solve subtraction problems. The findings of this investigation show that both techniques seem to be effective to teach subtraction skills, but the virtual manipulatives could be more effective than the physical ones. The authors suggested it could be due to the ease of using programs, as well as the graphical animation of the cubes being transferred from one place to another. One limitation that the authors stated was the location where the study was conducted (an autism clinic) where the participants received therapeutic intervention full time; thus, they received limited mathematics instruction. In addition, the presence of other students in the room could have affected the students' scores (Bouck et al., 2014). Other research studies have shown the value of virtual manipulatives for children with learning disabilities (Satsangi & Bouck, 2015) and intellectual disability (Bouck et al., 2017) but studies have yet to explore this type of ICTs for children with physical impairments.

Although there are multiple benefits of ICTs, there are also limitations found in the reviewed articles. One limitation is that most of the research studies performed drill-and-practice activities so it was difficult to know whether students acquired conceptual understanding of the mathematics concept, or if the performance improvement was because of working memory or practice effects (Kucian et al., 2011; Seo & Bryant, 2012). Regarding the use of computer programs, parents may not be willing to accept the implementation of this device with their children because it can affect a child's eyesight or children could have little time to spend on the programs because they have to do a lot of other homework (Zhang & Zhou, 2016). Some authors feel there are no advantages to using ICTs. Bryant et al. (2015) found that there was no meaningful difference in student's performance and perception across app-based instruction and teacher instruction. Wilson et al. (1996) reported that teacher-led instruction could be even better than computer instruction because students could have more opportunities to respond to the mathematics problems and receive feedback in the teacher instruction.

Finally, some methodological problems, such as many sessions performed in a short period of time, make it difficult to obtain statistical significance in increases in student's performance (Nelson-Walker et al., 2013). Moreover, students with disabilities might take more time for learning than their typically developing peers; therefore, it is unlikely that the performance of these students could improve in just one or two weeks (Seo & Bryant, 2009).

2.3 Contextual factors surrounding children who use AT in schools

Several researchers have investigated some personal factors that influence academic achievement and participation of students with physical impairments when they use AT in the classroom. Karlsson & Barker (2016) investigated some students' perceptions about the use of AT in academic activities. These were a) students felt that they could demonstrate their skills in the classroom, b) students felt that they could learn more easily, and c) students liked when they received encouragement by someone to use the AT device. Oladejo, Adetoro, Oyebade and Adedoyin (2018) stated that students with disabilities are more able to adopt a new AT device in their learning if they feel that they have the skills and self-efficacy to use the device in accomplishing a task. If students have a lack of training and do not know how to use the device, they tend to abandon it. Copley and Ziviani (2004) pointed out that if the child has motivation, resilience, and a cheerful disposition, they could fully participate in academic tasks. On the other hand, if the child has limited manipulation skills, lack of communication, and restricted mobility, they are less likely to be involved in the classroom. Sometimes, physical limitation leads to fatigue, pain, and excessive effort required during tasks, therefore the child may withdraw (Egilson & Traustadottir, 2009).

Regarding environmental factors, one of the most relevant factors in the implementation of AT in the classroom seems to be social support and attitudes that surround students. For instance, when teachers are supportive, giving assistance and encouragement to use AT, the willingness and confidence of the child to use the AT devices could increase (Huang et al., 2009). The limited knowledge of teachers about how to implement the AT devices in the classroom can also be a factor resulting in abandonment of the AT (Egilson & Traustadottir, 2009; Huang et al., 2009; Murchland & Parkyn, 2010). Finally, lack of government funding for providing AT to the schools and lack of regulations that provide support for teachers who have students with a disability may negatively influence the implementation of AT in the classroom (Jorgensen et al., 2017; Egilson & Traustadottir, 2009).

The design and features of the technology are relevant factors that can affect the implementation of AT in the classroom. The ease of use and compatibility with the student´s needs and abilities can increase the likelihood of adopting a new AT device in the student´s learning (Oladejo, Adetoro, Oyebade & Adedoyin, 2018; Jorgensen et al., 2017). Lack of portability of equipment, incompatibility among hardware and software, and limited adaptability of software for diverse needs are considered barriers to effectively integrate AT in schools (Copley & Ziviani, 2004; Jorgensen et al., 2017).

The physical environment also plays a role in the implementation of an AT device. The physical positioning in the classroom can affect the students' participation, with participation becoming limited if the child is set apart from their peers (Øien, Fallang, & Østensjø, 2015). Authors have called for future research regarding child-environment interaction in order to examine the effect of AT on children's participation and performance in the classroom (Egilson & Traustadottir, 2009; Huang et al., 2009; Söderström, 2016).

2.4 Summary of Reviewed Literature and Research Gaps

Students with physical impairments face challenges in their classroom that can potentially be reduced by the use of AT. Through the use of AT, students with disabilities can demonstrate their knowledge, achieve classroom goals, and interact actively with their peers (Karlsson & Barker, 2016; Murchland & Parkyn, 2010). Furthermore, teachers' support and knowledge about the device can make the AT a valuable tool in schools (Egilson & Traustadottir, 2009; Huang et al., 2009). However, there is limited research regarding contextual factors that may influence the implementation of AT in mathematics instruction.

Two AT strategies have been cited as mechanisms for improving performance, independence, and motivation of students with disabilities in mathematics activities: Lego Mindstorms robots and ICTs. Lego robots have been shown to enable children with physical impairments to manipulate objects, demonstrating their understanding and increasing their participation (Adams & Cook, 2014a, 2014b; Encarnação et al., 2017), but more research is needed about how the student's perceptions and physical environment can influence the application of this AT strategy in mathematics. ICTs have been considered one of the most successful virtual technologies to enhance mathematics performance in children with disabilities, such as learning disabilities and autism (Bouck et al., 2014; Huang et al., 2012; Wilson et al., 1996). However, there is little evidence of the use of ICTs with children with physical impairments.

There is a need for research studies regarding AT and its use for mathematics learning in students with disabilities (Bouck & Flanagan, 2009; Gomez-Beleño & López-Muñoz, 2016). However, it is important to acquire a holistic view of the student and the environment around him in AT research (Huang et al., 2009). This thesis provides an examination of diverse contextual factors, such as student's characteristics, student's attitude about the use of AT in mathematics activities, social environment, and features of the AT devices, that may help to determine if AT would be feasible to use by students with physical impairments in mathematics learning.

CHAPTER 3. METHODS

This chapter contains the philosophy that underpins the research, the rationale for the research design, a description of the participants, the data collection methods that I used, and the process of data analysis. The chapter concludes with ethical considerations and issues of trustworthiness.

Qualitative research is commonly used in the field of education and emphasizes description, discovery, and exploration (Bloomberg & Volpe, 2012). Qualitative research attempts to answer the research questions holistically (Baxter & Jack, 2008). The setting, people, their activities, their interactions, and their points of view are all taken into account (Merriam & Tisdell, 2016). The characteristics of qualitative research are congruent with the ICF, SETT and PEOP frameworks used in this study, which integrally consider the person-environment-occupation relationship.

Three features of qualitative research were incorporated into this study. First, the *researcher was the key instrument*. Through various methods and techniques, the researcher is the one who gathers the information and puts together different views to create a new vision (Creswell, 2003). Second, data were *analyzed inductively.* Data analysis in qualitative research uses a bottom-up approach. The results of the data analysis take shape as the researcher examines the parts and assembles them into themes (Merriam & Tisdell, 2016). Third, the study used *descriptive data*. Data in qualitative studies are words and observations rather than numbers. This form of data is used when the researcher is looking for understanding rather than a definitive answer (Creswell, 2003).

3.1 Research Philosophy

A post-positivism paradigm guided this study. Positivism follows specific scientific methodologies to establish universal laws and objective realities (Clark, 1998). In contrast, the post-positivism paradigm allows more flexibility and does not identify a correct scientific methodology (Phillips & Burbules, 2000). Post-positivist researchers engage in natural settings to create rich descriptions and meanings, as phenomenologists, but also take a structured research approach (Anderson & Arsenault, 1998). According to Phillips and Burbules (2000), a post-positivism paradigm tries to examine real-world problems and can better reflect the lived experiences of participants than other paradigms. Under a post-positivism paradigm, the results may not be generalizable. However, the research adds to the existing body of knowledge through the exploration of situations to enhance understanding (Anderson & Arsenault, 1998).

Within this thesis, the research aims to provide knowledge about how different AT strategies can be used with students with physical impairments in mathematics learning. This thesis attempts to study the interactions of the participants with the AT strategies "as they are" (Norum, 2008, p.2). Moreover, through the use of multiple data instruments, the study addresses the participants' real-world situations to try to get a better understanding of what is happening in reality. Finally, the findings are not generalizable to a broader population, but may enable future research in different contexts and types of disabilities.

A key feature of the post-positivism paradigm is the recognition of researcher bias within the study (Jennings, 2015). Therefore, it is essential to be aware of the researcher's background, knowledge, and values that may affect the interpretation of the findings. This bias is not considered a weakness in post-positivism research because it takes into account that social and historical events guide the researcher and interpretation (Jennings, 2015).

The reflections about the AT strategies and participants in this study were filtered through my knowledge and experience. I am from Colombia, and I pursued my bachelor's degree in Occupational Therapy there. During my undergraduate practicums, I worked with students with disabilities in a school setting. This experience was different compared to my experience in the school setting in Canada, where I was a volunteer. From my point of view, the school systems of both countries have some different characteristics. For instance, in Canada, the school system provides a variety of strategies to facilitate the inclusion of students with disabilities in the classrooms, such as, training to teachers, teams to assess the implementation of AT devices according to students' needs, and so on. On the other hand, in Colombia, schools are only starting to adopt the process of inclusion of students with disabilities and the creation of strategies to enhance this process. Before beginning my master's program, I had never been exposed to the use of high-tech devices to support students in the classroom. Therefore, I consider that I did not have a biased opinion on the effectiveness of assistive technology to help students with disabilities in their learning. However, prior to starting my master´s degree, I was a research assistant on a project using the Lego robot in play activities, and I saw its potential to increase children´s motivation because it was novel object. Thus, before the sessions, I considered that the robot might increase student motivation to perform mathematics tasks.

3.2 Research Design

This research study implemented a holistic, multiple case study design. Case study research can include either single cases or multiple cases. Multiple cases involve the study of a number of cases to analyze findings across them (Mills, Durepos, & Wiebe, 2009). A rich analysis can be carried out with two or more cases as opposed to a single case (Yin, 2009). The cases can be embedded or holistic (Yin, 2009). An embedded case study identifies a number of subunits each of which is explored individually. A holistic case study examines the case as one unit. The unit of analysis in this study was the student with physical impairment.

Yin's (2009) approach to case study falls within the post-positivist assumption that there is a reality that can be shaped by social structures, situations, and experiences. Use of a case study is ideal when certain conditions are met: a) the focus of the research is to answer "how" or "why" questions b) the research covers contextual situations that directly affect the phenomenon under study, c) the boundaries of the phenomenon and context are not clearly distinguishable, and d) the data collection relies on multiple sources of evidence (Yin, 2009). The research questions in this study met the criteria of a case study design. Detailed data on the use of the AT strategies by the students with physical impairments was compiled "using a variety of data collection procedures over a sustained period of time" (Creswell, 2003, p. 15). This study used observations, interviews and satisfaction surveys. Cases were analyzed individually and across using content analysis. Content analysis is appropriate because the aim of the study was to explore the influence of contextual factors surrounding the students, and content analysis allowed me to describe each case and find similarities.

3.3 Participants

The same non-random convenience sample of three students with physical impairments from the overarching project participated in the study. The pseudonyms Ethan, Dylan, and Jacob will be used here. The order that the participants are presented in this thesis is the order that they participated. All participants had difficulty moving their upper and lower limbs; therefore, they could not manipulate the objects used in mathematics activities. All of them used a manual wheelchair, not self-propelled. None of them had visual impairments and they all understood English.

Ethan.

Ethan was a 6-year-old boy, in kindergarten in a large urban school district. He had a brain stem stroke about one year before the study that resulted in quadriplegia. He was non-verbal, but he used an Accent 1000 communication device with the WordPower language system. This device had a 26 cm screen and 60 cell grid. Ethan controlled his communication device through a NuPoint head tracking interface to move the cursor on the screen and through a Jelly Bean switch on his wheelchair lap tray to select items. He hit the switch with his right hand.

Dylan.

Dylan was a 3-year-old boy, homeschooled before entering preschool, who had cerebral palsy. He was verbal but spoke softly, so he did not require a communication device. Dylan's alternative access method was two Jelly Bean switches that he hit with his left or right side of his head. During the time of the sessions, Dylan was also attending appointments in a rehabilitation hospital to learn how to control switches to operate a power wheelchair. Dylan was seated in the power wheelchair during the sessions in this study because it had head switches mounted on the headrest.

Jacob.

Jacob was a 17-year-old boy, in a special education classroom in a high school in an urban school district. His classroom was in a program intended for students of junior to senior high age with severe disabilities. Jacob had spastic quadriplegia cerebral palsy and was not able to communicate verbally, but shook his head to signal "no" and moved his right arm to signal "yes." In his classroom, he used a GoTalk communication device and the Proloquo2Go communication app on an iPad. The GoTalk is a mid-tech device where pictures or images can be inserted. The Proloquo2Go app has some pre-stored vocabulary and is customizable (AssistiveWare, 2009). His teacher added the vocabulary he was going to use during the day to the devices, especially jokes. During the study, Jacob sometimes used his iPad to tell a joke before the research sessions. While controlling the robot or the computer, he did not use either communication device.

Jacob's alternative access method was three Jelly Bean switches. A flexible mounting system was attached to the left side of his wheelchair for a head switch. Two switches were mounted on the wheelchair lap tray and he controlled them with his right hand.

3.4 Setting

Ethan's sessions took place in an AT lab in a rehabilitation hospital. During the sessions, his mother was always present, as was his brother. His mother had educational assistant experience in the classroom and sometimes gave Ethan some prompts, especially in the communication aspect (what words he should say on his communication device). His brother played computer games with a research assistant to avoid any distraction he might present, such as wanting to play with the robot. In most of the sessions, my supervisor was also present, as well as the special education teacher who was working on the overarching project.

Dylan's sessions were conducted in an AT centre in a rehabilitation hospital. It was a large space and had materials that were used in the sessions, such as toy food or cars. His mother and an education assistant that his mother hired were present in all the sessions, but did not intervene during them. My supervisor, as well as the special education teacher, were present in some sessions.

Jacob's sessions took place in a therapy room next to his special education classroom in his school. His teacher requested that the sessions be conducted there so as not to interrupt the other classroom activities. This room had some therapeutic materials, such as a swing chair, some bicycles, and rocking chairs, which other students sometimes used during Jacob's sessions. Only the research-assistant/teacher and I were present for the research sessions, my supervisor was present for the post-session interview.

3.5 Materials

3.5.1 Mathematics lessons.

Prior to the sessions, the special education teacher who worked on the overarching project met with Ethan and Jacob's teachers to discuss the mathematical concepts they were working on with the participants. Jacob's teacher indicated that he was learning preschool mathematical concepts such as spatial relationship and measurements. In the case of Dylan, the special education teacher determined the mathematical concept by choosing from the preschool mathematics curriculum. Table 1 shows the mathematical concept chosen for each participant.

Most of the lessons were based on the "Maximizing Math K" teacher resource (Campbell, Barteaux, & Holden, 2007). Lessons were adapted to be accomplished using the AT strategies. As much as possible, lessons with the robot and the computer were matched to focus on the same objective.

Table 1.

Mathematical concept for each participant

Participant	*Mathematical concept*
Ethan	Counting up to 10
Dylan	Sorting by colour, shape, or type (e.g. food or animal, fruit or car)
Jacob	Heavy/Light and In/Out

3.5.2 Lego Mindstorms Robot.

A Lego Mindstorms EV3 robot was provided through the AT lab. The features of the robot were as follows: a) a gripper for grasping and pushing concrete manipulatives (See Figure 2, left), b) a pointer that could be moved up and down for pointing at objects (See Figure 2, right), and c) robot-generated voice to count out loud. The robot was able to move forward, backward, left and right, open and close the gripper, count out loud, and move the pointer up and down. The research-assistant/teacher wrote robot control software in MATLAB that sent Bluetooth commands to the robot. The software allowed control of the robot through the participant's alternative access methods. During the sessions, if there were issues with the robot control software, the research-assistant/teacher verified if there was Bluetooth connection, or restarted the software, or adjusted the code in MATLAB.

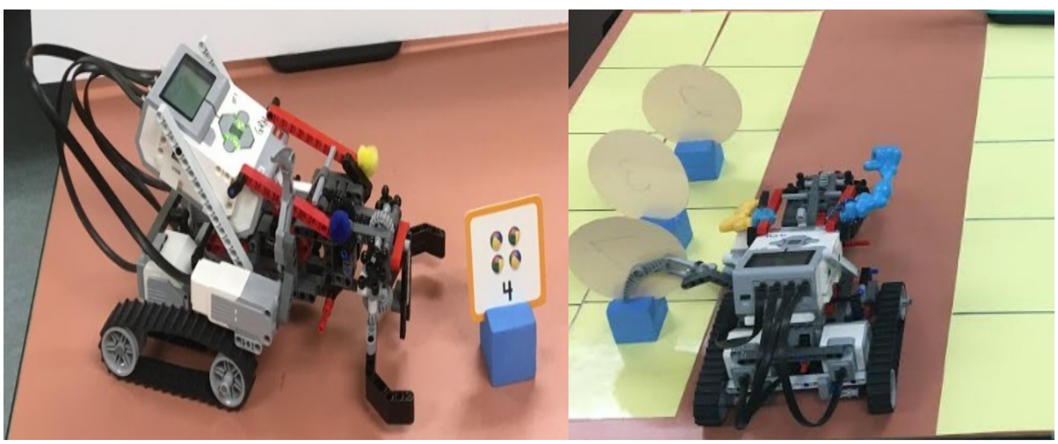


Figure 2. Lego Mindstorms robot with a gripper to grasp objects on top of blocks (left), and with a pointer to point at the objects (right).

The participants controlled the Lego robot using their alternative access methods mentioned above. Ethan used a communication page created on the Accent 1000 that had all of the robot commands and short phrases, such as "I am done," "move the robot," and so on. A USB

Bluetooth device was connected from the Accent to the computer that had the robot control software. Dylan could only move the robot to the left and right because he could only control two switches. Jacob used his head switch to move the robot forward, and the two hand switches to go left or right. Dylan and Jacob's switches were connected to the computer that had the robot control software through a Don Johnston switch interface, provided by the AT lab.

3.5.3 ICTs.

A laptop computer provided by the AT lab was used for the virtual mathematics programs. These programs were found by searching on the Internet or were created by using The Grid 2 Software or Boardmaker™, as described below.

Free virtual mathematics programs were used with Ethan and Jacob to do counting and Heavy/Light lessons, respectively. These programs were easily available online or as downloadable mathematics games. In the case of Dylan, the virtual lessons were created using The Grid 2 software (Figure 3) because it was not possible to find sorting activities that were accessible through switches. Likewise, the In/Out lessons for Jacob were created with Boardmaker™ because it was not possible to find In/Out programs accessible through switches (Figure 4).

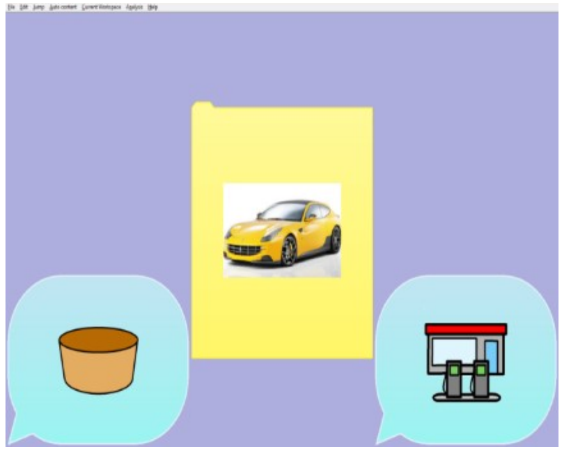


Figure 3. Sorting lesson created using The Grid 2 software. The object to be sorted is in the middle, and the two categories are food, selected by pressing the left switch, versus car, selected by pressing the right switch.

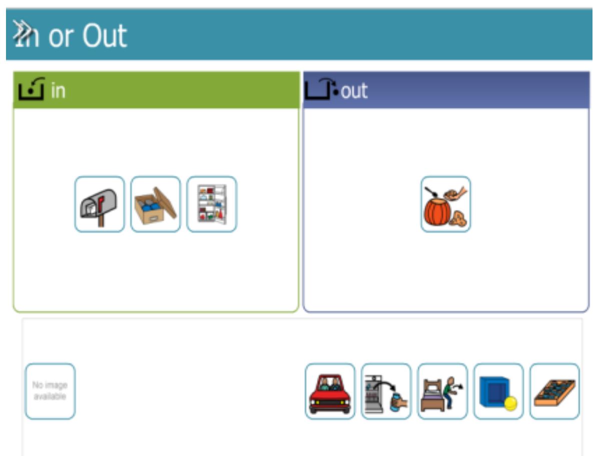


Figure 4. In/Out lesson created using Boardmaker™. The symbols at the bottom are selected and then moved into the In or Out category based on whether they are in or out.

The participants controlled the laptop computer using the same alternative access methods as they did with the robot. However, Ethan did not use his communication device. Instead, he used a HeadMouse Nano on the laptop and made mouse clicks with his hand switch. Dylan used his two head switches to choose the left or the right option. Jacob used two switch step scanning pressing his head switch to move through the options and pressing one hand switch to select the desired option. The switches were connected to the laptop computer through a Don Johnston switch interface.

3.6 Data collection instruments

3.6.1 Observations.

Observation of all of the sessions of the overarching project allowed me to identify personal factors, as well as environmental facilitators and barriers that influenced the use of the AT strategies during the sessions. I observed the sessions in person and the sessions were video recorded with the participant's permission. I imported the videos into Morae™ usability software to watch them and code events. This software allows the researcher to add timestamped notes and markers. The events tracked with Morae™ were device problems, challenges using the technology, understanding of the concepts, "aha moments" (e.g., when the student realized that he had made an error in his answer and modified his response), situations within the room that may have affected the use of the AT strategies, time to set up the robot or ICT and time to take them down. A qualitative note was attached to each event to describe the situation.

During the sessions, a field notes protocol using the SETT structure was used to record both descriptive and reflective notes (Merriam & Tisdell, 2016) (Appendix A). The descriptive part was detailed recordings of the physical setting, factors of body function (e.g. illness, use of splints), device problems, characteristics of the activity, use of the device, or performance during the lessons. The reflective information was the subjective part of the observation, meaning my own speculations and impressions related to personal or environmental factors while the student was using the AT strategies in mathematics.

3.6.2 Semi-structured interviews.

Ethan and Dylan's mothers and Jacob's teacher were interviewed after the sessions about contextual factors surrounding the students. Two interviews were conducted and together they included all SETT areas. The first interview was conducted by the research-assistant/teacher and it focused more on the Task and Tools, seeking to understand the perception of the participant's performance using both strategies, and opinions about AT characteristics (See Appendix B). The second interview was conducted by me between six months to one year after the first interview and it covered questions related to the Student and the Environment. The interviewees were asked about their perceptions about social attitudes and support surrounding the students and participants' factors of body function (See appendices C and D). Dylan's mother did not participate in the second interview because it was not possible to contact her after the study. The duration of the interviews was around 40 minutes and the interviews were audio-recorded with the parents' and teacher's permissions.

Both interviews were semi-structured interviews. One of the main characteristics of the semi-structured interview is that the questions can be open-ended and flexible, and there is not an exact wording of the questions or order in which the questions are asked (Seidman, 2013). Open-ended questions enable full and meaningful answers that allow the researcher to examine attitudes, feelings, and experiences of the participants (Bloomberg & Volpe, 2012).

3.6.3 Participants' satisfaction surveys.

Two surveys were used to evaluate participants' satisfaction using the AT strategies: *Quebec User Satisfaction with Assistive Technology 2.1 (QUEST 2.1)* for children (Murchland, Kernot, & Parkyn, 2011) and the *Psychosocial Impact of Assistive Devices (PIADS)* (Jutai & Day, 2002). The QUEST 2.1 was used to assess participant's satisfaction with factors related to the AT devices (e.g. ease of use, how it looks, weight, etc.). The PIADS examined the psychosocial impact of the AT devices. This questionnaire focuses on the functional independence, well-being, and quality of life of the individual (Murchland et al., 2011).

Each participant completed the QUEST 2.1 and the PIADS in the last session. To answer the QUEST 2.1 questions, Ethan used a 7-point smiley face scale. The smiley faces were attached to an eye gaze board, so the research-assistant/teacher could see which item Ethan was looking at. Dylan and Jacob used a 3-point smiley face scale (happy, neutral, and unhappy). To answer the PIADS questions, the same 3-point smiley face scale was used with all the participants. The surveys were administered using a Talking Mats strategy (Brewster, 2004) where a symbol representing the question was placed on a cardboard sheet under the happy, neutral, or unhappy column (See Figure 5).

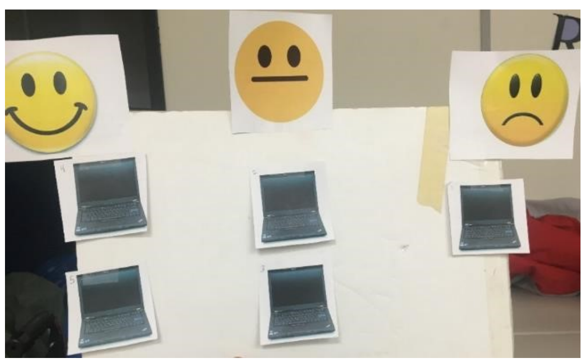


Figure 5. Talking Mats strategy with a 3-point smiley face scale to answer survey questions related to the computer. Each computer symbol represented a question from the survey.

The QUEST 2.1 and PIADS surveys were modified to have fewer choices; simplifying them for the participants and making the questions more suitable for them (See Table 2 and 3). The research-assistant/teacher explained both satisfaction surveys before starting them, including how to interpret the pictures of the smiley faces.

Table 2.

Modification to the QUEST 2.1 questions with each participant.

QUEST 2.1	*Modification of the questions*		
How satisfied are you …	*Ethan*	*Dylan*	*Jacob*
With how it looks?	How happy are you with the way the __ looks?	Did the ___ look cool or did it look ugly?	Do you think the ___ looks good? Or it is just ok? Or it is really ugly?
With how easy it is to use?	How easy was the ___ to use?	When I was setting up the ____, was I fast, or was I ok, or was I really slow?	Did the ___ was very easy to use? Or was ok? Or very hard?
With the time it takes to set up?	Did it take a good amount of time to set the things up? Or you did not really care or notice? Or did it take a way too long to set up the ___?	Not asked	How long did the set up take? Did it take a good amount of time? Or was ok? Or took a way too long?
With its reliability?	Did the __ always work that way it is supposed to? Only work half the time? Never ever work?	Not asked	Did the ___ always work the way it should? All the time? Sometimes? Or it never worked?
That it meets your needs?	Does the ___ never ever do what you want it to do, or it does what you want to do but it is not great on it, or it does everything you want every time, and it there is never ever any problem	Not asked	Did the _____ do what you needed it to do?

Table 3.

Modification to the PIADS questions with each participant.

PIADS	*Modification of the questions*		
	Ethan	*Dylan*	*Jacob*
Did you feel you were more effective to answer the math questions with the ____?	Did you feel that you could do those math problems really fast with the ____? or kind of OK speed? Or it took a really long time?	How fast do you think you were using the __? You were super-fast, in an ok speed, or really slow?	When you were using the ___, you were able to use it fast? Or OK speed? Or did it take a long time to use it?
Did you feel less upset about your progress in the math lessons when you used the ____?	When you were using the ____, did you feel that you really know how to control the___?	When you were using the ____, did it make you happy or ok or mad?	When you were using the ___, did you get mad because it was breaking all the time? Or did you get mad sometimes? Or you were never mad?
Did you feel that you were able to demonstrate your skills when you used the ____?	Do you think the ____ was good for showing me you know how to count?	When you were using the ___, did you get all the answers right, some of the answers right, or all of the answers wrong?	When you were using the ___, do you think you got the answers right all the time? Some of the time? Or almost never?
Do you feel you can use the ____ to be able to participate in the classroom?	If you were in your school and everybody was counting and I give you the ___? Do you think you could do that counting with them, joining them? Can you use the ___ to do the same thing as the other kids?	Not asked	If you got to take the ___ into a classroom with all the other kids who are measuring, you would be able to do the same thing with the ___?
Did you feel independent or not always needing help from someone when you used the ____?	When you use the ___ do you feel that you do not need help, or a little bit of help, or do you need a lot of help?	Not asked	When you were using the ___, did you feel you did everything by yourself? Or did you have some help? Or you needed a lot of help?

3.7 Procedures

I applied for ethical approval from the Human Research Ethics Board at the University of Alberta. The required operational approvals to perform research at the rehabilitation hospital and urban school district (through the Cooperative Activities Program) were also obtained.

The participants were recruited through the AT centre in the rehabilitation hospital for the overarching project. The coordinator of the centre identified potential participants who met the inclusion criteria and informed the parents about the study. If the family was interested in participating, they contacted us, and we proceeded to arrange a meeting. At that meeting, we explained the study and participants provided consent to take part in the study (See appendices E, F, and G for blank child assent form, and parents' and teacher's consent forms).

Participants were observed during two phases: baseline and intervention. In the baseline phase, the participant and the research-assistant/teacher performed mathematics lessons with the research-assistant/teacher manipulating the objects according to the participant's instruction or by asking questions, which the participant answered with yes or no signals. In the intervention phase, the participants used the two AT strategies randomly (Table 4 shows the order in which the AT strategies were presented). At the beginning of each session, the research-assistant/teacher used a visual schedule with drawings on a whiteboard to explain to the participant what AT device they were going to use in that session and what activity they were going to do. Then, the research-assistant/teacher gave the instructions to each question and prompted the participants in the use of the AT or provided assistance to complete the tasks. At the end of each session, the participants had an opportunity to play with the robot or the computer as a reward for having completed the lessons. The play activities the participants performed are described in the results.

A training protocol was implemented with the participants between the baseline and intervention phase so they could learn how to control the robot and the computer. This training involved tasks not related to mathematics but exposed the participant to all the processes needed to control the AT devices (Adams & Encarnação, 2011). Observations of the training sessions were not performed because the focus of this study was on the AT strategies in mathematics activities.

In the baseline phase, the number of lessons varied for each participant (from three to six lessons). In the intervention phase, all participants did five lessons with each AT strategy. Jacob had three Heavy/Light lessons and two In/Out lessons with each device. The number of intervention sessions to accomplish the lessons were different for each participant. Ideally, one lesson with one strategy was carried out in one session, but sometimes two lessons were conducted in one session, or one lesson was spread over two sessions. Table 4 shows the number of sessions carried out with each participant during the baseline and the intervention phases.

Prompts when participants were controlling the AT strategies were provided by the research-assistant/teacher. Usually when he gave a question, the participant started to control the devices to provide a response without assistance. If after 20 seconds, the participant did not provide any response, or if there was an incorrect answer, the research-assistant/teacher provided verbal prompting reminding the participant what he needed to do or what switch he had to press. If the participant continued pressing the wrong switches to control the AT devices, the research-assistant/teacher pointed to the switches the participant needed to press or to the object the student had to select.

The sessions were conducted twice per week. Ethan had sessions in the morning, whereas Dylan and Jacob had one session in the morning and the other session in the afternoon. Each session was one hour long. Two video cameras were located in the room where the sessions were conducted. One camera was recording the participant's face and body and the other camera was recording what was happening with the robot and concrete objects, or what was happening on the computer screen when the participant was using virtual manipulatives.

Table 4.

Lessons carried out with each participant during the baseline and the intervention sessions.

	Baseline sessions		*Intervention sessions*											
	1st	2nd	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th
Ethan's lessons		B1, B2, & B3	R1	C1& C2	R2	R2 cont'd	R3	R3 cont'd	C3	R4	R4 cont'd & C4	C4 cont'd & R5	R5 cont'd	C5
Dylan's lessons	B1, B2, & B3	B4, B5, & B6	R1& R2	C1 & C2	C3	R3 & C4	C5 & R4	R5						
Jacob's lessons	B1, B2, & B3	B4, B5, & B6	C1	R1	C2	R2	R2 cont'd	C3	R3	C4	C5 & R5			

Note. Lessons during the baseline phase (B), and with the robot (R) and the computer (C) are named as B1= Lesson 1 in the baseline phase, R1=Lesson 1 with the robot, C1= Lesson 1 with the computer, and so forth.

At the end of the intervention, participants were asked about their satisfaction with both AT strategies using the QUEST 2.1 and the PIADS, described above under the data collection instruments. Likewise, Ethan and Dylan's mother and Jacob's teacher were interviewed. I did member checking with them after I transcribed the interviews and interpreted them. The interviewees verified the accuracy of the information.

3.8 Data analysis

The process of data analysis in this thesis consisted of three phases. In the first phase, a within-case analysis was carried out using observational data. In the second phase, a cross-case analysis was conducted using content analysis to code data from interviews and observations. In the last phase, data triangulation was performed to examine the results according to the research questions. In a case study, a within-case analysis can be used initially to develop a description of each case, followed by a cross-case analysis to identify common elements among the cases, as well as the unique attributes of each case (Mills et al. 2009).

Phase I. Within-case analysis.

Field notes and observations of the videos of the sessions were used to describe each case individually using vignettes. The videos of each participant were analyzed using the Morae software (described in section 3.6.1. "Observations"). The markers of each video were exported into Microsoft Excel, thus having a spreadsheet for each video. Afterwards, the markers were compiled into an Excel document for each participant. Subsequently, each document was analyzed to separate personal and environmental factors. In this way, the observations were organized in an Excel document for each case that showed both personal and environmental factors separately.

To create the vignettes of each case, I read the observations and field notes produced for each participant to create a story in chronological order that showed a summary of participant's understanding of the mathematical concept, modifications, device problems, and so on.

Phase II. Cross-case analysis.

A cross-case analysis was performed to answer the research questions. The interviews and observations were coded using the NVivo 12 Pro software. The interviews were transcribed into a Microsoft Word document, and the observations were in Microsoft Excel documents. Word and Excel formats can be imported into NVivo. NVivo was used to administer and analyze categories that emerged in the responses.

The data were analyzed in NVivo using a conventional approach to content analysis. This approach is generally used to describe a phenomenon, and when the purpose is to classify and summarize descriptive qualitative data (Hsieh & Shannon, 2005). Content analysis "is useful in dealing with large volumes of data" (Stemler, 2001, p.1), and allows the researcher to examine the data in a systematic way by reducing the text into fewer categories (Stemler, 2001). In this thesis, an inductive content analysis was used and the categories emerged as the analysis was carried out (Elo & Kyngäs, 2008).

For the process of analyzing my data, I used the approach of Elo and Kyngäs (2008). According to these authors, the main phases of a rigorous content analysis of data are:

1. The researcher begins by selecting a unit of analysis. The researcher reads the material and becomes familiar with the data and starts selecting things of interest according to the research questions.
2. The data is coded by creating open nodes while reading the data. The data is organized by broader categories according to similar or dissimilar categories.
3. The researcher starts to describe the phenomenon by combining broader categories into

subcategories according to similar events and incidents. Subcategories are grouped together as generic categories.

4. The generic categories are combined into a main category.

Once the categories were identified, a cross-case analysis was performed for each data instrument separately. A cross-case analysis allowed to me search for similar categories and relationships in the three cases.

Phase III. Data triangulation.

Data triangulation facilitates the validity of the information through cross verification from all the data sources (Creswell, 2003). The triangulation process in this study was carried out to guide and inform the findings according to the research questions.

For research question 1 regarding student's personal factors, data from the *QUEST 2.1, the PIADS,* and themes from interviews and observations were triangulated. For research questions 2 and 3 regarding environmental facilitators and barriers, themes stemming from the field notes, interviews, and observations were triangulated.

Interpretation of the results informed how personal and environmental factors influenced the implementation of AT in the mathematics lessons. Table 5 summarizes the instruments that were implemented in this study in the data collection and how these are related to the research questions.

Table 5.

Data collection instruments.

Research question	*Data collection*	*Instruments*	*Source*
1) How do personal factors in students with physical impairments influence the use of two AT strategies, Lego Mindstorms robot and ICT, in mathematics learning?	Factors of body functions	Observations Interviews	Researcher Parents and teacher
	Satisfaction with the Lego robot and computer program	Interviews QUEST 2.1 and PIADS	Parents and teacher Student
2) How do environmental facilitators surrounding students with physical impairments influence the use of two AT strategies in mathematics learning?	Lego robot and computer program features	Observations	Researcher
	Social support and attitudes (teacher and peers)	Interviews	Parents and teacher
3) How do environmental barriers surrounding students with physical impairments influence the use of the two different AT strategies in mathematics learning?	Physical setting	Observations	Researcher

3.9 Ethical Considerations

I maintained confidentiality by using pseudonyms to protect the identity of the participants. In addition, the only individuals with access to participant information were me, the research-assistant/teacher, and my supervisor. Data was secured with hard-copy documents and external hard drives placed in a locked file and electronic material accessible to only the authorized individuals mentioned above. Data will be maintained for five years after the study. Then all data will be deleted permanently.

This study posed little to no risk to the participants. Parents were aware of possible risks, such as accidental contact with the robot, which was unlikely. On occasions, the participants became physically tired from controlling the devices; in this case, they were given a break.

3.10 Trustworthiness

Lincoln and Guba (1985) developed four accepted criteria for measuring the trustworthiness of qualitative research and ensuring its quality and integrity: a) confirmability, b) credibility, c) dependability, and d) transferability. Confirmability is concerned with the degree of neutrality of the study; i.e., the findings of the study are derived from the data and not researcher bias or interest (Tobin & Begley, 2004). Credibility is comparable to internal validity in quantitative research. Credibility links the study's findings with reality in order to demonstrate the truth of the study's findings (Shenton, 2004). Dependability refers to the consistency of the results, which can be replicated over time with the population studied (Joppe, 2000). Finally, transferability is the likelihood that the findings will be applicable to other similar situations and conditions (Trochim, 2006).

For this research study, five methods were employed to assure trustworthiness:

1. *Data triangulation.* Triangulation involved the use of multiple methods of data collection and multiple sources of data (Merriam & Tisdell, 2016). Data triangulation helped to ensure that confirmability was achieved.
2. *Member checking*. Credibility can be increased through member checking. Participants were allowed to review the information they provided after I had interpreted the data

(Shenton, 2004). We discussed the findings and the interviewees agreed that the interpretations reflected their views.

3. *Cross-case analysis*. The dependability in this study was strengthened by the findings in the cross-case analysis. The findings showed repetitions of codes across the participants.
4. *Frequent debriefing sessions*. I used a peer debriefer to establish dependability and credibility. A peer debriefer is a person who can review data collected and ask questions about the study (Creswell, 2003). The peer debriefer for my study was my supervisor and we met weekly. My supervisor provided feedback throughout the study in order to refine my thinking on the process.
5. *Thick descriptions*. The degree of transferability can be facilitated by thick detailed descriptions (Shenton, 2004). The time spent observing and asking questions about contextual factors that influence the use of the AT strategies resulted in obtaining thick descriptions.

CHAPTER 4. RESULTS

This chapter begins by presenting each case in a form of story, a vignette. Vignettes are described by Ely, Vinz, Anzul, and Downing (1997) as “compact sketches that can be used to introduce characters, foreshadow events, and analysis to come” (p.70). Then, a cross-case analysis is presented (Yin, 2009). Data from the observations, interviews, and participants’ satisfaction surveys are included to examine each of the research questions and identify similarities and differences as well as common themes across the cases (Mills et al., 2009).

4.1 Case vignettes

4.1.1 Ethan.

Ethan had participated in a trial at the I CAN Centre one year prior to starting the baseline sessions. This trial was conducted with the clinical purpose to observe Ethan’s control of a head tracking interface as an alternative access method. During this trial, Ethan controlled a Lego robot through the robot control software. He did activities that involved playful tasks, such as knocking over a tower of blocks with the robot or transporting blocks from one location to another. Ethan demonstrated excellent control over the robot and spatial awareness.

Ethan’s baseline lessons in this study consisted of counting different objects, such as dots on a balloon or dice, or marbles, and having someone put them on a ten frame recording sheet. A counting page was created on his communication device with numbers from one to ten. In the first session of the baseline phase, the special education teacher on the overarching project was the person who provided the instructions. She placed the objects on the ten frame, while Ethan counted them using his communication device. The special education teacher and Ethan did a total of three lessons. In the second baseline session, the research-assistant/teacher was in charge of providing the instruction. He and Ethan did three lessons similar to those in the first session. In the overarching project and in this thesis, only data from the second session were included because Ethan received a large amount of teacher support in the first session.

In the baseline lessons, Ethan did not need assistance to count objects up to three. When a question that required him to count more than three objects was given, the research-assistant/teacher counted out loud and pointed the objects. Ethan did not demonstrate understanding of one-to-one correspondence when he counted objects above six; therefore, the research-assistant/teacher taught Ethan how he could count each object using his communication device. Ethan often looked at his mother to ask for help. Although she did not provide any hints about the answers, she was involved along with the research-assistant/teacher in teaching Ethan how to count on his device.

During the intervention phase, he still showed difficulty in counting more than three objects in the early sessions. He often mixed the numerals six and nine. In the middle of the intervention phase, Ethan began to acquire one-to-one correspondence when counting to 10. For instance, he moved one block into each section of the ten frame and counted them with his communication device. Moreover, Ethan started using several strategies to solve the problems, according to the suggestions of the special education teacher. One strategy he used frequently was blinking for each object that the research-assistant/teacher counted out loud. In addition, he often used the counting page to count the objects together with the research-assistant/teacher.

Since he had experience controlling the robot because of the trial a year prior to the study, he was completely independent using this AT strategy. The research-assistant/teacher did not provide any assistance during the lessons regarding how to use the alternative access methods to control the robot. Likewise, Ethan did not need any assistance to control the computer due to his experience for more than one year controlling his communication device. One exception was that during four sessions, Ethan did not have his Accent device because it was broken. Therefore, a free trial version of the NuVoice software with the WordPower language set was installed on a laptop computer. The research-assistant/teacher created a robot page and a counting page similar to the ones on Ethan's communication device. However, it was difficult for Ethan to control the cursor on this laptop; thus, sometimes the research-assistant/teacher helped Ethan by clicking the objects with the mouse.

Several modifications while using the robot were made, either to the robot or to the lesson plan. For instance, a pointer was attached to the robot, so Ethan could drive the robot and have the pointer automatically move up and down to point at objects and the robot counted out loud at the same time. Ethan and his mother expressed that they really liked the pointer and his mother considered it a great resource for Ethan. Other modifications included shortcuts using the ten frame, such as starting to count after five, bringing the robot back to the starting position to reduce switch hits, moving Ethan closer to the table so he could see the objects better, or placing the objects at a height so that Ethan could see them more completely.

The most common problem with the AT strategies was that the connection of his communication device with the robot control software was sometimes lost. The research-assistant/teacher had to restart the robot control software and reconnect both devices. Furthermore, some virtual mathematics programs did not allow Ethan to change his response, going straight to the next question. Thus, if Ethan got an erroneous answer, the program did not provide any prompt or explanation of why the answer was incorrect. Also, some of these programs froze on the screen, so the research-assistant/teacher had to restart them.

Some of the play activities at the end of the session were driving the robot up and down a ramp, putting away the materials with the robot, or playing a virtual game called “Desktop destroyer”. Throughout all of these play activities, Ethan showed great enthusiasm. Several months after the intervention phase, his mother contacted us because she was interested in using the Lego robot at home for play activities.

4.1.2 Dylan.

Because of Dylan's low muscle tone, involuntary movements and poor head control, he accidentally pressed his head switches often, especially during periods of excitement. Sometimes his mother talked with my supervisor or special education teacher in the room, but this did not bother Dylan who was focused on the lessons, and it was not considered a distraction.

During the baseline phase, some of the lessons were more about labelling objects, rather than sorting them. For instance, the research-assistant/teacher showed an object to Dylan and Dylan said “it is a car” or “it is yellow”, instead of indicating which group the object belonged. In the questions where Dylan was labelling, he got all the answers correct, whereas when he was sorting he had one or two incorrect answers. A meeting with the research team helped to identify this situation and plan the lessons with the AT strategies so that the questions only involved sorting.

During the training, the hospital AT team occupational therapist initially set up Dylan to use three switches, for driving the robot forward, turning it to the right, and turning it to the left. However, he had trouble controlling the third switch with his hand to drive the robot forward, and he did not understand how to sequence the steps (turn, then go forward). Sequencing skill usually develops at five or six years of age (Cook, Encarnaçao, & Adams, 2010). That is why all of his lessons were adapted to only use two switches.

The lessons during the baseline and the intervention phase were created to sort on one dimension (e.g. colour, shape, size, or type). The lessons were created to be entertaining for him. For instance, Dylan had a preference for the colour yellow and food toys, so most of the lessons included objects with those characteristics. Dylan answered most of the questions accurately; thus, after the third lesson of the intervention phase, we decided to implement two-dimensional sorting (e.g., colour and size) to challenge him. This did present a challenge to him, and his accuracy decreased, and he sometimes expressed frustration when he got an answer wrong. In order to end off the study on a positive note, the last session included only one-dimensional sorting.

There were no device issues during the lessons with the robot. With the computer some issues arose with The Grid 2 software, such as sometimes the switches stopped working. The research-assistant/teacher attempted to repair the problem, but it was not successful, so he helped Dylan by clicking on the option with the mouse. Sometimes Dylan accidentally pressed his head switch and closed the program, so the program had to be restarted and the research-assistant/teacher had to resort the items Dylan had already done.

Dylan's play at the end of the sessions usually involved food toys and symbolic games such as cooking food or delivering food with the robot. Also, the research-assistant/teacher set up another Lego robot owned by the AT lab, to race with Dylan.

4.1.3 Jacob.

Jacob's seating did not provide enough support to stabilize his trunk; therefore, he often had difficulty holding his trunk in midline causing him to be inclined to his left side and rest on the head switch. This was a problem because it would make the robot move or make the selection on the computer move. Also the mounting system that held the head switch on the wheelchair often required adjustments. The research-assistant/teacher and I had to readjust the mounting system in most of the lessons by moving it closer to Jacob's head. Sometimes his teacher provided modifications to his seating, such as placing support on his back to help him in sitting up straight. Jacob was on a waiting list for a new seating system and wheelchair, but it did not arrive during the course of the study.

During the baseline lessons, Jacob had an adequate understanding of the In/Out questions because this was a concept that his teacher had worked on with him before. His accuracy in solving the Heavy/Light lessons in the baseline seemed to decrease over time, but the research-assistant/teacher used a Concrete-Pictorial-Abstract (CPA) approach (Bruner, 1966) during these lessons. He started first with concrete objects, then visual representations of concrete objects, and then symbolic representation of objects. The later representations were more difficult for Jacob to understand. The CPA approach was also used during the intervention phase. Again, he did better with the concrete objects than the representations of objects.

In the intervention phase, some modifications were made to assist Jacob in solving the problems. One of the main modifications was that either the research-assistant/teacher or I moved the switch away from Jacob's head while he was thinking about an answer. When he was ready to make a selection, we moved the switch closer to him, so that he could hit it only once. Also, the research-assistant/teacher helped by moving the robot back to the starting position.

Sometimes Jacob struggled to hold his head up; thus, while he was answering the questions, he was not looking at the objects or the screen. This usually happened when he got tired or distracted. When this happened, the research-assistant/teacher got his attention again, and Jacob regained his head control. Also, on certain occasions he coughed so hard that the lessons had to be stopped. We called his teacher two times while he was coughing to verify that he was okay.

In the last sessions during the intervention phase, Jacob was using other strategies to state his answer, instead of using the switches. For instance, Jacob pointed with his right hand where he wanted to place the object even though the research-assistant/teacher reminded him to use the switches to control the AT strategies. Also, while the research-assistant/teacher was giving the instruction, Jacob gave a yes or no response. On certain occasions, Jacob looked at the research-assistant/teacher before giving the answer. We interpreted this as him looking for a clue about the response; thus, the research-assistant/teacher indicated to Jacob that he would not provide any hints. His teacher had advised us that Jacob tended to examine the gestures or voice tone of the teachers to guess the correct answer; thus, we needed to be cautious about our body language so as not to reveal the response to him.

Several device problems occurred during the lessons. Sometimes the Lego robot did not follow the commands of the switches. If Jacob pressed the head switch to drive the robot forward, it turned; or, the robot did not stop when Jacob stopped pressing the switch. Regarding the virtual mathematics programs, the main issues were with the Boardmaker™. This program did not save Jacob's progress; thus, if he accidentally selected the exit button and closed the program, the research-assistant/teacher had to reorganize the objects according to what Jacob had already answered. In addition, sometimes this program froze on the screen, so it had to be restarted.

The games Jacob played at the end of the sessions consisted mostly of knocking over a tower of blocks with the robot or putting away the objects with the robot. The research-assistant/teacher played with him building towers with the blocks. Jacob expressed joy and laughed when he played with the robot.

4.2 Cross-case analysis

The cross-case analysis is organized around the three research questions and deals with each of them separately by presenting and comparing the data from observations, interviews, and satisfaction surveys. First, I present the findings regarding the influence of personal factors on the use of both AT strategies. Second, I present the results regarding the influence of environmental facilitators surrounding the students in both AT strategies. Finally, I conclude with the environmental barriers that can influence the use of the robot and the computer in mathematics learning. Data from the observations and interviews are organized by main categories and generic categories, and I discuss the findings of each generic category to answer the research questions. Generic categories are named using content-characteristic words (Elo & Kyngäs, 2008).

To analyze the observations, I created two main categories according to the research questions (personal and environmental factors). Under those categories, I classified each marker by creating 20 nodes. These nodes were grouped according to their similarity (see Appendix H).

To analyze the interviews, I created 11 nodes while reading the transcripts (performance, motivation, robot, computer, body factors, participation in the classroom, use of the strategies at home, modifications in the activity, relationships, opportunity for assessing, experiences with other participants). Then, I grouped these nodes together and began to create categories. I divided the data into 7 categories and 18 subcategories (See Appendix I). After creating the 7 categories, I carried out a process of organization and reorganization in different groups according to the research questions.

4.2.1 Influence of personal factors on the use of the two AT strategies in mathematics learning.

Results from observations.

The following tables related to personal factors provide examples of the different types of events created by observing the videos in the Morae software. The tables show data with respect to the understanding of the mathematics concepts, “aha moments”, or challenges presented in the participants. Selections show examples of when participants realized they had an error in their responses, what type of strategies the research-assistant/teacher provided to assist students to complete the questions, and participants’ comments. Tables 6 to 11 show data for each participant when using the robot and the computer.

Table 6.

Events created in Morae about Ethan's understanding of mathematics concepts or challenges during a lesson with the robot.

Ethan					
Lesson	*Time*	*# question*	*Target*	*Understanding of the concept, aha moments*	*Challenges*
R2- Ten frame bugs	25:07.7	3	8	Ethan is counting each object on his device at the same time it is placed on the frame.	
	26:49.3	3	8	The research-assistant/teacher says to Ethan: "let me know when I have put it in the right spot." Through guiding the research-assistant/teacher, Ethan lays the objects in sequence in the ten frame (from left to right starting on the top row).	
	32:29.7	3	8		Ethan signals he needs more objects on the ten frame (but it already has 8). Mother's comment: "Do you want to count them first?"
	34:00.1			Ethan states "let's put it in my idea book" with his device meaning he wants to put in his Idea Book that he was playing with the Lego robot today to tell his class. His mom writes it in the Idea Book.	
	35:10.0			Ethan's comment: "This is so much fun."	
	36:41.0	4	3		Ethan's comment: "I don't like this" (the robot is in a low speed).
	37:47.2	4	3		When asked, Ethan signals he wants the robot to move faster.
	46:52.1	5	9	Ethan realizes there is a mistake (he counts to 9 but in the ten frame there are only 8 objects) and starts counting the objects again.	

Table 7.

Events created in Morae about Ethan's understanding of mathematics concepts or challenges during a lesson with the computer.

Ethan					
Lesson	*Time*	*# question*	*Target*	*Understanding of the concept, aha moments*	*Challenges*
C4- Ten frame online	33:25.5	1	8	The research-assistant/teacher says: "we have too many objects" (there are 9), and Ethan signals yes.	
	34:17.2	3	9		While Ethan clicks and drags the object to the ten frame, the research-assistant/teacher is counting out loud.
	35:56.0	6	10	Ethan realizes he moved 8 objects but he needs 10, so he brings more objects to the ten frame.	
	37:12.0	8	6		Ethan has moved 9 objects to the frame. It seems that he is mistaking 6 and 9.
	37:56.7	8	6	The research-assistant/teacher asks Ethan if he has too many objects, and he signals yes.	
	43:08.9	10	9		Ethan puts 7 objects first, then 8, and then he takes some of the objects off, but ends up putting 10 objects. He may have been confused from having taken the objects off.
	44:05.3	10	9	Ethan is removing all the objects from the ten frame and starts again.	
	44:11.8	End		The research-assistant/teacher shows Ethan how to put 5 objects onto the frame at the same time, so the whole row is filled up.	

Table 8.

Events created in Morae about Dylan's understanding of mathematics concepts or challenges during a lesson with the robot.

Dylan					
Lesson	*Time*	*# question*	*Category to sort on*	*Understanding of the concept, aha moments*	*Challenges*
R3-Lego/Mr. Potato-green-blue	13:46.7	1	Colour	Dylan's comment: "It's blue."	
	15:20.5	2	Toy		It seems Dylan is frustrated because he got a wrong answer (he didn't understand why, because he sorted the blue arm with the blue colour, but he needed to sort by toy).
	17:04.0	3	Colour	The special education teacher stays beside Dylan repeating the instruction and giving him positive reinforcements.	
	17:40.4	4	Colour		Dylan is only pressing his left switch to move the robot, so he drives the robot in a full circle.
	19:37.3	7	Toy		The research-assistant/teacher asks: "where does it go?" Dylan says "blue." He is sorting by colour but he needs to sort by toy.
	20:29.2	9	Toy	Dylan now understands how to sort by toy. He puts a green Lego piece on the Lego box.	
	21:04.8	End		Dylan's comment: "let's build them now" (play time).	

Table 9.

Events created in Morae about Dylan's understanding of mathematics concepts or challenges during a lesson with the computer.

Dylan					
Lesson	*Time*	*# question*	*Category to sort on*	*Understanding of the concept, aha moments*	*Challenges*
C4- Red/blue circle/square	22:48.0	1	Colour		During all this lesson, the research-assistant/teacher helps with the mouse to select the options while Dylan hits the left or right switch to indicate his answer.
	25:22.5	3	Shape	Dylan realizes that the shape is a square and not a circle.	
	25:29.7	4	Colour		Dylan tries to say the answer, but the research-assistant/teacher reminds him to press the switch to select the answer he wants.
	26:45.8	4	Colour		The research-assistant/teacher asks Dylan "red and blue are the same colour?", and he answers yes. Dylan does not realize he has made a mistake.

Table 10.

Events created in Morae about Jacob's understanding of mathematics concepts or challenges during a lesson with the robot.

			Jacob		
Lesson	*Time*	*# question*	*Target*	*Understanding of the concept, aha moments*	*Challenges*
R4- In/Out of the box	10:36.8	3	Out		The research-assistant/teacher asks Jacob if he remembers where OUT goes. Jacob signals no, so the research-assistant/teacher explains it again.
	11:24.7	3	Out	The research-assistant/teacher asks Jacob if he wanted the object IN the box, Jacob signals no and he realizes he made a mistake.	
	14:41.5	7	Out		Jacob immediately hits the head switch without waiting for the instructions.
	15:13.3	7	Out	The research-assistant/teacher asks Jacob "is this object supposed to be IN the box?" Jacob signals no, so he realizes that his answer was wrong.	
	18:22.9	10	Out		Although the research-assistant/teacher explains that Jacob needs to turn the robot with the hand switch to put the object OUT, Jacob is only pressing the head switch.
	18:26.6	10	Out	The research-assistant/teacher points to the OUT symbol 'is this IN?' and Jacob signals no. He realizes his answer is incorrect.	

Table 11.

Events created in Morae about Jacob's understanding of mathematics concepts or challenges during a lesson with the computer.

Jacob					
Lesson	*Time*	*# question*	*Target*	*Understanding of the concept, aha moments*	*Challenges*
C3- Heavy/ Light Boardmaker	11:20.7	1	Light	Jacob completes the question by himself (no help from the research-assistant/teacher).	
	11:51.6	2	Heavy		When Jacob misses an option because he presses the hand switch too many times, the research-assistant/teacher helps him to come back to the option by using the keyboard keys.
	12:02.3	2	Heavy		The research-assistant/teacher says to Jacob to not press the head switch until he is on the option he wants.
	16:13.0	2	Heavy	Jacob points to the screen, the research-assistant/teacher asks him if that is the option he wants and Jacob signals yes.	
	16:39.2	2	Heavy	Because his answer was wrong, Jacob presses the hand switch to select the other option.	
	22:04.8	4	Light		Jacob is coughing a lot in this task.
	27:59.6	7	Light	Jacob has good control of his hand to press the hand switch. The research-assistant/teacher asks Jacob if that is the option he wants because Jacob is looking at him.	

Three generic categories from the observations were created to answer research question 1 about personal factors that influence the use of the AT strategies: 1) Body functions, 2) Cognitive factors, and 3) Motivation in the sessions. These generic categories fall under the main category of "psychological and motor attributes during the sessions" (See Fig 6).

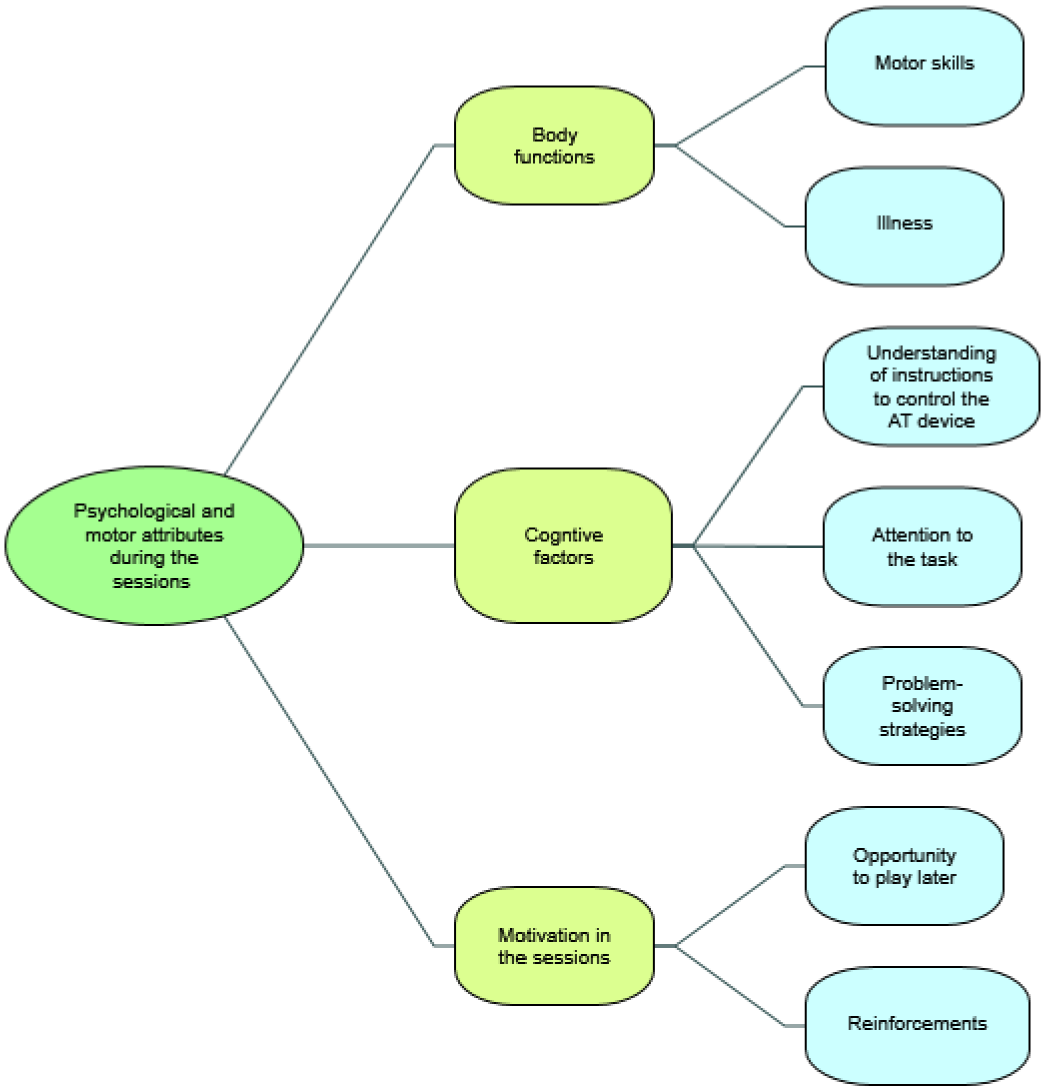


Figure 6. Categories that emerged from the observations about the influence of personal factors in the use of AT devices.

Body functions.

Under the generic category of “body functions” were the subcategories of: 1) Motor skills and 2) Illness.

During the sessions, the motor skills of the participants affected their accuracy to control the AT strategies. The involuntary movements of Dylan and Jacob caused them to accidentally hit the switches. Therefore, they could not drive the robot accurately, or they skipped options on the screen when scanning on the computer.

The participants were juggling motor, cognitive, and language factors when operating the AT strategies. They needed to control their body to press the switches, perform mental computations, understand instructions, and respond verbally or through signals to the questions of the research-assistant/teacher. The participants had to respond to more factors while controlling the robot than the computer, such as deciding in which direction they needed to drive the robot. It was observed that sometimes Dylan only used one switch to turn the robot, or Jacob often only used the head switch to move the robot, and they needed verbal prompting to use the other switch(es).

Another personal factor that affected the use of AT strategies was that participants manifested symptoms of illness, such as a cough or nasal congestion. It was noted in the observations that there was a decrease in their physical performance and level of attention when they came at the sessions ill. For instance, in one session Ethan had a stuffed nose, so he felt uncomfortable and began to cry. The session had to be stopped. Likewise, Jacob coughed often, so the lessons had to be stopped until he could recover. When these unexpected stops happened in the lessons, the research-assistant/teacher repeated any instruction the participants missed.

Cognitive factors.

In the category of "cognitive factors" were the subcategories of: 1) Understanding of instructions to control the AT devices, 2) Attention to the task, and 3) Problem solving strategies.

It was observed that the participants had differences in their operational competence in controlling the AT strategies. Ethan had no problem understanding how to use his alternative access methods to control the robot and the computer because he had more than one year of experience prior the study controlling his head tracking interface and hand switch. On the other hand, Dylan and especially Jacob, required more verbal prompting on how to properly use their switches. In general, the research-assistant/teacher gave them prompts such as "remember, the head switch is to drive the robot forward", "use your hand switch to select the option on the screen," or "you have to take your head off the switch." Although Dylan and Jacob had an improvement controlling their switches more accurately as the sessions progressed, they still needed verbal prompting or physical assistance from the research-assistant/teacher until the end of the intervention.

Regarding the level of attention of the participants during the mathematics lessons, it was observed that Dylan and Jacob had issues maintaining sustained attention during some lessons with the computer. For instance, Dylan sometimes continuously pressed the switches without letting the game indicate to him if the answer was incorrect or correct. The research-assistant/teacher had to repeat to him that he had to choose one of the two options presented. Similarly, Jacob tended to select the options at random, without looking at the screen. The research-assistant/teacher often had to get his attention; after the teacher got is attention, Jacob raised his head to look at the option he was selecting. During the lessons with the robot, the amount of times that the research-assistant/teacher had to get the participants' attention to continue with the lesson was less compared to the lessons with the computer. Therefore, the level of attention of the participants with the computer was lower compared to when they used the robot.

Another cognitive factor presented during the mathematics lessons was that participants started to use problem-solving strategies, either to solve the mathematics questions or with respect to the use of the AT device. The strategies the participants used are described in section 4.1. "Case vignettes.” Dylan and Jacob often had difficulty in controlling the switches; thus, they sometimes pointed or gave a verbal response to indicate the place where they wanted to place the object, instead of using the switches. This finding suggests that Dylan and Jacob did not master the control of their alternative access methods; therefore, they used other strategies to indicate their answers without using the AT strategies.

Motivation in the sessions.

Under the generic category of “motivation in the sessions” were the categories of: 1) Opportunity to play and 2) Reinforcements.

The participants had several opportunities to play during the lessons. For instance, the research-assistant/teacher created games with the concrete objects used in the lessons (e.g., making a poster, or drawing doodles on the objects), or provided time to play with the AT devices at the end of each session. Most of the free play activities were performed with the robot, although Ethan played with the computer a few times. During the play activities with the robot, the research-assistant/teacher interacted with the participants in a playful way.

It was observed that during the lessons, the research-assistant/teacher implemented positive reinforcements to maintain the motivation of the participants and create a good relationship with them. The research-assistant/teacher used reinforcement phrases such as: “awesome!” “excellent job!" "you got it all right," or "it is okay to make mistakes." The participants reacted to these reinforcements by smiling and being attentive to listen to the next question.

Results from interviews.

To answer research question 1 about personal factors, I created 3 generic categories: 1) Engagement using the AT strategies, 2) Student's mathematics skills, and 3) Physical requirements (See fig. 7). These categories were grouped under the umbrella concept of "psychological and neuromusculoskeletal attributes can impact the use of AT devices". After this, I worked my way from the generic categories organizing the findings using content words and creating sub-categories.

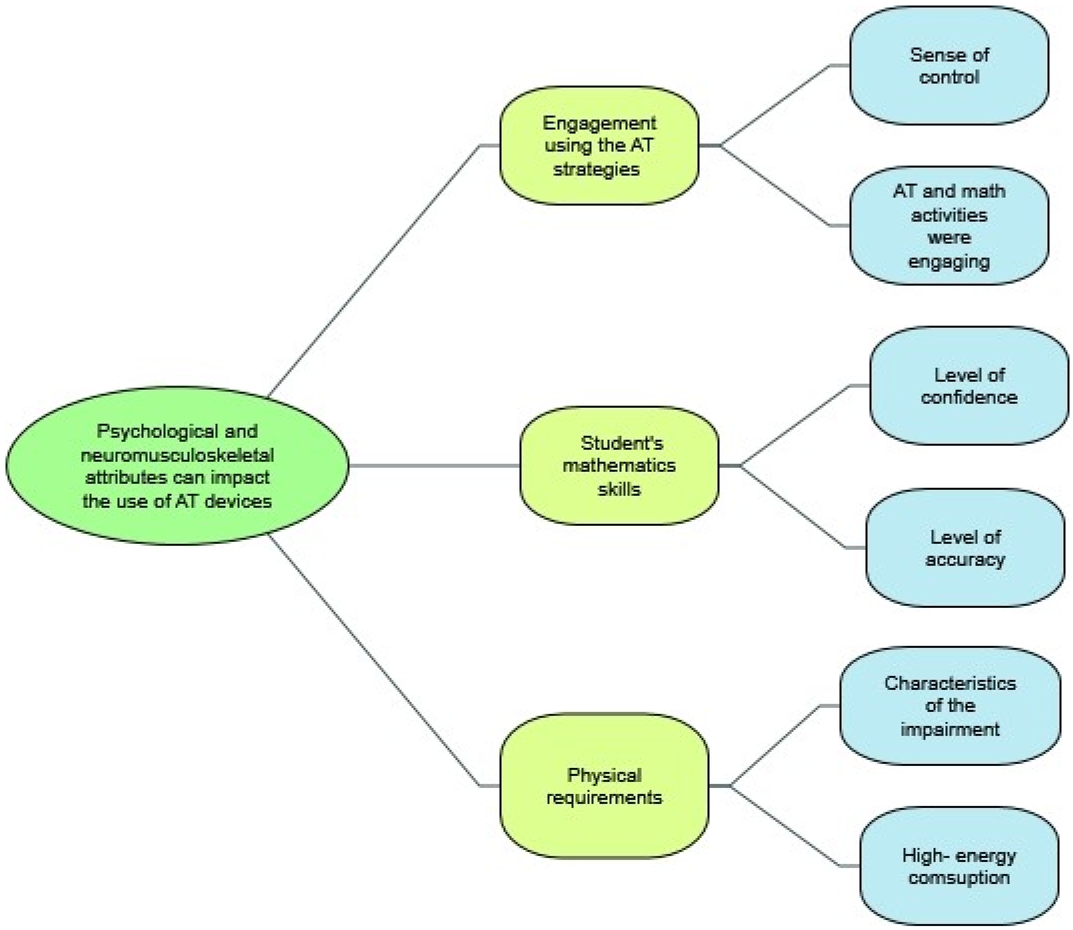


Figure 7. Categories that emerged from the interviews about the influence of personal factors in the use of AT devices.

Engagement using the AT strategies.

Under the generic category of "engagement using the AT strategies" were the subcategories of: 1) Sense of control and 2) AT and mathematics activities were engaging.

The AT strategies gave the participants a sense of control during the mathematics lessons. The participants had the opportunity to choose the options they wanted and actively participate in the lessons by controlling the AT strategies. Dylan's mother expressed: *"I think just watching now* *[sic] the freedom to do certain things with it is pretty cool […] just watching him be able to have control over [sic] he was playing was a big deal."*

The mathematics lessons and the AT strategies were considered by the interviewees as engaging. When Jacob's teacher was asked about Jacob's performance during the mathematics lessons, she stated: *"He was very motivated by the activities… he really enjoyed the*m." Dylan's mother expressed enthusiasm because Dylan was proud of his performance during the lessons: *"the way he would brag about things he did after, like he was really proud of himself"* and added: *"the whole situation kept him more interested and focused on the task."* The robot was considered the AT device that most improved students' engagement by making learning interesting and fun. Dylan's mother said that *"the robot kept [Dylan] more interested than the computer."* Ethan's mother considered the robot a viable tool to give students the opportunity to actively participate during the activities, instead of be passively observing others. When asked about factors that influenced her decision to use the robot at home, she mentioned: "*I want Ethan to play by himself. He usually relies on me or his brothers to do things for him, to engage in play. I want him to be able to feel like "Oh, I want to do this now" and just do it."*

Student's mathematics skills.

The category of student's mathematics skills consisted of two different subcategories: 1) Level of confidence and 2) Level of accuracy.

Ethan and Dylan had an improvement in their confidence to solve mathematics questions after the use of the AT strategies. Ethan's mother pointed out: *"Ethan is more confident with his counting… he has just made huge gains."* On the other hand, Jacob's confidence during mathematics lessons after the intervention phase was evaluated as not positive. After the study, his teacher assessed his understanding in Heavy/Light and In/Out concepts, but Jacob could not provide a consistent answer. She said that she had not given feedback or reinforcement during the questions, and that this could have affected Jacob's confidence about his responses, because he could have thought that his answers were incorrect. She reported: "*He really did poorly [when she tried mathematics activities after the intervention]. He changed every answer because I did not give him any response […] he is lacking in confidence in his answers. If you are not telling him he is right, then he assumes he is wrong."*

Regarding the level of accuracy of the participants, the parents reported that they could see an improvement in the participant's accuracy to solve the questions from the beginning to the end. The parents also expressed how at the end of the intervention phase, they could see a mathematical understanding in the participants. Ethan's mom stated: *"watching from the beginning when he did not really know the numbers and then towards the end when he would go back and go: "okay let's check if we got the right answer", and he knew when he did not get it right. And then he was able to correct it on his own."* Concerning Jacob, his teacher mentioned that his lack of confidence to provide an answer hindered him from being accurate in his responses. Therefore, his understanding of mathematics could not be observed. Jacob's teacher mentioned: "*That doesn't mean he doesn't know the concept. It means that he was demonstrating that on that day, cause he's lacking in confidence in his answers."*

Physical requirements:

Under the generic category of "physical requirements" were the subcategories of: 1) Characteristics of the impairment and 2) High-energy consumption.

The characteristics of the impairment had an impact on how students accessed the technology. For instance, Ethan had a brain stem stroke, but he had voluntary control of his head movements and right hand; thus, he could adequately control his alternative access methods. Dylan and Jacob were diagnosed with cerebral palsy. The spasticity associated with cerebral palsy often hindered the students' ability to move their body accurately and to be able to control the switches. Establishing an adequate control of AT devices can be difficult because of the movement pattern that children with cerebral palsy exhibit (McCarty & Morress, 2009). Jacob's teacher said: "*It is very difficult for him because of the cerebral palsy. He works very hard to control his body… so, he does fatigue.*" Dylan´s mother pointed out: "*I think every day was a little bit different with the switches because we had a couple of days where his body was not really cooperating with him.*"

Tiredness was related to the high-energy consumption of the participants to manipulate the devices, especially the robot. The interviewees pointed out that controlling the robot required additional steps, such as thinking about the correct answer and which switch it is necessary to press, pressing it, looking at the robot to know if it performed the desired action, and verifying the answer. Ethan's mom expressed: "*There are extra steps [using the robot]. So Tony [Ethan's brother] can do ten questions and Ethan can only do 4 before he gets tired.*"

The interviewees suggested that academic activities that demand higher-order thinking skills, such as mathematics, would be better performed in the morning, because students tended to get exhausted as the hours pass. Jacob's teacher stated: "*Fatigue is always an issue for all of our kids, especially with kids that are like Jacob […] we get the best work with them in the morning and by the afternoon, they are toast, they are tired, many would like to have a nap.*" Also, she pointed out: "*We structure [Jacob's] day, so we get the hardest things done first and out of the way while he is fresh, then as the days goes on, the workload is easier because he is more fatigued.*" Ethan's mother also mentioned that the structure of the lessons in Ethan's school is doing most of the academic subjects in the morning, before students get tired: *"Usually the mornings are better for him, and that is when he does most of the academics, you know writing* *and reading, social studies, science things. Gym and music are typically more in the afternoon when kids have less concentration, they get tired."*

Results from satisfaction surveys.

Ethan and Jacob answered all of the modified questions in the QUEST 2.1 and PIADS surveys. Dylan did not answer some of the questions because the questions were too hard to understand due to his chronological age, so they were not asked. Ethan's answers in the QUEST 2.1 were predominantly between the extremes (very satisfied or very unsatisfied) or neutral; for that reason, his results were analyzed on a 3-point scale. The item about competence in the PIADS for Ethan was not scored because he indicated that he did not understand the question, even though the research-assistant/teacher provided other simplified questions. Thus, the research-assistant/teacher skipped this item and continued with the next question. Tables 12 and 13 show participants' answers in both surveys.

Table 12.

Participants' answers to the QUEST 2.1, on a 3-point numerical rating scale [1 (unsatisfied), 2(neutral), 3 (satisfied)]

Satisfaction items	*Robot*			*Computer*		
	Ethan	*Dylan*	*Jacob*	*Ethan*	*Dylan*	*Jacob*
How it looks	3	3	3	3	3	1
Time it takes to set up	3	1	3	1	1	3
How easy it is to use	3	NA	3	3	NA	1
Reliability	2	NA	3	3	NA	2
Meets your needs	3	NA	1	3	NA	1

NA = Not asked

Table 13.

Participants' answers to the PIADS on a 3-point numerical rating scale [1 (disagree), 2(neutral), 3 (agree)]

Items	*Robot*			*Computer*		
	Ethan	*Dylan*	*Jacob*	*Ethan*	*Dylan*	*Jacob*
Efficiency	1	3	2	1	3	2
Frustration	2	3	2	3	3	2
Competence	3	3	2	NA	3	3
Independence	1	NA	3	2	NA	1
Ability to participate	1	NA	2	1	NA	3

NA = Not asked

According to the tables, Ethan was mostly satisfied with both AT strategies, except for the time it took to set up the virtual mathematics programs. Regarding the items in the PIADS, he indicated that he was not effective in answering the questions with the AT strategies and that he could not use them to participate in the classroom, but that he had low frustration during the lessons when controlling both devices. Finally, Ethan felt that his independence was higher using the computer than the robot.

Dylan was satisfied about the appearance of the robot and the virtual mathematics programs, but indicated that he did not like the time it took to set up both strategies. Regarding his answers in the PIADS, he stated that both strategies helped him to be more effective and more competent in solving the problems, and that he had low frustration to complete the lessons using both devices.

Jacob's responses show that he had a higher level of satisfaction with the robot than with the computer. He indicated that the time it took to set up both devices was fast, but the AT strategies did not meet his needs. Moreover, Jacob agreed that both strategies helped him be more effective in answering mathematics questions, be more competent in mathematics, and he felt he could use both strategies in his classroom. Regarding the independence item, he felt more independent using the robot than the computer.

Overall, the findings showed that participants were mostly satisfied with the robot. Students were pleased with the robot's appearance, ease to use, and reliability. Moreover, they considered that they were more competent and more efficient in solving the mathematics questions using the robot compared than using the computer. However, when participants were asked if they were able to participate in the same mathematics activities as their peers using the robot, their answers varied.

In relation to participants' satisfaction with the computer, findings differ between students. Participants agreed on satisfaction regarding computer's reliability and low frustration to answer the questions using it. However, participants were mostly dissatisfied with the time it took to set up the computer, and they felt that they required a lot of help while controlling it.

Participants' comments.

At the end of the surveys, participants were asked to provide some comments about the AT strategies. Ethan used his Accent device to indicated "I like robot page" (likely to indicate, "I like robot") and "I like" when he was asked about his opinion regarding the computer. Jacob was asked three additional closed-ended questions. He indicated that it was easier to learn using the AT strategies compared to regular instruction, that he wanted to continue learning using the AT strategies, and that he felt more committed to learning with both strategies.

4.2.2 Influence of environmental facilitators in the use of AT strategies in mathematics learning.

Results from observations.

Tables 14 to 19 show environmental factors surrounding each participant when using the robot and the computer. The tables are selections of data regarding environmental facilitators and barriers observed during the sessions. The tables include device problems, interruptions in the sessions, or modifications to the sessions.

Table 14.

Events created in Morae about environmental factors surrounding Ethan during a lesson with the robot.

				Ethan	
Lesson	*Time*	*# question*	*Target*	*Facilitators*	*Barriers*
R1- Ten frame train	00:07.7	Practice		We try the pointer to select blocks.	
	01:48.4	Practice		Mom tells Ethan that the pointer is going to help him in his counting. Ethan blinks to agree with her.	
	04:32.8	1	7		The special education teacher asks Ethan if he can see the blocks on the table and he signals no.
	04:45.5	1	7	The special education teacher moves Ethan to another position so he can see the blocks better.	
	14:51.6	3	6		Robot goes forward and does not stop. The research-assistant/teacher fixes it.
	23:52.4	5	10	When asked, Ethan wants the robot speed increased.	
	30:56.9	7	3		A piece came loose on the robot and the research-assistant/teacher attaches it to the robot.
	34:37.0	8	9		The robot speed is adjusted to reduce the number of switch hits required.
	38:12.3	End		Ethan is playing with the research-assistant/teacher and the robot. He is pushing the ten frame train off the table with the robot.	

Table 15.

Events created in Morae about environmental factors surrounding Ethan during a lesson with the computer.

Ethan					
Lesson	*Time*	*# question*	*Target*	*Facilitators*	*Barriers*
C1-Underwater counting	12:14.9	Practice			The program does not allow Ethan to review his answer when he got it wrong twice.
	17:48.4	2	6	Ethan got an incorrect answer, so the research-assistant/teacher helps him by counting out loud while Ethan controls the HeadMouse to put the cursor over the objects being counted.	
	21:58.8	5	6	After seeing Ethan counting mentally 3 times (he seems to be struggling to count in his head), the research-assistant/teacher asks him “Do you want me to count out loud with you?”	
	22:21.0	5	6		His brother provides a hint saying “the number is what your age is.”

Table 16.

Events created in Morae about environmental factors surrounding Dylan during a lesson with the robot.

			Dylan		
Lesson	*Time*	*# question*	*Category to sort on*	*Facilitators*	*Barriers*
R5- Superheroes vs Monsters	00:51.8	Practice			Dylan's mom and the special education teacher are talking. There is background sound. But it seems it doesn't affect Dylan's attention.
	03:49.6	3	Monster		It is difficult to place blocks on the robot. They fell off often.
	04:00.1	4	Superhero	The research-assistant/teacher brings the robot back to the starting position.	

Table 17.

Events created in Morae about environmental factors surrounding Dylan during a lesson with the computer.

			Dylan		
Lesson	*Time*	*# question*	*Category to sort on*	*Facilitators*	*Barriers*
C1- Ninja Turtles and Transformers	02:53.2	Practice			Dylan wants to hear the sound effects of the program but the volume of the computer is not very loud.
	04:04.5	Practice			Dylan cannot hear the sounds in the program. It seems that he gets frustrated and is making a sad face.
	04:32.5	1	Transformer		Ethan accidentally hits a switch and The Grid 2 starts displaying another activity that is not the correct one.
	06:59.8	7	Ninja Turtle		Dylan does not know the character

Table 18.

Events created in Morae about environmental factors surrounding Jacob during a lesson with the robot.

			Jacob		
Lesson	*Time*	*# question*	*Target*	*Facilitators*	*Barriers*
R2-Teeter-totter 2	03:40.7	Practice			A student and a teacher enter the room. Jacob gets distracted looking at them. The student is sitting in the swing chair and there is music playing. Jacob turns his head to observe them.
	04:34.2	7	Light	The research-assistant/teacher holds a bag with the objects. Jacob tries to grab an object inside the bag to feel the weight with his hand.	
	09:02.0	8	Heavy		Teachers are talking and Jacob does not pay attention to the question. The research-assistant/teacher waits until Jacob pays attention to him.
	16:30.0	10	Light	The research-assistant/teacher holds a bag with the objects. Jacob tries to grab an object inside the bag to feel the weight with his hand.	

Table 19.

Events created in Morae about environmental factors surrounding Jacob during a lesson with the computer.

Jacob					
Lesson	*Time*	*# question*	*Target*	*Facilitators*	*Barriers*
C2-Compare mass	02:39.8	Practice			Jacob accidentally presses his hand switch, skipping several of the questions. The program only has 10 questions, so it has to be restarted. When the research-assistant/teacher restarts the program, it shows the same 10 questions.
	04:06.3	1	Heavy	The research-assistant/teacher moves the head switch away, so Jacob does not accidentally press it. When Jacob is over top of the answer he wants, the research-assistant/teacher brings back the head switch.	
	06:34.3	5	Heavy	The research-assistant/teacher proposes that Jacob selects with the hand switch which option he wants and the research-assistant/teacher will help him to select it with the head switch (the research-assistant/teacher presses the head switch).	

Four generic categories emerged from the observations to answer research question 2 about environmental facilitators that influence the use of the AT strategies: 1) Robot, 2) Computer, 3) Physical setting, and 4) Social support. These generic categories fall under the main category of "Features of the devices and social environment have a role in the use of AT strategies" (See Fig. 8).

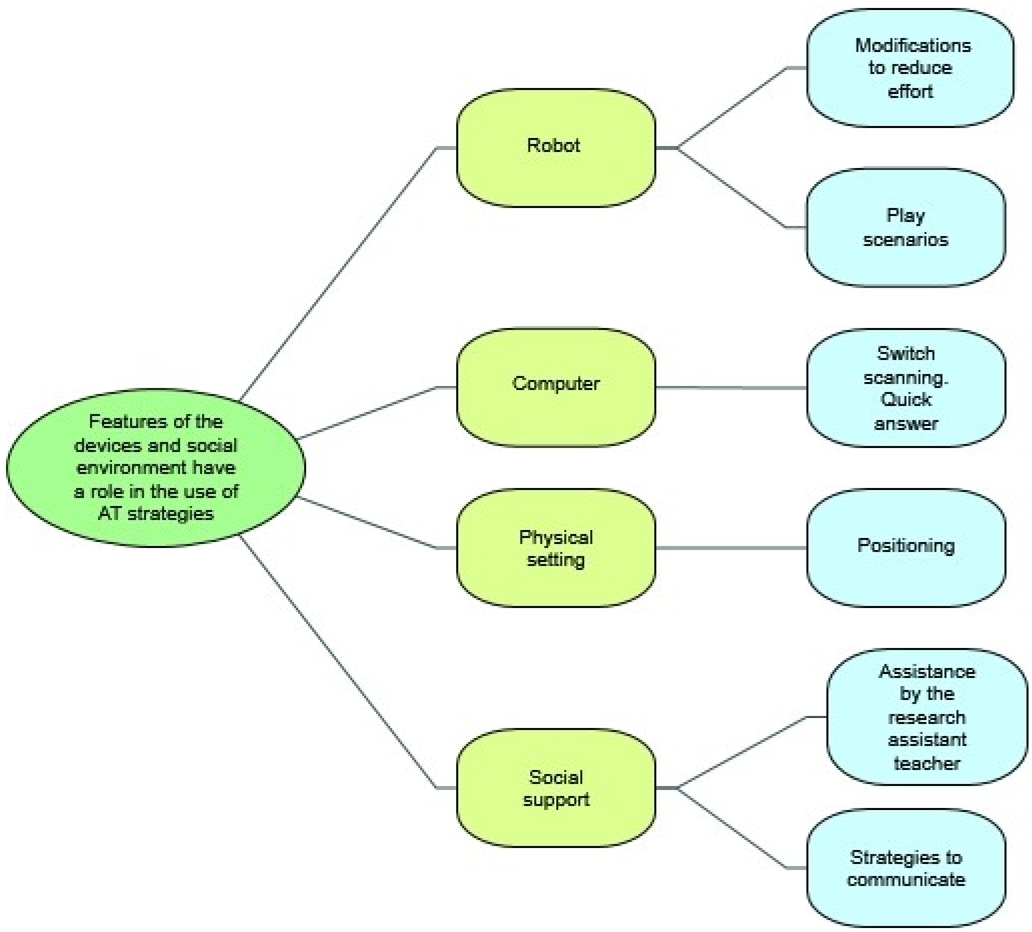


Figure 8. Categories that emerged from the observations about the influence of environmental facilitators in the use of AT devices.

Robot.

Under the generic category of “robot” were the categories of: 1) Modifications to reduce effort and 2) Play scenarios.

The research-assistant/teacher implemented several modifications and strategies to help the participants to use the robot and thus be able to perform the mathematics tasks. For instance, with all the participants, the robot was always brought to the initial position when the participants finished completing the question, or when they were driving the robot in the wrong direction. With Ethan and Jacob, although they could turn the robot to the left and to the right, the research team decided to modify the lessons so the questions could be solved by only driving the robot forward. When this modification was implemented, the participants reduced the number of switch hits, and there was a decrease in their physical effort.

During the sessions with Dylan and Jacob, and in most of the sessions with Ethan, the robot was implemented in play scenarios. The research-assistant/teacher indicated to the participants through the visual schedule that they were going to play with the robot at the end of the lessons. The participants showed enthusiasm by smiling or providing yes responses when asked if they were excited to play with the robot. It was also noted that the robot was engaging during the mathematics lessons.

Computer.

In the category of “computer” was the subcategory of “switch scanning – quick answer”. For the computer programs, the participants accessed them through switch scanning, except Ethan who directly selected the options on the screen through the HeadMouse. The participants answered the mathematics questions faster using the computer than using the robot. The average time to complete a question with the computer was 00:38 seconds and with the robot, it was 03:03 minutes.

The lessons with the computer were carried out in one session. In contrast, some of the lessons with the robot were done in two sessions because the participants could not answer the mathematics questions during the scheduled time. An exception was in one lesson with the computer (C4) with Ethan that had to be spread over two sessions. This lesson was carried out after a lesson with the robot (R4) and the remaining time to complete C4 was about 10 minutes, so, Ethan only completed four questions in that session.

Physical setting.

In the generic category of "physical setting" was the subcategory of "positioning". In the three settings where the study was conducted, a large table was present in the rooms where the robot, the computer, and the concrete objects were placed. The table had an adequate height, so that the participants could see the AT strategies and objects properly. Figure 9 shows an example of the physical setting during a session with Ethan using the robot. When working with robots with students with physical impairments, it is important to have the robot on a table with the appropriate height so that students can see the robot and interact with it (Barker, Nugent, Grandgenett, and Adamchuk, 2012).

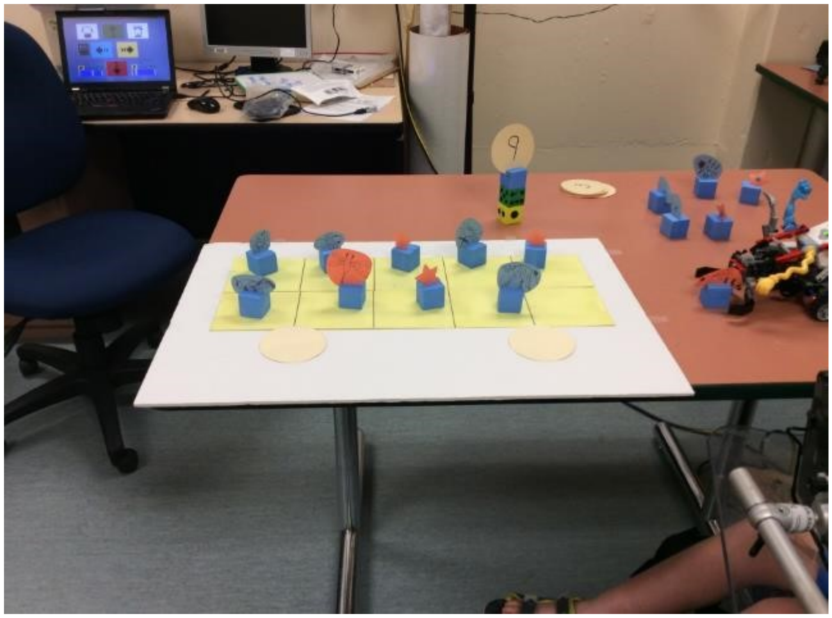


Figure 9. Physical setting during a counting lesson with the robot.

The AT strategies were accommodated at the table so they were as close as possible to the participants. In the sessions, we ensured that the participants were able to see the robot by leaning towards the table so that our eyes were at the same height as the student's eyes. From that perspective, we could observe if the participant could see the objects adequately. If that was not the case, we moved the AT strategies and the objects, or the participants were repositioned (e.g. we moved the wheelchair) until they could see the objects.

Social factors.

Under the category of "social factors" were the subcategories of: 1) Assistance by the research-assistant/teacher and 2) Strategies to communicate.

The research-assistant/teacher provided prompting when participants were controlling the AT strategies. Prompts were used during all lessons, and verbal prompt was often used with all the participants to indicate them that they had to press a specific switch to move the robot or select an option. At the end of the intervention, it was observed that the participants required few prompts to control the devices.

The participants were also given assistance in the non-mathematical demands of the lessons. The research-assistant/teacher often acted as ¨the hands¨ or ¨the voice” of the participants. For instance, he counted out loud while Ethan pointed at the objects with the HeadMouse. Also, the research-assistant/teacher pointed to the objects on a scale to ask Jacob which object was the heaviest. Dylan did not need assistance like this because he could speak to indicate his answers. The results of the level of prompting and assistance that the participants needed can be found in the papers published about the overarching project (Adams, McGarvey, David, Esquivel, & Morgan, 2018; Adams, Esquivel, Morgan, McGarvey, & David, n.d).

The participants used different communication modalities to express their responses or make statements. During the sessions, the most frequent communication modalities were Yes or No signals, or two hand choice making where the research-assistant/teacher named two choices and used his hands as place holders for each choice. The participant indicated his choice by looking at one of the hands.

In the case of Ethan, though he was quite proficient with his communication device, the above modalities were used to reduce the cognitive-linguistic load while he was controlling the AT strategies, especially the robot. In addition, he used his communication device to make comments such as “This is so much fun” or “I am done.” With Dylan, although he could speak, the yes and no modalities were frequently used. Jacob primarily communicated through yes or no signals; therefore, the research-assistant/teacher asked him closed-ended questions.

Results from interviews.

The process of categorizing the data about research question 2 followed the same steps as the categorization to answer research question 1. I divided the 11 nodes created from the interviews to create one main category regarding environmental facilitators: “Influence of the AT strategies and social factors”. Under this main category are three generic categories: 1) Use of the robot, 2) Use of the computer, and 3) Social support (see Fig 10).

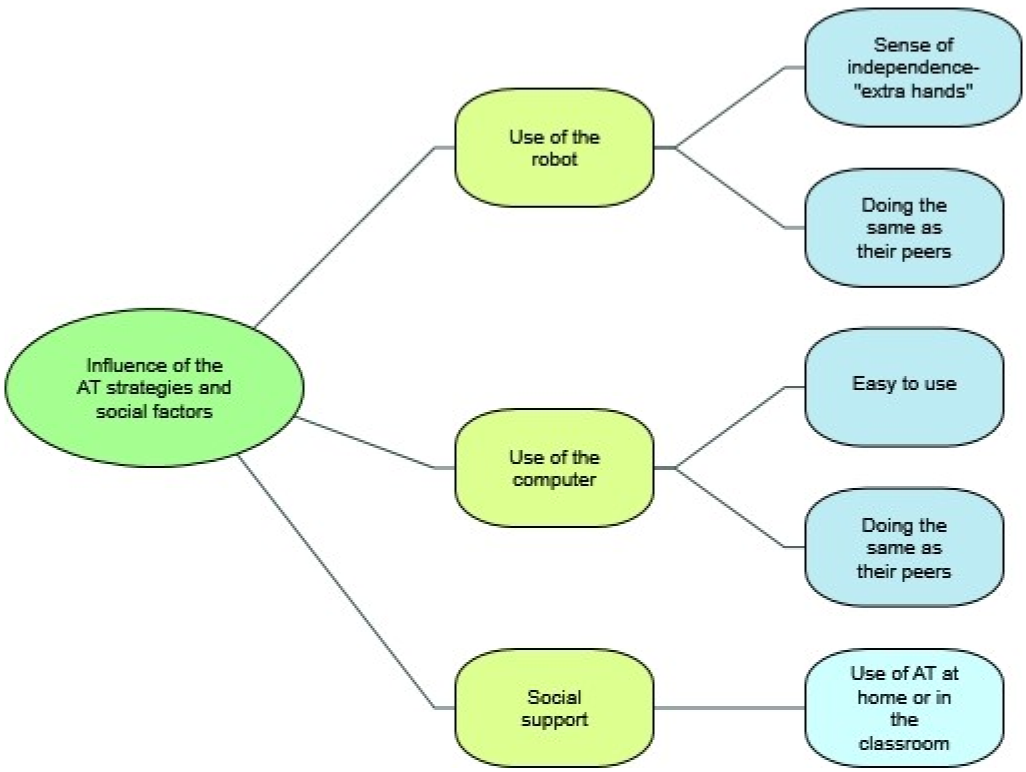


Figure 10. Categories that emerged from the interviews about the influence of environmental facilitators surrounding students in the use of AT devices.

Use of the robot.

The category of "use of the robot" consisted of two different subcategories: 1) Sense of independence- "extra hands" and 2) Doing the same as their peers.

The interviewees expressed as a positive outcome of the robot, the opportunity that it offered to the participants to be able to manipulate objects. The parents and the teacher mentioned that they observed that the students had independence with the robot to move the objects according to what they wanted. Dylan's mother said: "*the robot was becoming that extra set of hands which was really neat to see [...] he could choose between sorting the stuff with the robot."*

In addition, the parents expressed that the Lego robot could be a viable tool in the classroom for students with disabilities to do the same type of academic activities as their peers. Ethan´s mother expressed enthusiasm for Ethan to learn the same mathematical concept as his peers. She said: "*he is learning to do things [with the robot], the same things as everybody else but in a different way*."

Use of the computer.

Under the generic category of the "use of the computer," two subcategories were created: 1) Easy to use and 2) Doing the same as their peers.

One of the main features of computer programs is the ease of use, which promotes their implementation in school. Ethan's mother pointed out that she had the idea, before starting the sessions, that the robot was going to be the easiest strategy for Ethan to control. However, after the sessions, she realized that Ethan was faster to complete the lessons with the computer compared to the robot. She mentioned: *"It is faster to use the computer. He does not have to look away from the screen to see and look back. It is always presented to him on the screen."*

Computer programs can also provide opportunities for students with disabilities to participate in the same activities as their peers. Dylan's mother emphasized that the use of the computer can help Dylan to develop the same cognitive abilities as a typically developing child: "*Dylan cannot play like other kids and we always need to find things to challenge him cognitively, and those computer games did that."* Ethan's mother mentioned that Ethan used the computer in his classroom along with his classmates and that he participated in the same academic activities. Although Ethan was slower than his peers to control the computer, his teachers included him in the activities with the computer. The teachers waited for Ethan to nod when he finished giving his answer to continue with the next activity. Ethan's mother said: *"He is able to use the computer, and they [his teachers] just wait for his answer yes or no, if that is what he wants."* Moreover, Jacob's teacher also used computer activities during her teaching instructions with her students with disabilities. Based on her experience, she commented on one of the advantages of using computers in the classroom: *"Students are so used to living their lives as observers in life and not participants in life. There are so many things they can't engage in. So, it is nice to have something that they can feel they have control over it and participate well."*

Social support.

In the category of "social support" was the subcategory of "Use of AT at home or in the classroom."

After seeing the benefits that the students gained from using the robot, parents considered using this strategy at home to play or for educational activities. Ethan's mother contacted us to implement the robot at home. When asked about this decision, she mentioned that she would like to use the robot with Ethan for play activities initially. She said: "*It would be mostly for play, and then, as time goes on, when things like math and spelling become more difficult, or writing [...]*

we would probably use it in different applications." Furthermore, Dylan's mother was excited to implement the robot at home for learning activities. She said: "*When I'm watching you guys, I'm thinking I could do like alphabets and numbers and stuff and help him learn that way, because when you're putting stuff on the table he gets bored so easily and in this way you can keep him interested. He's got the set up at home with switches and everything on the computer."*

Regarding the use of the AT strategies at school, the interviewees reported that schools had a very supportive staff to assist the students and expressed the collaboration and willingness of school administrators to implement AT in students' learning. Jacob's teacher said: *I think they [school administrators] will be very open to it [implement the robot]. It is a really great school and they always want to try something new."* Ethan's mother expressed that school administrators would be willing to include technical support or educational aides to facilitate the use of AT devices in the classroom. She said: "*I know they are always welcome, they are always asking for people to come in and help teaching and to work with the staff, so everybody can become more independent and confident with using the technology*."

Finally, Jacob's teacher provided a suggestion when implementing a new AT device in the classroom. She mentioned providing constant training and support to students to use the AT device often. She pointed out: "*Do it every day, every day, every day, every day, in a variety of settings so the kids can get used to the device [...] Then, it becomes second nature and everybody is comfortable with it. I found that with the communication devices."*

4.2.3 Influence of environmental barriers in the use of two AT strategies in mathematics learning.

Results from observations.

Three generic categories emerged from the observations to answer research question 3 on the influence of environmental barriers in the use of the AT strategies: 1) Robot, 2) Computer, and 3) Social factors. These generic categories fall under the main category of "Barriers on the AT strategies and the social environment" (See Fig 11).

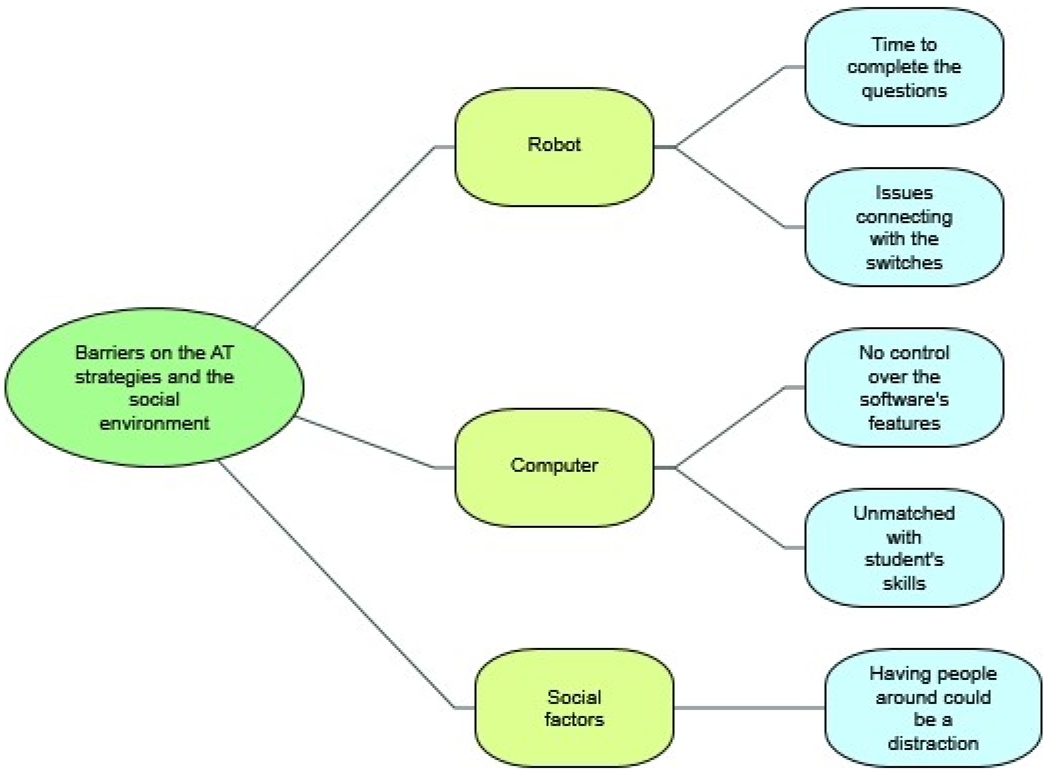


Figure 11. Categories that emerged from the observations about the influence of environmental barriers in the use of AT devices.

Robot.

In the generic category of "robot" were two subcategories: 1) Time to complete the questions and 2) Issues connecting with the switches.

All the participants needed more time to complete the lessons with the robot compared to the lessons with the computer, as mentioned above. Some of the robot lessons had to be spread over two sessions because there was a greater amount of time to set up the robot and the concrete objects (04:27 minutes) compared to the computer (00:58 seconds), or the participants spent a great deal of time answering the questions when they answered incorrectly, or they got tired, thus, they requested to finish the lesson.

A common difficulty encountered during the sessions was the issues with the robot control software. Often, the robot did not move when the participants pressed their switches or, on the contrary, did not stop. The research-assistant/teacher solved these issues with the software through the methods mentioned in Chapter 3 (e.g. restarting the robot control software). Although this did not affect the lessons, it could be considered a barrier if a non-technical person tries to use the robot. Because the research-assistant/teacher had technical knowledge, he was able to solve the problems on the robot control software, but a person without this skill might not be able to implement the robot in academic activities.

Computer.

Under the category of "computer" were the subcategories of: 1) No control over the software features, and 2) Unmatched with student's skills.

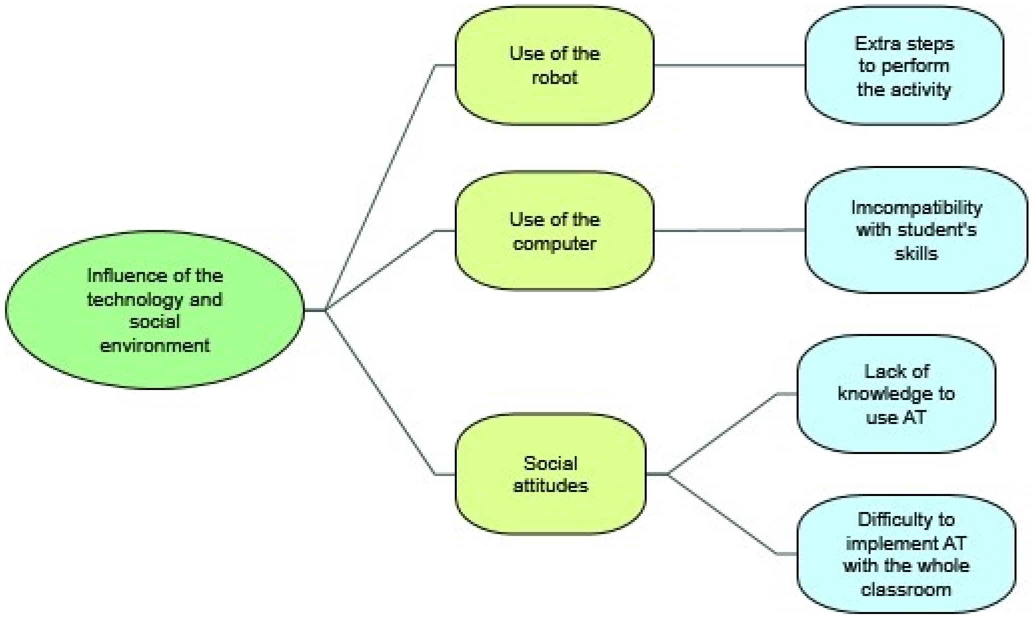
The free virtual mathematics programs used in this study did not allow changing their configuration, such as size, sound, or colour. Also, there was no control over the mathematics questions of the programs. For example, the computer programs that were implemented with Ethan often repeated the same number and were usually small numbers, or the programs used with Jacob had few questions and when they were restarted, they repeated the same questions. This is a disadvantage compared to the robot, where the research-assistant/teacher had control over the type of question he was going to ask (e.g. all the numbers from 1 to 10 were asked for Ethan, or half of the questions were in one category and the other half were in the other category for Dylan and Jacob).

Another disadvantage that was observed about the use of the computer in mathematics lessons was that computer programs that could be controlled using the students' alternative access methods were scarce. For instance, in the case of Dylan and Jacob, it was not possible to find programs about sorting or the In/Out concept, respectively, that could be controlled through switches. With Ethan, several accessible virtual mathematics programs could be found that could be controlled through the HeadMouse. However, if Ethan had required switch scanning, it would probably have been harder to find counting programs that could be controlled through switches.

Social factors.

The category of "social factors" consisted of one subcategory: "Having people around could be a distraction."

The distraction of the participants when people other than the research team were in the same room was more evident with Jacob. During the sessions with Jacob, it was very common for teachers or students to enter the room where the sessions were conducted, because it was a therapy room. When people came into the room to use the therapeutic materials, Jacob turned his gaze away from the AT strategies to where the other people were. Therefore, the research-assistant/teacher had to get Jacob's attention again and re-explain the instructions. With respect to Ethan and Dylan, their levels of attention during the sessions were not affected by the presence of other people. However, there was no opportunity to observe if Ethan would have been distracted if he had interacted with his brother, who was in the same room where the sessions were held. My supervisor and the special education teacher considered that Ethan's brother could be a distracting factor due to his



behaviour during the head tracking device and robot trials a year previous. He was interested in playing with the robot that Ethan was using or was constantly talking to him in those trials, so in this study we asked him to play on the computer, rather than with his brother.

Result from interviews.

To answer research question 3 regarding environmental barriers, the same categorizing process to answer the previous questions was conducted. The 11 nodes were divided to create one main category regarding environmental barriers "Influence of the technology and social environment." In this category were three generic categories: 1) Use of the robot, 2) Use of the computer, and 3) Social attitudes (see Fig 12).

Figure 12. Categories that emerged from the interviews about the influence of environmental barriers surrounding students in the use of AT devices.

Use of the robot.

Under the category of "use of the robot" was the subcategory of "extra steps to perform the activity." The interviewees indicated that the only barrier that the robot presented was the amount of additional steps the participants had to carry out to solve a problem, in comparison with the computer. When asked about some challenges in using the robot, Ethan's mother said: "*I thought that doing the Lego robot was easier because it's fun, he enjoys doing it. But there's more he has to think about and manage. Where's he's going to drive it and that stuff*." She added: "*because there are extra steps there is more cognitive load."*

Use of the computer.

The generic category of "use of the computer" consisted of one subcategory "incompatibility with student's skills." One of the main concerns of the interviewees was that some computer programs may not be compatible with the student's abilities. The interviewees mentioned that it is difficult to find computer programs which students can access through their alternative access methods, or programs that are at a suitable speed for the student. These factors could prevent students from showing their mathematics knowledge through the computer. Ethan's mother said: "*We are constantly looking for [computer programs], but it's hard to find one that only uses point and click. A lot of them need keyboards and use arrows and all kinds of different things and that for Ethan is too tiring. He just needs point and click.*" She stated with respect to time constraints: "*There are timed games which do not work for Ethan because he takes a long time to complete them. It does not mean he does not know the answer, it just that it takes time to show what the answer is.*"

Social attitudes.

Under the generic category of "social attitudes" were the categories of: 1) Lack of knowledge to use AT, 2) Difficulty to implement AT with the whole classroom and 3) Lack of funding.

The lack of understanding about how to program the Lego robot was considered a barrier to implement this AT strategy in students' learning according to the interviewees. Jacob´s teacher emphasized: *"understanding how to make the software work [...] is my problem."* Likewise, Ethan´s mother pointed out that the main barrier to the implementation of the robot is the: *"technology glitches. Especially for people who do not have a lot of training or background knowledge in programming, it could be really challenging for them. If anything goes wrong, they just don't use it."*

The amount of time that parents and educators would spend programming and configuring the Lego robot may lead to a stressful experience and an unsuccessful outcome. Jacob's teacher tried to download the Lego Mindstorms commander program on her computer in her classroom, but it was not successful. She was excited to implement this AT strategy with her students and continue working with Jacob using the robot. Yet, due to her failed attempt with the software, she gave up on that idea. She mentioned: *"I tried to use the software on my computer, I can't make it work. So, if I was able to make it work, I would have felt that it would be a good activity for Jacob, but I haven't been able to connect it with my Bluetooth."* In the same way, parents also expressed issues when they tried to download the Lego Mindstorms robot software at home. Ethan's mother stated: "*We borrowed one [Lego robot] from a friend and have not had a chance to set up it yet. It is difficult to download the software onto Ethan's tablet."*

Another aspect that is considered a barrier to implement the Lego robot in mathematics is the difficulty of integrating it so that it can be used with the whole classroom. In general, teachers may encounter different types of disabilities, such as cognitive or sensory disabilities, in the same classroom, or students who may not have the cognitive skills to understand the robot's commands. Jacob's teacher said when asked about if she would implement the robot with all of her students: *"It is hard because some of my students have visual problems, so they have to be close enough. I cannot sit them back because they are not going to see it. So I would do it more as one-on-one or in a very small group activity just because the types of disabilities the students have."* In addition, she added: "*Most of my students would not have the coordination or the cognitive abilities to manage turn left, turn right, that sort of thing, using the robot. Jacob was a student who could understand those concepts; the other two students, they would use a switch but not necessarily [...]. So, I would have to choose who are going to be in the robot activities."* Ethan's mother mentioned that teachers would have difficulty implementing the robot in the classroom because they would not have enough time to download the software and try to understand how it works and how to incorporate it into their teaching lessons, she pointed out: *"they do not have time to sit and play with it while teaching a whole classroom; it has to work right away."*

When interviewees were asked about the implementation of computer programs with the whole classroom, they did not mention any barriers. Teachers generally implement computer programs with most of their students with disabilities or without disabilities. Jacob's teacher said: "*I use computers with all my students and I will continue doing that.*" However, she pointed out that although she tried to implement ICTs devices in her teaching planning, those devices often were not effective in supporting learning: "*We have done something with iPads and stuff but it is more game playing. I am not sure if [students] understand what is happening. It's more a game for fun; they may not understand the concepts.*"

Finally, the topic of funding was also mentioned as a barrier at the institutional level to implement the robot at school. Jacob´s teacher stated: *"The devices we use with our kids are very cheap and not a lot of places have money for that [buy the robot]."* In addition, she emphasized that the ability to buy a Lego robot would depend on the school, she explained that "*the school I will move to has no budget, zero. It will be a very different experience compared to here.*"

CHAPTER 5. DISCUSSION OF RESULTS AND CONCLUSION

This thesis had the aim of exploring the influence of contextual factors surrounding students with physical impairments when they used two AT strategies, a Lego Mindstorms robot to move concrete manipulatives and a computer to move virtual manipulatives, in mathematics learning. There is a dynamic interaction between contextual factors and the components of body functions, and activity and participation. Therefore, the influence of these components in using the AT strategies are also discussed. Three case studies were performed where participants used both AT strategies to learn different mathematics concepts (counting, sorting, and Heavy/Light or In/Out). In this chapter, research questions are analyzed followed by a discussion about how the interaction between the personal and environmental factors influenced the occupational performance. Limitations, significance of the study, future research, and conclusions drawn from this study finish the chapter.

5.1. Research Question 1

How do personal factors in students with physical impairments influence the use of the two AT strategies in mathematics learning?

Personal factors are not yet classified in the ICF; “their assessment is left to the user, if needed” (WHO, 2001, p. 19). In this study, an overlapping was found between the components of body functions and participation to describe the personal factors that influenced the use of the AT strategies. This overlapping of body functions with participation corresponds with the discussion of other authors (Badley, 2006). In the current study, the use of the AT strategies by the participants was influenced by physical and mental body factors, by changes in student participation, as well as by the students’ previous experiences using AT and their attitude towards the technology.

Physical factors influenced how the participants controlled the AT strategies during the mathematics lessons. Dylan and Jacob were not successful in adequately controlling their alternative access methods due to their severity of muscle tone, or the presence of involuntary movements. These findings are consistent with Schenker, Coster, and Parush (2005) who found that limited performance in children with cerebral palsy in activities that require motor control is associated with the severity of the physical impairment. Likewise, the concomitant illnesses of all the participants interfered with the course of some of the sessions. According to the interviewees, the participants were quickly fatigued when controlling the AT strategies, especially the robot, and this may represent a difficulty when implementing it in class. The interviewees also mentioned that mathematics lessons at school were usually given in the morning, which is when the participants were less tired compared to in the afternoon. Hence, the AT strategies in this study should be implemented in the morning. In this way, students with physical disabilities may control the devices for longer.

Although the participants had difficulties with their motor performance to control the AT strategies, they were able to complete all the mathematics lessons. The lessons were one-on-one; therefore, prompting and assistance to complete the lessons could be implemented to remedy the impact of physical factors. For instance, the switches were repositioned so that the participants could access them better, or the research-assistant/teacher repeated the instruction after the student coughed, or helped to select the options using keyboard keys or mouse. The interviewees pointed out that it is possible that school staff may have difficulty adjusting mathematics activities using the AT strategies for the student with disability while attending to the other students. For this reason, the one-on-one instruction might be complicated to integrate into the classroom, which would increase the chances of technology abandonment. This result is in accordance with the findings of Egilson and Traustadottir (2009) and Copley and Ziviani (2004) who stated that training students to control an AT device and adjust activities to include the student with disabilities represent a significant barrier for teachers who are contemplating using AT in the classroom.

Mental factors were also considered as influential factors in using the AT strategies. The parents observed that the students obtained an understanding of the mathematical concepts they worked on during the intervention phase. This result is in line with some of the findings related to the use of computers in mathematics, where students with disabilities improved their performance in solving mathematics problems using the computer compared to teacher instruction (Xin et al., 2017). The levels of attention of the students also influenced the use of the AT strategies. Dylan and Jacob often had problems in terms of sustained attention. Their levels of attention were affected when they were using the computer or by distractions in the environment. I will come back to the attention factor when discussing the results of research questions 2 and 3.

The communication skills of the participants did not affect the use of the AT strategies in this study. Through different communication modalities, especially closed-ended questions, the students were able to indicate their responses or comment during the mathematics lessons. Even though studies have pointed out that teachers might have an opportunity to assess mathematics understanding of students with physical disabilities when they use communication devices (Adams & Cook, 2014a), in this study, the use of a communication device was not required. The research-assistant/teacher also facilitated other communication modalities to obtain the responses of the students.

The use of the AT strategies enhanced the engagement of the students in the mathematics lessons. According to the interviewees, the students were engaged because they could actively participate and had the opportunity to control the objects and choose the options they wanted thanks to the use of the robot or the computer. Moreover, the interviewees mentioned that students could participate in the same lessons as their peers through the use of both devices. Therefore, the opportunity to make choices and actively participate increased the engagement of the students. Similar results were reported by Eriksson (2006) and Huang et al. (2009). The increase in student engagement is a positive outcome towards the use of the AT strategies in learning.

The previous experience that the participants had with AT also played an important role in the use of the robot and the computer during the lessons. Ethan had previous experience controlling a Lego robot and a computer. Hence, Ethan was more successful in controlling both devices during the mathematics lessons, and this contributed to a positive result regarding his performance in counting. On the other hand, Dylan and Jacob had no experience controlling a Lego robot, and Dylan and Jacob were in training to control their switches. This lack of experience is one of the factors that could have affected the performance of Dylan and Jacob. Dylan did not have improvement in his performance during the intervention. At the beginning of the study, Dylan had 100% accuracy in solving the problems, so his lessons were changed to two-dimensional sorting in the middle of the intervention phase. This modification could have been too demanding for him, and he may not have had enough sessions to improve his accuracy in sorting on two dimensions. In the case of Jacob, he could not demonstrate to his teacher his knowledge of the mathematics concepts after the study, and his performance was not consistent during the intervention phase; thus, it was not possible to determine if he had an increase in his performance. Previous studies (Poudel, 2014) have associated that experience using AT is crucial for the effective use of new AT in the long-term. Recommendations from the literature have focused on the importance of equipping students with the AT skills required before implementing the device in a classroom since students with severe disabilities often lack necessary skills and training to use AT in their academic learning (McCarty & Morress, 2009).

Finally, regarding the attitude of the participants towards the AT strategies, the students were more satisfied using the robot than using the computer. The time to set up the computer had the highest ratings of dissatisfaction among the students. When students with physical impairments used computers in Borgestig et al. (2013) for educational tasks, and in Murchland, Kernot and Parkyn (2011) for writing and communication activities, students indicated that they did not perceive any change in their quality of life during the intervention with the computer. Also, the students were more satisfied using another type of hardware, i.e., portable note-takers.

The measures of students' satisfaction in this study may not have accurately reflected their opinion. It is possible that participants did not understand the questions in the surveys or how to answer them. Thus, the results must be interpreted with caution.

5.2 Research Question 2

How do environmental facilitators surrounding students with physical impairments influence the use of the two AT strategies in mathematics learning?

The AT strategies themselves seem to be the most crucial environmental factor that influenced their use in mathematics by the participants. There were some differences between the robot and the computer concerning their features and their influence on the participants' performance. These differences can be represented as facilitators or barriers when implementing them in the classroom. Device related factors, such as ease of use and accessibility, were factors that previous studies have also identified that might influence the intention to adopt AT devices for learning (Oladejo, Adetoro, Oyebade & Adedoyin, 2018; Copley & Ziviani, 2004).

The Lego robot seems to be the AT strategy that increased the students' engagement the most because it allowed the manipulation of objects and created play opportunities. The interviewees stated that the robot seemed to give the students a sense of independence, and one interviewee pointed out it was because the robot acted like an extra set of hands to manipulate the concrete objects. This is similar to the results found by Cook, Encarnaçao, and Adams (2010) who stated that robots allow exploration and manipulation of the environment for students with physical disabilities to participate in some educational activities. Additionally, the robot enabled play actions during the lessons and was used as a reward at the end of each session. The students expressed enthusiasm every time they were going to play with the robot. According to McCarty & Morress (2009), it is important to include play activities during lessons as students can explore the new skills learned to control the switches and gain proficiency controlling the AT devices without the inclusion of academic instructions. Increased students' engagement using the robot during mathematics lessons is consistent with previous studies (Adams & Cook, 2014b).

Regarding the virtual mathematics programs, the interviewees considered them easy to use, and it was observed that the students could solve the problems faster using the computer than using the robot. The interviewees' responses about ease of use of virtual programs were similar to those expressed by special education teachers who used tablet computers with students with special needs (Huang, Liu, & Chang, 2012; Johnson, 2013).

One of the factors that influenced completing the lessons faster with the computer was that the participants could quickly select the virtual manipulatives through direct selection, as in the case of Ethan and Dylan, or through switch scanning in the case of Jacob. In contrast, grasping concrete manipulatives with the robot took longer due to the distance between the robot and the objects or the speed of the robot. A task on a computer can be accomplished quickly by directly selecting the item, or by using multiple switches to scan through the items (Jones & Stewart, 2004). However, although the participant's access methods allowed them to complete the lessons on the computer in an adequate time range, the scanning technique presented some disadvantages. For instance, scanning was very laborious for Jacob due to the demand to press the switches repeatedly; therefore, he easily got tired. In the same way, scanning requires a high level of attention. Jacob had low levels of attention when he used the computer, so his scanning skills were not very effective and often required prompting from the research-assistant/teacher. Several studies have found that scanning is more demanding than direct selection (Horn & Jones, 1996) even in typically developing children (Dropik & Reichle, 2008). Therefore, it is advisable that students should control the computer through direct selection if possible. However, scanning may be the only option for some students, such as Jacob, so it is important to evaluate that the scanning technique is consistent with the physical, cognitive, and visual capabilities of the person (Cook & Polgar, 2015).

Parents and school staff were considered an essential social factor to provide support for the use of the AT strategies in mathematics. The interviewees were mainly interested in implementing the robot in the students learning because they had observed the multiple benefits that this technology might provide in academic activities. Regarding the use of computers, this technology was already accepted by school administrators, teachers, and students to support learning in the classrooms.

Furthermore, social support through positive reinforcements or modifications facilitated the use of the AT strategies during the lessons. The use of reinforcements, prompts and assistance by the research-assistant/teacher helped the participants to complete the questions satisfactorily and to decrease the physical and cognitive load when using the devices. In addition, the social support of the research-assistant/teacher contributed to an increase in the level of engagement of the participants during the sessions.

In accordance with the results of the current study on social factors, previous studies have indicated that the positive attitudes of the school staff about the AT device, as well as the provision of immediate feedback after an activity with the AT, are indicative that an AT strategy could be successfully implemented with students with disabilities (Coleman, 2011, McCarty & Morress, 2009).

Some aspects of the physical environment facilitated the use of the AT strategies in this study. It was observed that the rooms where the lessons were conducted had a large table to place all the concrete manipulatives and the AT strategies, and the tables had an adequate height so the participants could see the objects while seated in a wheelchair. Also, the objects were placed near the students so that they could see them correctly. The physical setting can be a barrier if the classroom does not have enough tables, or if the student has to be positioned far from the objects. This finding is consistent with Adams and Cook (2014a) who highlighted as a limitation in their study that there was not enough room to accommodate the objects and the robot. Therefore, in addition to considering the device features or social support, it is relevant to analyze in which setting the objects and the AT strategies are going to be placed.

In summary, each AT strategy presented some positive characteristics during the study that can facilitate their use. The robot allowed the opportunity to manipulate objects and to play, so the interviewees highly considered their involvement in the students' learning. On the other hand, the virtual mathematics programs were easy to use, and computer programs have already been widely used in the classroom. These are advantages of the computer over the robot. Additionally, adequate social support and physical environment facilitated the use of the strategies, enabling the students to complete the lessons and reducing the physical and cognitive burden of controlling both devices.

5.3 Research Question 3

How do environmental barriers surrounding students with physical impairments influence the use of the two different AT strategies in mathematics learning?

Environmental barriers to using AT strategies in educational activities are well documented in the literature. Of the many barriers identified, it has been found that the lack of knowledge of teachers to use the devices, funding, and device features are the most recurrent barriers when AT is introduced in schools (Copley & Ziviani, 2004; Murchland & Parkyn, 2010). The results in the current study also identified those environmental barriers.

The interviews and observations identified as a barrier the lack of technical knowledge on how to install the robot control software onto a computer or a tablet and how to connect the software to the robot via Bluetooth. Two interviewees mentioned that they had tried to download the software, but they were not successful. Therefore, they had not yet been able to use the robot, as they had planned, to support the students' learning. Added to this factor, teachers may not understand how to solve technical problems with robot control software that may arise during the class. In this study, the research-assistant/teacher was the one who solved all the technical issues with the robot, because he was the one who created the software, besides having experience programming. Teachers who do not have technical experience might not consider the use of this device in the classroom.

Another barrier identified in using the robot in education was that it may be considered expensive for some schools or some parents and there may not be enough financial resources to buy it. The interviewees mentioned that the budget in each school varies, and usually the AT devices that are implemented in classrooms are cheaper than the robot. Although the cost of a Lego Mindstorms robot could be considered low, CAD ~ $400, it could still be too high to be implemented in educational environments with insufficient funds or in a low-income family (Cruz, Ríos Rincón, Rodríguez Dueñas, Quiroga Torres, & Bohórquez-Heredia, 2017).

Finally, the robot device itself imposed limitations. For instance, the participants in this study required more time to complete a question using the robot than using the computer or in the baseline. The additional time required to complete a mathematics question with the robot could affect its use in a regular classroom. Teachers may find it challenging to provide specialized support or manage time for the student with disabilities to use the robot to do the same activity as typically developing students (Encarnação et al., 2017). Although the research-assistant/teacher gave prompting and assistance so that the participants could solve a question in a more effective way, this implies that an adult would always need to be with the student to provide support while the student uses the robot.

Often, teachers must manage a whole classroom and may not have time to focus on a single student. The interviewees pointed out that the robot could not be used with all the students at the same time in the classroom; therefore, the lessons would have to be individualized.

Overall, the environmental barriers can be a powerful determinant that can influence the use of the robot in educational activities. If there is a lack of technical training for teachers or lack of funding, or if there is no support for the student to use the robot effectively in the classroom, the robot could not be used in schools. These findings of barriers to use the robot are related to the findings reported by Cruz, Ríos Rincón, Rodríguez Dueñas, Quiroga Torres and Bohórquez-Heredia (2017), and Encarnação et al. (2017).

Regarding environmental barriers to using the computer in mathematics learning, two factors were found in this study that could influence its use. The first factor is related to the incompatibility of the virtual mathematics programs with the alternative access methods of the students. The sorting lessons with Dylan and the In/Out lessons with Jacob had to be designed using custom software for people with disabilities. It was not possible to find online programs about the mathematical concepts that were accessible or that could be controlled according to the students' abilities to use a computer. This finding implies that the teachers would have to design each of their lessons using accessible software and this can result in the same barriers found with the robot. The lessons would have to be individualized, or the teachers would not have enough time to design the lessons in the custom software. Therefore, it could be challenging to implement virtual mathematics programs in the classroom.

The second factor is related to a lack of control of online mathematics programs to be configured according to the lesson plans for the students. For instance, the programs used with

Ethan suggested the same number to count several times, and usually, the numbers were small like 2 or 3. Thus, it was more difficult for Ethan to achieve learning of larger numbers with the computer in comparison with the robot, where we had control of the questions. Furthermore, the programs used with Jacob only had a limited number of questions. The research-assistant/teacher used the programs to show Jacob how to control them, but when the programs were restarted for Jacob to answer, the same questions appeared. Hence, Jacob could have remembered some of the answers due to the demonstration that the research-assistant/teacher provided, instead of having acquired an understanding of the concept. According to Case & Davidson (2011), much of the student's success in using ICT will depend on how a program is designed, and programs are often designed without thinking about the needs of people with disabilities. This is one of the reasons why AT devices are abandoned, as there may be a lack of matching between the user's needs and the device features (Coleman, 2011).

Another environmental barrier that could be observed in this study was the distractions presented in the environment, such as the people present during the sessions. This was most evident in Jacob. When other teachers and classmates were in the room, Jacob tended to divert his attention away from the lessons to observe them, and the research-assistant/teacher often had to repeat the instructions. This may have been one of the factors that caused difficulties in increasing his performance and in controlling the AT strategies. Similar results have been found in Reed, Bowser and Korsten (2004) who emphasized that it is essential to identify if there are distractions in the environment when using AT devices in the classroom.

5.4 Occupational performance

Occupational performance is formed by the transaction between the person, the environment and the occupation in which the person is involved (Christiansen, Baum, & Bass, 2015). A change in the environment through the implementation of AT can improve the PEOP fit; therefore, there may be an improvement in occupational performance and engagement (Law & Barker, 2007). According to the findings, Ethan had an improvement in his occupational performance because the AT strategies were effective in improving his accuracy in solving the questions and increasing his participation and engagement. With Dylan and Jacob, it could be noted that the intervention was not effective to improve their occupational performance. This may be related due to an inadequate understanding of their neuro-behavioural and cognitive abilities or an inadequate structure of the tasks during the lessons. If there is a lack of matching between personal competences, physical environment (AT strategies), or activity, the occupational performance may be diminished (Law et al., 1996).

Although it was observed that the students had an increase in their engagement and participation when using the AT strategies, this may be attributed to the fun factor the devices presented, so the participants could associate them more as devices for play and not for learning. Likewise, the students had active participation during the lessons, but these lessons were one-on-one. Therefore, it is necessary to conduct future research to determine if the AT strategies can increase the participation of students with physical disabilities in a classroom.

5.5 Limitations

The main limitation of this study was the locations where the sessions were conducted. A simulated mathematical instruction was created in a controlled environment; therefore, it is not possible to establish whether the results will be applicable in a school setting. If the students had used the AT strategies in their respective classes, I would have encountered more facilitators and barriers with respect to the social environment than in a laboratory or rehabilitation center where there was no interaction with peers or school staff.

Other limitations that were observed in this study are related to the design of the study. For instance, the planning of the lessons by the research-assistant/teacher and me, as well as the sessions conducted by the research-assistant/teacher could be considered as not faithful to mathematics lessons in a school setting. Although we had guidance from the special education teacher, the research might be more valid if a mathematics teacher with several years of experience in the classroom would have conducted the lessons. Moreover, social environmental factors were drawn from the interviews with parents and one teacher. Having more interviews to collect perspectives of multiple people such as school staff, school directives, and teachers might have led to varying interpretations.

It is important to note that in qualitative research, the results are contextual and subject to individual characteristics and knowledge (Mills, Durepos, & Wiebe, 2009), therefore, it would not be possible to generalize the results of this study. However, the findings present some factors and characteristics that might inform other researchers and clinicians who want to implement the robot or ICTs.

5.6 Significance of the study

This thesis contributes to the current body of knowledge about the use of AT to support the learning of students with physical impairments. It describes the contextual factors that could influence the uptake of different AT strategies to contribute to the mathematics learning. The findings show that the severity of the impairment, the students' engagement, the device features, social support, and impact in the occupational performance played a relevant part in the use of the technology.

This study addresses children with disabilities who are 3.7% of the children between 0 to 14 years in Canada. This population is expected to grow to one in five children in the next few years (Statistics Canada, 2006). Statistics Canada in 2012 reported that more than 8 out of 10 Canadians with disability aged 15 years or older use AT. In fact, 81.3% of people with disabilities reported using some kind of AT to facilitate their functioning in daily activities (Statistics Canada, 2012).

Many students with disabilities rely on AT to help them function and participate in a school environment (Akpan & Beard, 2014). This study may provide useful information for teachers and rehabilitation staff working with students who require AT. This study revealed those factors that can make the use of AT in mathematics succeed or fail. Also, the study is significant because it may influence the provision of AT at administrative and policy levels. The findings may lead to an improvement in curriculum development and teaching resources with the goal of improving student achievement while using AT.

This study also has several contributions for occupational therapy practice. It provides several recommendations for occupational therapists working in schools who are interested in implementing AT to enhance student's occupational performance. Occupational therapists need to consider the students' physical and cognitive skills as well as their needs, so that they can implement the AT strategies in accordance with those factors. Besides, occupational therapists need to perform a task analysis of the academic tasks that the student will perform. Through task analysis, occupational therapists can identify what type of modifications are required so that the child can use the AT strategies adequately and efficiently to complete the task. Finally, it is essential to consider the implementation of an exploratory phase to learn how to control the alternative access methods before the intervention.

5.7 Future research

The results of this study suggest a need for future research in several areas. Future studies should focus on the design of the ICTs to be used by students with disabilities. For instance, researchers could develop mathematics programs following the principles of universal design, or develop free software that can be used through different alternative access methods. Moreover, researchers could develop a training protocol for students and school staff to use the Lego robot, including guidance on technical aspects.

In addition, future research directions might include investigating how children report their perceptions about the AT strategies using interviews, rather than using questionnaires. The QUEST 2.1 and PIADS are two of the few standardized surveys used in the AT field. Yet, as in this study, the surveys may be difficult for children to do. Creative methods of interviewing, such as photoelicitation (Harper, 2002), might allow children with severe disabilities to have better representation within the research. Children's perspectives may differ from that of their parents and teachers.

The interviewees reported that students could use the AT strategies to participate in the same activities as their peers. Student’s participation with peers when the student is using the AT strategies could not be observed in this study. Thus, future research could determine the effect of the AT strategies on student’s participation in hands on and collaborative activities.

Future research could explore contextual factors in a regular classroom while a real teacher is giving the mathematics instruction and the student is solving the problems while using the AT strategies. That may shed more light on the personal and environmental factors that can influence the use of the robot and the computer.

5.8 Conclusion

The purpose of this thesis was to explore contextual factors that could influence the use of the Lego Mindstorms robot and computer programs in mathematics lessons. This study contributes to the current body of knowledge of AT in academic learning. The findings from this study make several contributions to the current literature by describing personal and environmental factors that may contribute to the long-term use of the AT strategies to support mathematics learning, or to an abandonment of the devices.

The results of this study indicate that the AT strategies and the demands of the task should be matched to the motor and cognitive abilities of the student with physical disability. Moreover, it is relevant to consider the student's previous experiences using AT so that the new AT strategies can be implemented smoothly and be used successfully in mathematics. In the same way, it should be taken into account that mathematics is an academic subject that demands high-order thinking skills; thus, providing assistance to use the AT devices, simplifying the lessons, and doing the activity in the morning hours are factors that can reduce the physical and cognitive burden on the student.

In this study, it was also shown that each AT strategy itself provided different facilitators and barriers affecting their use in mathematics. The Lego robot allowed manipulation of concrete manipulatives and the students were more motivated to use the robot than the computer. However, teachers may not know how to troubleshoot if problems arise with this device, and it may be considered expensive for some schools. The virtual mathematics programs were easy to use, and the students were able to solve the problems quickly, which can positively influence the participation of students with physical disabilities in the same activities as their peers. Yet, many of these programs are not designed to be accessible, nor were they configured according to the lessons plans. Therefore, students with physical disabilities might have difficulties using these programs to strengthen their mathematical learning, and teachers may find it challenging to implement the computer in their mathematics lessons.

This thesis contributes to the occupational therapy literature. Occupational therapists recognize the importance of identifying different AT devices that can support children's ability to engage in one of their principal occupations, education, and thus improve their occupational performance. It was identified through the literature review that robots and computer programs can increase the participation of students with disabilities in mathematics activities. This thesis contributes to that literature and may be useful for occupational therapists who are considering to implement these devices to support the participation and enhance the learning of students with disabilities. This study suggests that teachers and parents need to be trained to use the AT devices, that the demands to control the devices and student abilities should be matched, and that several modifications may be necessary for satisfactory use of strategies. Occupational therapists see the client in a holistic way, and this study can provide information on a few personal and environmental factors that influence the use of the robot and/or the computer, taking into account that each client is unique and the factors mentioned here can be presented or not.

Parents and school staff had a positive perception of the use of both AT strategies to improve the academic performance of students with disabilities. Besides, many research studies have shown that the robot and the computer are viable tools to increase the mathematics learning in students with disabilities. However, there is still the need for future research to propose solutions to reduce the limitations that arise with both devices, so students with physical disabilities can use them in their classroom.

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APPENDIX A: Field notes used during the sessions

Student	
Environment	
Task	
Tool	

Efficiency notes: (set-up time, time for participant to do problems)

Effectiveness notes: (# of device problems)

Other observations: ("aha!" moments, connections, frustrations, etc.)

Next time:

APPENDIX B: First semi-structured interview with parents and teacher

1. What do you think about –participant's name- performance in mathematics activities?

2. Did you notice any difference in his performance between when he did it with the research-assistant/teacher moving things versus when he did it with the robot versus when he did it with the computer?

3. What did you think about your ability to assess –participant's name- understanding of the mathematical concept?

4. Do you feel that using a robot as a tool to assist students with severe disabilities is a viable option? Why/why not?

5. What were some of the positive observations you saw while –participant's name- was using the robot?

6. What do you think would be the challenges of using the robot?

7. Do you feel that using the computer as a tool to assist students with severe disabilities is a viable option, why and what are some of your thoughts about it?

8. What were some of the positive observations you saw about using the computer?

9. What do you think would be the challenges of using the computer?

10. Do you feel that the student's perception of himself as a learner has changed through the use of the robot or the computer?

Do you have any other additional comments?

APPENDIX C: Second semi-structured with parent

1. What types of AT devices has –participant's name- used at home and/or at school? Has he tried any AT device that was not successful? Why?
2. Can you describe a typical weekday for –participant's name? Does –participant's name- fatigue easily or experience a change in his performance at different times of the day?
3. How has your experience been with –participant's name- in the school system?
4. Does –participant's name- like going to the school? Why/why not? What does he think about mathematics?
5. Who works with –participant's name- in the classroom (teachers, school/rehabilitation staff)? What kind of things they do to support him?
6. Does –participant's name- interact with his classmates? Do they help him in class? Why/why not?
7. What factors influenced your decision to implement the robot at home? Do you or will you use any computer program for learning at home?
8. How do you think the robot can help –participant's name- at home?
9. What kind of barriers do you consider may affect the implementation of the robot and the computer in –participant's name- classroom (e.g. funding, support, etc.)? What about facilitators?

Is there anything else you would like to add that has not been addressed?

APPENDIX D: Second semi-structured with teacher

1. How long have you been teaching? How long have you been working with students with disabilities?
2. What types of AT devices have you used with –participant's name- in the classroom?
3. What strategies (tasks or activities) do you use when you are teaching mathematics?
4. Can you describe a typical day at school for –participant's name-? Does –participant's name- fatigue easily or experience a change in performance at different times of the day?
5. Who works with –participant's name- (teachers, school staff)? What kind of things they do to support him in the classroom?
6. Does he interact with his classmates? Can you give an example?
7. How have you perceived the institutional support (e.g., school administration, learning inclusion teams) to –participant's name- to use AT in the classroom?
8. How confident do you think you would be using the robot with –participant's name-? What about the computer?
9. Do you think you can use the robot and the computer when teaching all the students in your classroom? Why/ why not?
10. How do you think the robot and the computer may fit into your lessons planning and instruction?
11. What kind of barriers do you think may affect the implementation of the robot and the computer in the classroom? What about facilitators?
12. What advice would you recommend for other teachers who work with students who use AT devices in the classroom?

Is there anything else you would like to add that has not been addressed?

APPENDIX E: Child Assent Form

Title of Research Study: Active engagement in mathematics for children with disabilities: a comparison of assistive technology strategies for hands-on learning

Principal Investigator: Kim Adams, Ph.D., Associate Professor Faculty of Rehabilitation Medicine

Phone: 780.492.0309. Fax: 780.492.1626. Email: kdadams@ualberta.ca

Address: 3-48 Corbett Hall. T6G 2G4. Edmonton, Alberta, Canada

Co-Investigator(s):

Lynn McGarvey, Associate Professor, Department of Education, University of Alberta

Bonnie-Lynn David, Special Education Teacher, I Can Centre for AT, GRH

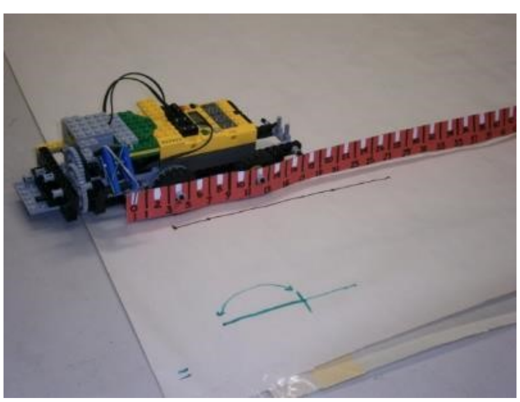
Study Coordinator: Paola Esquivel**,** MSc student, University of Alberta

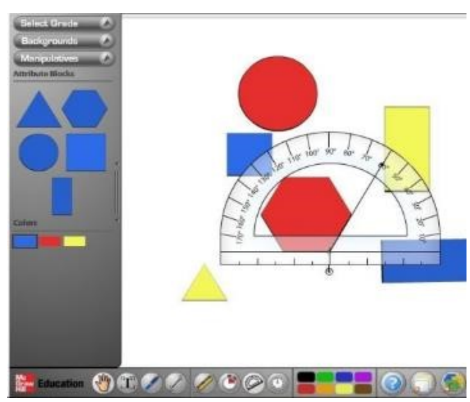
We have some different ways for doing some math activities. We want you to try them so we can see how they work. Five other children who have disabilities will do this study.

What will you have to do?
You will do some math activities. We will visit you several times over two or three weeks. Each visit will be for about 20 minutes. You can have as many rest breaks as you need.

- First, we want to see how fast you can type on your talking box or computer.
- Then, you will do 5 math activities as you normally would. We will ask you to do at least 5 math questions.
- Then you will learn how to control a Lego robot. You will control it with your talking box or iPad or tablet if you use one. You will use the robot to knock over some blocks and drive through a race course. This will take about an hour.
- Then, you will learn how to use a program to do math. This will take about half an hour.

Here are pictures of the robot and one type of program to do math.





- Then, you will do 10 math activities again. This time you will switch between the robot or the computer. A researcher will be there to help with any problems. We will ask you to do at least 5 math questions each day.

We will watch you to see what it is like to use the robot and computer. We will make a video of you and watch it later. Afterwards, will ask you to tell us what you think of the robot and computer.

Will it help?
It might help you to learn some math concepts. You may enjoy playing with the robots or computer.

Will it hurt?
No, it will not hurt.

Can you quit?
You don't have to take part in the study at all. You can quit any time. No one will be mad at you if you don't want to do this. You can even stop part way through. Just tell your parents or the researcher if you want to stop.

Who will know?
No one except your parents and the researchers will know you're in the study. If you want you can tell other people. Your name and your information won't be seen by anyone except the investigators. The videos will be locked in a drawer.

Your signature:
We would like you to sign this form to show that you agree to take part. You can sign however you like. For example:
- You can write your name, if you are able.
- Or, you can say "Yes" with your voice or with your talking box if you have one.
- Or, you can nod your head.
- Or, make the sign that you do for "yes".

Your mom or dad will be asked to sign another form agreeing for you to take part in the study.

Do you have more questions? You can ask your mom or dad about anything you don't understand. You can also talk to Dr. Kim Adams. Her phone number is 780-492-0309.

I agree to take part in the study.

____
<signature of research participant>

I believe the child signing this form (or indicating assent) understands the study and voluntarily agrees to participate.

______________________________ __________
<signature of witness> <date>

______________________________ __________
<signature of investigator> <date>

APPENDIX F: Parent/Guardian Consent Form

Title of Research Study: Active engagement in mathematics for children with disabilities: a comparison of assistive technology strategies for hands-on learning

Principal Investigator: Kim Adams, Ph.D., Associate Professor Faculty of Rehabilitation Medicine

Phone: 780.492.0309. Fax: 780.492.1626. Email: kdadams@ualberta.ca

Address: 3-48 Corbett Hall. T6G 2G4. Edmonton, Alberta, Canada

Co-Investigator(s):

Lynn McGarvey, Associate Professor, Department of Education, University of Alberta

Bonnie-Lynn David, Special Education Teacher, I Can Centre for AT, GRH

Study Coordinator: Paola Esquivel**,** MSc student, University of Alberta

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Why is your child being asked to take part in this research study?

We have been trying ways for children who have physical disabilities to do the "hands-on" activities in math. Teachers often use small objects when they teach students the math concepts. But, it can be difficult for children with disabilities to hold, touch, or point to the objects. We call the small objects manipulatives. Children can use Lego Robots to move manipulatives, like blocks or paperclips. Or, they can use iPads or computers to move virtual representations of manipulatives on the screen. We would like your child to try these strategies.

The purpose of this information sheet is to provide you with the information needed to decide if you want your child to participate in this study. Before you make a decision, one of the researchers will go over this form with you. You are encouraged to ask questions if you feel anything needs to be made clearer. You will be given a copy of this form for your records.

What is the reason for doing the study?

Learning involves seeing, speaking, and *doing*. Children with disabilities sometimes watch other students doing activities. Using robots or software may allow the children to do the activities themselves. There are strengths and weaknesses for each strategy. We want to watch your child using each strategy so we can learn about them. We also want to find out his/her teacher's opinions about each strategy. This will help us learn how to make the technology useful in the classroom.

What will my child be asked to do?

Your child will do math activities as usual. We will observe several times over two or three weeks. The details of what we will do, how long it will take, and who needs to be there is shown in the table on the next page. Videos of the sessions will be made only with your consent.

If your child has a file at the I Can Centre at the Glenrose Hospital we might want to look at it. We might need to know diagnosis, or the length of time since obtaining devices. This information helps us describe the participants accurately. Also, it will help us see if prior experience with devices effects how well your child can control the robot or computer.

What are the risks and discomforts?
Your child may get tired during the task. Breaks will be given as needed. The robot is battery operated and there is no danger of electrical shock. The robot is small and lightweight. So it will not hurt your child if it does contact him or her.

It is not possible to know all of the risks that may happen in a study. But the researchers have taken all reasonable safeguards to minimize any known risks to a study participant.

What are the benefits to my child?
Children have had fun in our other studies using robots. They will be able to interact with "hands-on" learning materials. Students with motor impairments will have a method to demonstrate what they know. This study could result in methods for using robots in other lessons. However, your child may not get any benefit from being in this research study.

Does my child have to take part in the study?
Being in this study is your choice. If you decide to be in the study, you can change your mind and stop being in the study at any time. It will in no way affect the services that you are entitled to.

	Procedure	Length of time	Who attends		
			Teacher	Child	Helper
Before the study	Testing before the study:			Yes	
	- communication device use (if applicable)	1 hour			
	- speed and accuracy with access method.	30 minutes			
	We will meet with the **teacher** to discuss the math goal for your child. We will ask the **teacher** to identify a peer or Education Assistant to work with your child in part a).	About a half hour	Yes		
a) Baseline	Your child and a helper will do math lessons in the classroom the way they usually do. Each time will involve 5 problems.	This will be five times, about 15 minutes each.	Observe if desired	Yes	Yes
	At the first and last session of the baseline: we will ask the teacher to do an assessment of your child's understanding of the concept.	About 15 minutes each time.	Yes		
	After the last baseline session: a researcher will do two surveys with your child about what he/she liked or didn't like.	About 15 minutes.		Yes	
b) Training	Your child will learn how to use the robot and a computer programs. This can be done in a convenient location for the teacher. The training involves playful games like knocking over blocks.	This will take about an hour and a half.	Observe if desired	Yes	
c) Intervention	Your child will do math lessons in the classroom with the robot or the computer. Which one will be randomly selected each time. A research assistant will be there to help. Each time will involve 5 problems.	This will be 10 times, about 20 minutes each time.	Observe if desired	Yes	
	For the last two sessions: the teacher will do an assessment of student understanding.	About 15 minutes each time.	Yes		
	After the last session with each method: a researcher will do the two surveys with your child again.	About 15 minutes each time.		Yes	
After the study	Interview with the teacher	About a half hour each.	Yes		

Will my child's information be kept private?
During the study we will be collecting data about your child. We will do everything we can to make sure that this data is kept private. No data relating to this study that includes your child's name will be released outside of the researcher's office or published by the researchers. Sometimes, by law, we may have to release your child's information with his/her name so we cannot guarantee absolute privacy. However, we will make every legal effort to make sure that your information is kept private.

The video recording does not obscure your child's face. But, we will not identify children by name. Computer files will be password protected. Other data is kept in a locked drawer. The information will only be available to the researchers. After the study is done, we will still need to store the data. At the University of Alberta, we keep data stored for a minimum if 5 years after the end of the study. After 5 years we will securely destroy the data.

If your child has a file at the I Can Centre, Glenrose Hospital, the investigator or study staff may need to look at it. Any information that we get from these records will be only what is needed for the study. By signing this consent form you are saying it is okay for the study team to collect information about your child as described above. If we do want to look at the file, we will ask you to complete the appropriate Glenrose Hospital consent forms.

What if I have questions?

If you have any questions about the research now or later, please contact: Dr. Kim Adams (Phone 780- 492-0309, Fax 492-1626, e-mail - kim.adams@ualberta.ca) Faculty of Rehabilitation Medicine, University of Alberta.

If you have any questions regarding your rights as a research participant, you may contact the Health Research Ethics Board at 780-492-2615. This office has no affiliation with the study investigators.

There are no actual or potential conflicts of interest with respect to remuneration received from the funding agency for conducting or being involved with any part of the study and/or the possibility of commercialization of research findings. The study is being sponsored by the Social Sciences and Humanities Research Council of Canada. The Institution and Principal Investigator are getting money from the study sponsor to cover the costs of doing this study. You are entitled to request any details concerning this compensation from the Principal Investigator.

CONSENT

Title of Study: Active engagement in mathematics for children with disabilities: a comparison of assistive technology strategies for hands-on learning

Principal Investigator(s): Kim Adams **Phone Number(s):** 780-492-0309
Study Coordinator: Paola Esquivel **Phone Number(s):** 780-492-5422

	Yes	**No**
Do you understand that you have been asked to be in a research study?	☐	☐
Have you read and received a copy of the attached Information Sheet?	☐	☐
Do you understand the benefits and risks involved in taking part in this research study?	☐	☐
Have you had an opportunity to ask questions and discuss this study?	☐	☐
Do you understand that you are free to leave the study at any time, without having to give a reason and without affecting your services?	☐	☐
Has the issue of confidentiality been explained to you?	☐	☐
Do you understand who will have access to your child's study records, (including personally identifiable health information?)	☐	☐
Do you consent to the researchers using your child's video recordings for scientific presentation and/or publication?	☐	☐

Who explained this study to you? ____

I agree for my child to take part in this study:

Signature of Research Participant's Parent or Guardian____

(Printed Name) ____

Date:____________________________

I believe that the person signing this form understands what is involved in the study and voluntarily agrees for his/her child to participate.
This should be signed by the person who is conducting the informed consent discussion (if that is not the Investigator – the person that obtained the consent needs to sign here)

Signature of Investigator or Designee ______________________________ Date __________

THE INFORMATION SHEET MUST BE ATTACHED TO THIS CONSENT FORM AND A COPY GIVEN TO THE RESEARCH PARTICIPANT

APPENDIX G: Teacher Consent Form

Title of Research Study: Active engagement in mathematics for children with disabilities: a comparison of assistive technology strategies for hands-on learning

Principal Investigator: Kim Adams, Ph.D., Associate Professor Faculty of Rehabilitation Medicine

Phone: 780.492.0309. Fax: 780.492.1626. Email: kdadams@ualberta.ca

Address: 3-48 Corbett Hall. T6G 2G4. Edmonton, Alberta, Canada

Co-Investigator(s):

Lynn McGarvey, Associate Professor, Department of Education, University of Alberta

Bonnie-Lynn David, Special Education Teacher, I Can Centre for AT, GRH

Study Coordinator: Paola Esquivel**,** MSc student, University of Alberta

Why are you being asked to take part in this research study?

We have been trying ways for students who have physical disabilities to do the "hands-on" activities in math class. Teachers often use small objects when they teach students the math concepts. But, it can be difficult for children with disabilities to hold, touch, or point to the objects. We call the small objects manipulatives. Students can use Lego Robots to move manipulatives, like blocks or paperclips. Or, they can use iPads or computers to move virtual representations of manipulatives on the screen. We would like your student to try these strategies in their classroom.

The purpose of this information sheet is to provide you with the information needed to decide if you want to participate in this study. Before you make a decision, one of the researchers will go over this form with you. You are encouraged to ask questions if you feel anything needs to be made clearer. You will be given a copy of this form for your records.

What is the reason for doing the study?

Learning involves seeing, speaking, and *doing*. Children with disabilities sometimes watch other students doing activities. Using robots or software may allow the children to do the activities themselves. There are strengths and weaknesses for each strategy. We want to watch your student using each strategy so we can learn about them. We also want to find out your opinions about each strategy. This will help us learn how to make the technology useful in the classroom.

What will you be asked to do?

Your student will attend your math class as usual. We will visit the class several times over two or three weeks. The details of what we will do, how long it will take, and who needs to be there is shown in the table on the next page. Videos of the sessions will be made only with your consent.

What are the risks and discomforts?

The student may get tired during the task. Breaks will be given as needed. The robot is battery operated and there is no danger of electrical shock. The robot is small and lightweight. So it will not hurt you if it does contact you.

It is not possible to know all of the risks that may happen in a study. But the researchers have taken all reasonable safeguards to minimize any known risks to a study participant.

What are the benefits?
Students have had fun in our other studies using robots. They will be able to interact with "hands-on" learning materials. Students with motor impairments will have a method to demonstrate what they know. This study could result in methods for using robots in other lessons. However, you may not get any benefit from being in this research study.

Do you have to take part in the study?
Being in this study is your choice. If you decide to be in the study, you can change your mind and stop being in the study at any time. It will in no way affect the services that you are entitled to.

Will your information be kept private?
During the study we will be collecting data. We will do everything we can to make sure that this data is kept private. No data relating to this study that includes your name will be released outside of the researcher's office or published by the researchers. Sometimes, by law, we may have to release your information with your name so we cannot guarantee absolute privacy. However, we will make every legal effort to make sure that your information is kept private

The video recording does not obscure faces. But, we will not identify anyone by name. Computer files will be password protected. Other data is kept in a locked drawer. The information will only be available to the researchers. After the study is done, we will still need to store the data. At the University of Alberta, we keep data stored for a minimum if 5 years after the end of the study. After 5 years we will securely destroy the data.

	Procedure	Length of time	Who attends		
			Teacher	**Child**	**Helper**
Before the study	Testing before the study:			Yes	
	- communication device use (if applicable)	1 hour			
	- speed and accuracy with access method.	30 minutes			
	We will meet with you to discuss the math goal for your student. We will ask you to identify a peer or Education Assistant to work with your student in part a).	About a half hour	Yes		
a) Baseline	Your student and a helper will do math lessons in the classroom the way they usually do. Each time will involve 5 problems.	This will be five times, about 15 minutes each.	Observe if desired	Yes	Yes
	At the first and last session of the baseline: we will ask you to do an assessment of your student's understanding of the concept.	About 15 minutes each time.	Yes		
	After the last baseline session: a researcher will do two surveys with your student about what he/she liked or didn't like.	About 15 minutes.		Yes	
b) Training	Your student will learn how to use the robot and a computer programs. This can be done in a convenient location for you. The training involves playful games like knocking over blocks.	This will take about an hour and a half.	Observe if desired	Yes	
c) Intervention	Your student will do math lessons in the classroom with the robot or the computer. Which one will be randomly selected each time. A research assistant will be there to help. Each time will involve 5 problems.	This will be 10 times, about 20 minutes each time.	Observe if desired	Yes	
	For the last two sessions: you will do an assessment of student understanding.	About 15 minutes each time.	Yes		
	After the last session with each method: a researcher will do the two surveys with your student again.	About 15 minutes each time.		Yes	
After the study	Interview with you	About a half hour each.	Yes		

What if I have questions?

If you have any questions about the research now or later, please contact: Dr. Kim Adams (Phone 780- 492-0309, Fax 492-1626, e-mail - kim.adams@ualberta.ca) Faculty of Rehabilitation Medicine, University of Alberta.

If you have any questions regarding your rights as a research participant, you may contact the Health Research Ethics Board at 780-492-2615. This office has no affiliation with the study investigators.

There are no actual or potential conflicts of interest with respect to remuneration received from the funding agency for conducting or being involved with any part of the study and/or the possibility of commercialization of research findings. The study is being sponsored by the Social Sciences and Humanities Research Council of Canada. The Institution and Principal Investigator are getting money from the study sponsor to cover the costs of doing this study. You are entitled to request any details concerning this compensation from the Principal Investigator.

CONSENT

Title of Study: Active engagement in mathematics for children with disabilities: a comparison of assistive technology strategies for hands-on learning

Principal Investigator(s): Kim Adams **Phone Number(s):** 780-492-0309
Study Coordinator: Paola Esquivel **Phone Number(s):** 780-492-5422

	Yes	No
Do you understand that you have been asked to be in a research study?	☐	☐
Have you read and received a copy of the attached Information Sheet?	☐	☐
Do you understand the benefits and risks involved in taking part in this research study?	☐	☐
Have you had an opportunity to ask questions and discuss this study?	☐	☐
Do you understand that you are free to leave the study at any time, without having to give a reason and without affecting your services?	☐	☐
Has the issue of confidentiality been explained to you?	☐	☐
Do you understand who will have access to your study records, (including personally identifiable health information?)	☐	☐
Do you consent to the researchers using your video recordings for scientific presentation and/or publication?	☐	☐

Who explained this study to you? ____

I agree to take part in this study:

Signature of Research Participant____

(Printed Name) ____

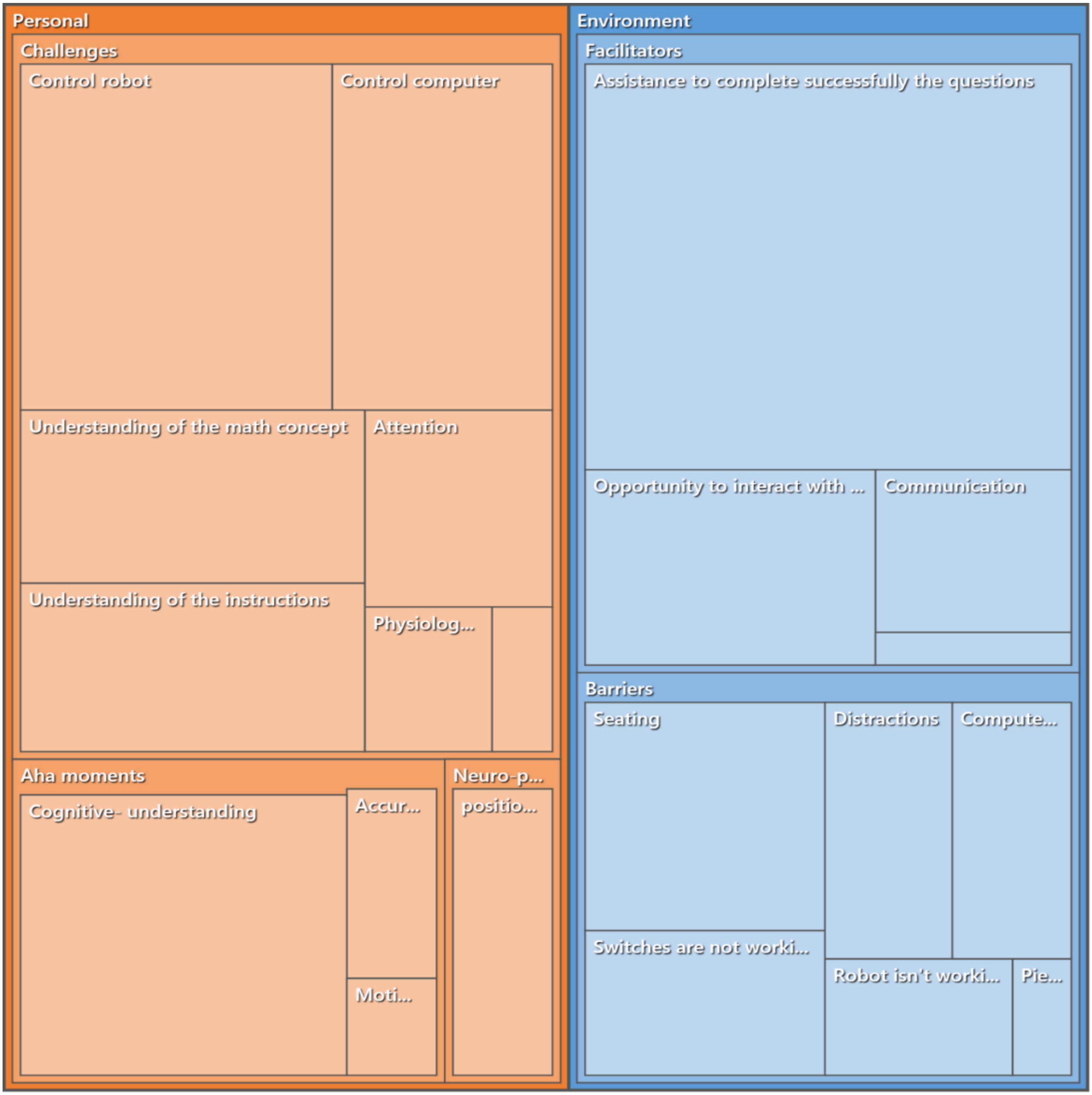
Date:______________________________

I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate.
This should be signed by the person who is conducting the informed consent discussion (if that is not the Investigator – the person that obtained the consent needs to sign here)

Signature of Investigator or Designee ________________________________ Date __________

THE INFORMATION SHEET MUST BE ATTACHED TO THIS CONSENT FORM AND A COPY GIVEN TO THE RESEARCH PARTICIPANT

APPENDIX H: Categories and subcategories that emerged from the observations using the NVivo 12 software.



APPENDIX I: Categories and subcategories that emerged from the interviews using the NVivo 12 software.