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Children with Disabilities Engaging in STEM: Exploring How a Group-Based Robotics Program Influences STEM Activation

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Abstract Children with disabilities encounter many barriers in engaging in science, math, and technology courses such as discriminatory attitudes and inaccessible classes, which can limit their educational and future employment opportunities. Helping children to foster an interest in science, technology, engineering, and math (STEM) disciplines early on can help to expand their career options. This study explored how a group-based robotics program impacted the STEM activation among children with disabilities. Children ($n = 33$) aged 6–14 completed pre-and post-surveys to assess any changes in STEM activation. Our results showed that for most groups, children's STEM activation scores increased from the beginning to the end of the program; however, these differences were not significant. It was encouraging to see that among the children who participated in the program more than once ($n = 18$), there was a significant increase in their STEM activation. Qualitative findings of children's experience in the programs show that they liked building, programming, and learning about robots. These findings suggest that it is worthwhile to engage children with disabilities in STEM programs.

Résumé Les enfants handicapés se heurtent à de nombreux obstacles lorsqu'ils veulent suivre des cours de sciences, de mathématiques et de technologies, par exemple à certaines attitudes discriminatoires ou encore à des salles de classe inaccessibles, ce qui peut limiter leurs perspectives d'éducation et d'emploi. Le fait d'aider ces enfants à s'intéresser dès le début aux sciences, aux technologies, à l'ingénierie et aux mathématiques (STEM) peut contribuer à élargir leurs options de carrière. Cette étude explore l'impact d'un programme de formation collective en robotique sur l'engagement actif envers les STEM chez les enfants handicapés. Ces enfants (n = 33), âgés de 6 à 14 ans, ont répondu à un questionnaire avant et après l'enquête afin d'évaluer tout changement dans leur engagement actif envers les STEM. Nos résultats montrent que pour la plupart des groupes, le niveau d'engagement actif des enfants a augmenté entre le début et la fin du programme; toutefois, ces différences ne sont pas significatives. Il est encourageant de constater une augmentation significative de cet engagement parmi les enfants ayant participé au programme

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plus d'une fois (n = 18). Les résultats qualitatifs de l'expérience des enfants dans ces programmes montrent qu'ils aiment construire, programmer et apprendre à utiliser des robots. Ces résultats suggèrent qu'il est utile et intéressant de faire participer les enfants handicapés à des programmes STEM.

Keywords Disability · Inclusion · Robotics · Under-represented groups · Autism · Physical disability

Introduction

People with disabilities are persistently under-represented in science, technology, engineering, and math (STEM) education and careers (Dunn et al., 2012; National Science Foundation, 2017; Thurston et al., 2017). Youth with disabilities are less likely than their peers without disabilities to enroll in science or math courses or to pursue post-secondary STEM majors (Beck-Winchatz & Riccobono, 2008; Duerstock, 2014). The under-representation of this group extends to the workforce, where people with disabilities are less likely than the population as a whole to be employed in STEM fields (National Educational Association of Disabled Students (NEADS), 2010; National Science Foundation, 2017). For example, data from the National Science Foundation (2017) indicates that 23% of undergraduate students with disabilities are enrolled in science or engineering majors, and out of all students with disabilities who obtain a bachelor's degree, 22% obtain employment in science or engineering. Engaging under-represented groups in STEM education is an important component to maximizing economic competitiveness and productivity (Basham et al., 2010; Caprile et al., 2015; Council of Canadian Academies, 2015; Henry et al., 2014; Marginson et al., 2013; National Science Foundation, 2017). Further, graduates with STEM majors report better employment outcomes and higher earnings than non-STEM graduates (Noonan, 2017; Statistics Canada, 2016). Therefore, improving the participation and inclusion of youth with disabilities in STEM disciplines can provide viable employment opportunities for them, while also promoting innovation and productivity growth (Council of Canadian Academies, 2015).

There are many barriers to accessing and participating in STEM disciplines for young people with disabilities (Dunn et al., 2012). For example, within the education system, educators often have little knowledge or training on inclusive STEM teaching (Bargerhuff, Cowan, & Kirch, 2010; Johnson, 2000; Moon et al., 2012; Mumba & Chitiyo, 2008) and make little effort to provide accommodations (Lindsay, 2011; Moriarty, 2007). Additionally, STEM curricula are typically inaccessible (Langley-Turnbaugh et al., 2009), and students with disabilities face inequitable access to learning content in the classroom (Faulkner et al., 2013; Mutch-Jones et al., 2012). Further, parents and teachers often do not encourage youth with disabilities to pursue STEM careers (Alston & Hampton, 2000). Of the few people with disabilities who do pursue employment within a STEM field, they face challenges to obtaining and persisting with this employment. For example, employers often lack understanding regarding the needs and abilities of employees who have a disability (Dunn et al., 2012). There are also few role models to support people with disabilities in STEM careers (Lee, 2011; Napper et al., 2002).

Recently, there has been an increasing emphasis on implementing programs to stimulate the participation of youth with disabilities in STEM (Beckstead & Gellatly, 2006; Government of Canada, 2018), including research investigating the effectiveness of interventions for developing interest in STEM fields. These studies have applied a variety of delivery formats, including a web-based course (Barman & Stockton, 2002), face-to-face courses or workshops (Burgstahler & Chang, 2007, 2014; Burgstahler & Cronheim, 2001; Burgstahler & Doyle, 2005; Dunn et al., 2015; Izzo et al., 2011; Kim-Rupnow & Burgstahler, 2004; Lam et al., 2008; Lemaire et al., 2002; Ludi & Reichlmayr, 2011; Napper et al., 2002; Powers et al., 2015; Sowers et al., 2017; Street et al., 2012; Wedler et al., 2014), and virtual mentoring (Gregg et al., 2017). Overall, positive outcomes were reported for these interventions, with improvements in perceived self-advocacy, self-esteem, social skills and independence (Burgstahler & Chang, 2007; Gregg et al., 2017), preparation for college and employment, and perceived career options (Kim-Rupnow & Burgstahler, 2004), as well as increased interest in enrolling in STEM classes and pursuing STEM careers (Izzo et al., 2011; Lam et al., 2008; Napper et al., 2002). Notwithstanding these positive outcomes, many of these studies apply multiple intervention methods simultaneously and do not explore the impact of participant characteristics like gender or disability type on STEM outcomes (Kolne & Lindsay, 2019). More rigorously designed research is required to understand the impact of specific intervention methods on developing interest in STEM education and careers among youth with disabilities (Kolne & Lindsay, 2019).

Robotics programs (e.g., *FIRST*®) are an increasingly popular approach for developing youth's interest and skills in STEM disciplines (FIRST® Robotics Canada, 2017; Lindsay & Hounsell, 2017; Ucgul & Cagiltay, 2014). Research shows that robotics programs are a promising tool for engaging children without disabilities in STEM (Benitti, 2012; Leonard et al., 2016; Mohr-Schroeder et al., 2014; Sullivan & Heffernan, 2016). Among youth with disabilities, adapted robotics programs may also be an effective mechanism for fostering interest and participation in STEM. Adapted robotics programs can help to increase confidence and participation in computers and programming among youth with visual impairments (Dorsey et al., 2014; Ludi & Reichlmayr, 2011), cerebral palsy (Adams & Cook, 2013, 2017; Howard et al., 2012), and Down syndrome (Taylor et al., 2017). However, the available evidence supporting the effectiveness of robotics for engaging youth with disabilities in STEM is disability-specific and primarily based on case studies. Therefore, there remains a need for rigorously designed research exploring a robotics intervention that is inclusive of children with a variety of disability types, especially within a group-based format.

This study addresses several important gaps in the literature. First, there are few group-based robotics programs for children with disabilities. Having a group-based program is an important feature because most previous robotics interventions for youth with disabilities are a one-to-one format (Adams & Cook, 2017; Taylor et al., 2017). Group-based robotics activities can also help to enhance personal development such as communication and teamwork skills, while promoting an interest in STEM (Eguchi, 2016; Huang & Chen, 2015). Second, of the few robotics programs that do exist for children with disabilities, they often have pre-built robots to engage children (Adams & Cook, 2017; Howard et al., 2012; Taylor et al., 2017), rather than teaching them how to build a robot themselves. Further, of the few studies focusing on STEM and/or robotics for children with disabilities, they mainly focus on case studies and involve children with intellectual disabilities. Little attention has been paid to a variety of disability types (Adams & Cook, 2017; Dorsey et al., 2014; Taylor et al., 2017). Finally, little is known about early STEM activation among children. Most research focuses on high school age. Focusing on younger ages is important because helping youth to foster an interest in STEM early on has the potential to enhance their educational and employment outcomes later on in life (Noonan, 2017).

Method

We used a pre-post survey to explore how a group-based robotics program influenced STEM activation among children with disabilities. This study received ethical approval from a research ethics board at a children's hospital and a university.

Description of the robotics program

This robotics program developed out of a partnership with FIRST® Canada (For Inspiration and Recognition of Science and Technology), which is a non-profit organization that operates after-school robotics programs for children (FIRST® Robotics Canada, 2015). The objective of the program is to help inspire young people to go into STEM fields by engaging them in mentor-based programs that build science, engineering, and technology skills and inspire innovation while helping to build self-confidence, communication, and leadership skills. Recently, FIRST® Robotics Canada partnered with a children's hospital to create an adapted version of their program to provide children with disabilities an opportunity to develop STEM skills while also working on therapy goals (Lindsay & Hounsell, 2017; Lindsay, Rampterab, & Curran, 2019). It is a group-based program that provides experience-based opportunities to build self-confidence, independence, communication, teamwork, and STEM skills (Lindsay & Hounsell, 2017; Lindsay et al., 2019). The program involves two separate age groups, aged 6–9 (juniors) and aged 10–14 (intermediates) with up to 10 children in a group. The program involves six, two-hour weekly sessions that are held in a classroom at a children's hospital. Each age group had two levels, an introductory and a more advanced and team-based version.

In the junior group, children work in pairs along with clinical staff (i.e., therapeutic recreation specialist) and a volunteer who has either knowledge of robotics and/or experience working with children who have a disability (Lindsay et al., 2019). Children build models using WeDO 2.0 while applying math and science concepts. In the intermediate group, there are approximately 10 children who work in small groups of 2 or 3 while using LEGO® MINDSTORMS®. They learn about robotics, mechanisms, simple machines, programming, and design and build and test a robot in a team environment (for examples and full description of program, see Lindsay & Hounsell, 2017; Lindsay et al., 2019).

Data collection and analysis

Data were collected from January 2017 to November 2018, which included five separate six-week-long sessions. Participants were asked to complete a questionnaire (either by themselves or with a parent) prior to starting the study, and again at the end of the last session. Questions asked about demographics, STEM activation (Dorph et al., 2011; Melchior et al., 2005), along with open-ended questions on why they joined the program, what they liked the most and least, and their interest in taking further robotics programs in their community. We used the STEM learning activation scale for our main outcome, which has a good internal reliability (Cronbach's $\alpha > 0.7$) and assesses the science of learning activation including fascination, values, competency belief, and scientific sense making that in parallel with the dimensions of science learning activation (Dorph et al., 2011; Melchior et al., 2005).

Data were analyzed using SPSS, version 25. Descriptive statistics were used to describe the sample characteristics using means and standard deviations for continuous variables and frequencies and proportions for categorical variables. Paired sample t tests were used to assess differences in STEM activation scores between time 1 (beginning of the program) and time 2 (end of the program). A level of 0.05 was used as the criterion for statistical significance. Open-ended survey questions were analyzed thematically (Braun & Clarke, 2006) by two authors.

Participants

Children were recruited from a pediatric rehabilitation hospital. All parents of children ($n = 151$) who registered for the robotics program were given an information package informing them about the study. Researchers were available to answer any questions that they had before deciding to take part. Thirty-three children and their parents signed a written consent form and completed both a pre- and post-survey.

Results

Sample characteristics

Our sample involved children in grades 1–8, including 29 male, 3 female, and 1 identified as other. Eighty-seven percent of the children had autism spectrum disorder, 3% had a physical disability, and 9% had a developmental or intellectual delay or a learning disability (see Table 1 for an overview of participants). Over half of the sample (54.5%) participated in a robotics program more than once.

Primary outcome: STEM activation

Our primary outcome focused on STEM activation. Paired sample t tests between time 1 and time 2 were computed to examine differences in STEM activation before and after children completed the program. All but one session showed improvements in STEM activation from time 1 to time 2 (see Table 2); however, these differences were not significant. When examining the participants who participated in the program more than once, we noticed a significant difference in STEM activation from time 1 (59.0 ± 8.24) to time 2 (64.2 ± 10.71) ($t = -3.55$, $p < 0.03$).

Table 1 Overview of participant characteristics

	n	%
Grade		
1	2	6.0
2	8	24.2
3	5	15.2
4	6	18.2
5	4	12.1
6	4	12.1
7	3	9.2
8	1	3.0
Gender		
Male	29	87.8
Female	3	9.2
Other	1	3.0
Disability type		
Autism	29	87.8
Cerebral palsy	1	3.0
Developmental delay	1	3.0
Intellectual delay	1	3.0
Learning disability	1	3.0
No. of times participated		
1	15	45.5
2	7	21.2
3	6	18.2
4	4	12.1
5	1	3.0

Table 2. Paired sample *t* tests of participant STEM activation outcomes by session

Session	Mean ± SD	*t*	*p*
Session 1			
Time 1	55.67 ± 4.16	− 0.950	0.442
Time 2	60.33 ± 7.63		
Session 2			
Time 1	63.33 ± 8.68		
Time 2	65.67 ± 7.99	− 1.24	0.268
Session 3			
Time 1	61.78 ± 16.85		
Time 2	61.56 ± 18.11	0.57	0.956
Session 4			
Time 1	59.89 ± 12.94		
Time 2	63.33 ± 11.97	− 1.22	0.255
Session 5			
Time 1	60.33 ± 9.99		
Time 2	61.83 ± 8.51	− 0.392	0.711
Participants taking the course more than once			
Time 1	59.00 ± 8.24	− 3.55	*0.024*
Time 2	64.20 ± 10.71		

Value in italic indicates statistical significance

Secondary outcome: children's experiences in the program

In their open-ended survey responses, children described what they liked about the program, which involved building and programming, learning about robots, and moving the robots, and also that it helped them to think about their career pathway (see Table 3 for illustrative quotes). The children reported overwhelmingly positive experiences in the program. For example, a child said, "I liked how I could build a robot and then connect it to an iPad" (JFL603). Of the few children who reported something that they liked the least, they mentioned things such as "wanting more time for programming" (IFL504).

Discussion

Given that our economy is increasingly dependent on technological innovation, it is critical to encourage children to foster an interest in STEM disciplines early on. Our study explored youth with disabilities, a group that is persistently under-represented in STEM, and who are often excluded from mainstream science and robotics programs (Dunn et al., 2012). Although diversity in STEM disciplines is increasing, people with disabilities remain under-represented (National Science Foundation, 2017; Thurston et al., 2017). Our study explored how a group-based robotics program for children with disabilities impacted their STEM activation. Our results showed that for most groups, children's STEM activation scores increased from the beginning to the end of the program; however, these differences were not significant. It was encouraging to see that among the children who participated in the program more than once, there was a significant difference in their STEM activation. These findings suggest that it is worthwhile to engage children with disabilities in STEM programs and that persistence in robotics programs associated with increased STEM activation. Helping youth to develop an interest in STEM early on has the potential to enhance their educational and employment outcomes later on in life (Noonan, 2017), not to mention enhancing diversity

Table 3 Overview of themes and illustrative quotes

Theme	Example participant quotes
Building and programming	"I want to make 1 meter Robot which can do awesome things like crashing LEGO® buildings into small pieces." (JFL605) "I like programming robots and building them." (IFL107) "I hope to learn how to program robots and follow instructions." (JFL708) "It is pretty cool, like star wars droids. I was happy with how much I learned." (IFL702)
Learning about robots	"I like learning new stuff. It makes me feel good." (JFL702) "I liked to control the robot with the tablet." (JFL707) "It was so much fun." (IFL204)
Moving the robots	"Being able to use my hummer (adaptive switch to make the robot move)." (IFL301) "I liked the robot wars and the obstacle course." (IFL503) "I liked customizing my robot and battling!" (IFL707)
Career pathways	"I was very excited to be part of robotics program." (JFL603) "I can tell you that I want to be a scientist, an animator, an artist and an engineer." (JFL701) "It is a very good program that gives us confidence to build stuff." (JFL702)

and innovation within this field (Council of Canadian Academies, 2015). Educators should make an effort to ensure that their STEM programs are accessible and inclusive of children with a wide variety of abilities and also supportive of their needs.

Our findings are consistent with research focusing typically on developing children that report using robots to increase interest in STEM (Howard et al., 2012; Lindsay & Hounsell, 2017; Ludi & Reichlmayr, 2011). Other research shows that youth without disabilities who are activated towards science learning are more likely to have an affinity towards STEM careers, certainly about their future career goals, and have identified a specific STEM career goal (Dorph et al., 2017). Our results are congruent with other research exploring youth with visual impairments who engaged in LEGO® interventions and reported more motivation to pursue computer programming opportunities (Howard et al., 2012; Ludi & Reichlmayr, 2011). Fostering children's interest in potential career fields is important because early career aspirations are a predictor of pursuing STEM careers (Cleaves, 2005). Therefore, early learning experiences should be designed to support the development of science interest and career awareness (Dorph et al., 2017). Other research shows that learning improves when teachers provide accommodations and adapt to diverse learning styles (Grumbine & Alden, 2006; Mutch-Jones et al., 2012).

Our findings from the open-ended questions showed that the children enjoyed the program and especially learning how robots work and how to build them. These results are consistent with our pilot study showing that children with disabilities enjoyed learning about and building robots (Lamptey et al., 2019; Lindsay & Hounsell, 2017). Other research also shows that robots can help to engage children in learning about STEM (Dorsey et al., 2014; Ludi & Reichlmayr, 2011; Sullivan & Bers, 2018). These findings indicate that the robotics program was successfully adapted for children and youth with disabilities and that robotics programs are worthwhile and enjoyable for children with disabilities.

Limitations and future directions

It is important to consider the limitations of this study. First, for some children, especially the younger ones, their parents may have completed the survey for them and the results may not be an accurate reflection of the child's experience in the program. Second, although the type of robot built may have changed slightly from session to session, the concepts learned remained the same throughout the program. Nevertheless, this may have impacted their motivation and interest in learning STEM. Third, teachers, clinicians, and volunteers were inconsistent in the amount and type of support they provided to youth across the period of data collection, which may have influenced differences between the groups. Fourth, we had a relatively low overall response rate in those who completed both a pre- and post-survey leaving us with a relatively small sample size. Fifth, although we made a concerted effort to include girls in our program, we had an unintentional over-representation of males. This is partly due to the majority of our sample having autism, which is more common in males.

Future research should be directed in several areas. Future studies should explore potential differences in STEM activation by disability type. It could be that children with certain types of disabilities may need more or different types of supports to enhance their STEM activation. Second, more research is needed to explore potential gender differences in STEM interest among children with disabilities. Third, researchers should consider the longer term impact on robotics programs on social and academic outcomes. Fourth, given the significant increase in STEM activation among children who took the program once, future studies should examine the relationship between persistence in robotics programs and STEM activation. Fifth, future research should explore the optimal frequency and duration of programs intended to enhance STEM interest in children with disabilities. Last, future research could explore the potential differences in STEM activation by group size and dynamic, volunteer or instructor interaction with youth, and program curriculums.

Conclusion

Our study addressed an important gap in the literature by exploring STEM activation within a group-based robotics program for children with disabilities. It is important to foster children's interest in STEM disciplines to increase diversity in these fields and also to expand their career and future employment options. Our findings showed that for most groups within our study, children's STEM activation scores increased from the beginning to the end of the program; however, these differences were not significant. It was encouraging to see that among the children who participated in the program more than once, there was a significant difference in their STEM activation. These findings suggest that it is worthwhile to engage children with disabilities in STEM programs.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This study received ethical approval (REB #16-677) from a research ethics board at Holland Bloorview children's rehabilitation hospital and the University of Toronto. Parents and children were informed of the study and given an information and consent form prior to their participation, and parental consent and youth assent were provided for children's participation in the study.

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