Catching Up: An Observational Study of Underserved Primary and Secondary Student Mindsets When Introduced to Educational Robotics

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Abstract
Student attitudes toward STEM subjects decline as they progress through primary and secondary school, making interventions even more critical for students in these age groups. Integrating educational robotics into the classroom has been shown to increase student perceptions of STEM topics while also having many other positive learning benefits such as increased mastery of STEM concepts and STEM degree achievement. Furthermore, research on mindset in school-aged children found that students who held growth mindset beliefs had higher learning outcomes, persistence, and self-esteem compared to students who held fixed mindset beliefs. In this observational study, an educational robotics curriculum was implemented across grades 3–8 in an urban private school consisting primarily of underserved, minority students. The same robotics kit was used across all ages with differentiation in the STEM labs taught to different ages. The technology teacher—the principal investigator for this study—recorded results from a growth mindset survey and journaled about student reactions to the robotics curriculum as the school year progressed. Observations about student prior experience, attitudes, self-beliefs, and mastery are used to draw insights on the effects of educational robotics for underserved student populations. As the body of research on STEM learning through educational robotics expands and robotics increasingly becomes considered a standard in primary and secondary education, it is critical to consider the needs of students encountering robotics for the first time and how to support and grow their attitudes and mindsets.

Keywords: Educational Robotics, STEM learning, Mindset, Resilience, Underserved Students

Introduction

Educational robotics has become increasingly integrated into primary and secondary school curriculum for its ability to combine science, technology, engineering, and math (STEM) concepts with valuable 21st century skills. Government agencies have focused on the necessity of STEM education for all students as well as the need for interdisciplinary solutions that have real-world applications and combine skills such as critical thinking, communication, and collaboration (National Science Foundation; National Science and Technology Council). A meta-analysis found that educational robotics increased student learning across STEM topics (Bentini). Robotics also helps increase student attitudes and positive perceptions toward STEM learning across a range of ages (Nugent et al., 2010; Robinson, 2005; Rogers & Postmore, 2004). This is especially critical, as students can begin to form negative attitudes toward STEM subjects as early as fourth grade (Unifried et al., 2014). For young students, educational robotics fosters critical thinking and problem-solving skills while also helping to form positive perceptions of STEM topics (Renninger & Hidi, 2011; Wigfield & Cambria, 2010; Tai et al., 2006).

While student perceptions of STEM subjects and educational robotics are valuable for their future interests and success, their beliefs on their *ability* to learn and succeed using educational robotics is also a critical line of research. For several decades, Carol Dweck and colleagues have been studying implicit theories of ability (also called mindset) and how those affect student behavior and outcomes. Dweck (1991) studied children who were presented with a set of questions wherein some were intentionally too difficult for them to solve. The children were identified using two groups (helpless or mastery) based on their reactions to the difficult problems. The children in the helpless category began to describe themselves as failing the task, became pessimistic, and their problem-solving strategies became less sophisticated. They defined themselves as having limited ability. However, the students in the mastery category displayed increased concentration, increased self-talk of instructions and problem-solving strategies, and spoke positively of being able to master the difficult problems. Dweck (1991) proposed these different responses and behaviors from the children were related to their conceptions of their own ability. Students with a fixed mindset believe ability is a static entity and cannot be controlled while those with a growth mindset believe ability can be changed incrementally with effort.

Blackwell et al. (2007) identified that what students believe about their ability corresponded to types of goal setting, approaches to dealing with failure, and responses to challenges. Students with a fixed mindset often have performance goals, believe failure is due to low ability, and develop helpless attitudes when challenged. Students with a growth mindset often have mastery goals, believe effort is worthwhile, and will employ new strategies or increased effort when challenged. Blackwell et al. also identified that middle school students with fixed mindset decreased in math grades over time while students with growth mindset maintained or increased. Dweck (2008) argued that mindset has a relationship with challenge-seeking, resilience, self-regulation, and that mindset can be changed. Researchers have found similar relationships between mindset and self-beliefs and increased achievement (Paunesku et al., 2015; Yeager et al., 2019; Claro et al., 2016).

An educational robotics curriculum using the VEX GO robotic kits was introduced to students ranging from third to eighth grade at a small Catholic school consisting of under-served, minority students. The technology teacher (first author) planned to conduct research on student self-beliefs and attitudes over time, as none of the students had previous experience with robotics. Through observation and journaling, patterns emerged related to student mindset on ability. This study aims to provide initial findings on mindsets of traditionally underserved students through a brief survey as well as an analysis of the teacher's observations. As studies have found that mindsets are meaningful for minority and low-income students (Aronson et al., 2002; Claro et al., 2016), investigating how the students at STBCA perceive their ability when introduced to educational robotics can provide insights into future practices to benefit students.

Methods

There were a total of 101 students in the third through eighth grade classes at Sister Thea Bowman Catholic Academy (STBCA) in Pittsburgh, Pennsylvania. STBCA is an urban school that receives scholarships through the Extra Mile Foundation and all students are 100% supported by a free/reduced lunch program. All students in this study were African American. In an initiative to better support STEM learning for students, STBCA introduced an educational robotics program. Each grade would receive one hour of robotics instruction each week. Parent/guardian permission was obtained for students to participate in the research project. As none of the students at STBCA had prior experience with robotics, several pre- and post-surveys were planned to measure self-beliefs and perception of STEM topics and robotics. The PERTS growth mindset survey (PERTS, 2015) was distributed part way through the curriculum to gauge student mindsets after initial teacher observations. This instrument, developed at Stanford University, has been shown to have acceptable reliability and validity (Hanson, 2017; Farrington et al., 2012). As part of the research, a journal was kept to record observations of each class, their responses to the robotic curriculum, and notes and relevant quotes from the students.

The VEX GO robotic kits were selected as the robot for Sister Thea Bowman Catholic Academy. The VEX GO robotic kit is a plastic construction set of the beams, pins, plates, sensors, motors, etc needed to build a wide variety of robots. This robotic kit was also beneficial in the use-case at STBCA because the younger students were able to manipulate the plastic pieces with their level of strength and dexterity, while the older students were appropriately challenged through the range of complexity of the robot builds themselves. The kits can also be packed and unpacked, so a single classroom set was used by each class throughout the day. With the robot was also a coding software, VEXcode GO, where students coded certain robot builds to move based on a challenge. While there is a more advanced robot recommended for middle school students, due to no previous experience in robotics and for consistency, the same robotic kit of Vex GO was used for all grades third through eighth.

A full curriculum is included with the VEX GO robot that includes different unit topics with individual STEM labs. The STEM labs are interdisciplinary and align to standards. The teacher created a curriculum plan with a set of STEM labs and activities differentiated by elementary students and middle school students. Some STEM labs were completed by all grade levels, while other labs and activities were completed only by older or younger students based on their level of difficulty. Each grade received a total of 13 weeks of robotics curriculum that included basic builds (following build instructions), creative builds (free-build, student choice), and application builds (interdisciplinary STEM goals).

Results and Discussion

Mindset Survey

The PERTS mindset survey consists of three "fixed-worded" Likert scale questions (PERTS, 2015; Hanson, 2017) that included statements such as, "You can learn new things but you can't really change your intelligence." The responses ranged from "strongly agree" to "strongly disagree" and were coded to numeric values 1 to 6; a lower score indicates fixed mindset (range 3 to 10.5) and a higher score indicates growth mindset (range from 10.5 to 18). Question scores were added for each student, and a mean score calculated for each grade. The results in Table 1 show the number of students and mean results for each grade. No consistent trend in mean mindset score is apparent by grade level. This could be due to the small number of responses by grade. It was also observed that each grade level had unique attitudes depending on the individual students in each class, which is mirrored by the variation in scores here. For instance, the overall growth mindset mean score for the 8th grade students was strongly influenced by a few students with strong growth mindsets. All grades were split between strong to moderate growth and fixed mindset scores, resulting in mean scores near the middle. One interesting case is the fixed mindset score of 8 for the 3rd grade students, however. It is possible that the fixed-worded statements with the Likert scale were difficult for these young students to interpret.

In two studies using this same three question instrument (Blackwell et al., 2007; McCabe et al., 2020), the mean mindset score was reported as 13.35 (their original mean was 4.45, as it was divided by the number of questions). The mean mindset scores are lower across all grades and in four of six grades, the mean is fixed mindset instead of growth mindset. While the limitation of these results is the small number of students in each grade, the results indicate that a fixed mindset is more prevalent in this sample of students.

	3rd Grade	**4th Grade**	**5th Grade**	**6th Grade**	**7th Grade**	**8th Grade**
n	12	15	13	17	9	14
Mindset Mean	8	10.2	10.3	13.2	9.4	11.5

Table 1. Mean mindset scores by grade.

Observations

Introduction to Robotics

All grade levels were introduced to robotics at the most basic level with a simple robot that followed step-by-step build instructions. Choosing a simple build was intended to ensure success for the students, as we were aware fostering early success could help increase is engagement. Even with beginning a basic build, drastic differences were observed between grades. On the first introduction, third through fifth graders made comments such as, "I love robots. Wait, what are robots?" and "It was hard, but fun." These younger students were generally enthusiastic, even when they weren't sure what they were going to be doing. This response contrasted starkly with attitudes from the sixth through eighth graders, who shared thoughts such as, "This packet is too long," "We can't get this all done," and "I don't know which way to connect it." The older students displayed apathy or dread when first introduced to robotics, and expressed doubt and helpless behavior before beginning the builds at all. One interesting statement that revealed the lack of prior experience with construction in general was an eighth grader who asked, “Is this like legos? I never got to play with legos.” It was notable that when introducing robotic builds to underserved students who did not have experience with robotics (or often construction toys in general), the younger students jumped into the builds with excitement and enthusiasm while the middle school students approached initial builds with much more trepidation.

In addition to initial attitudes toward the robotics curriculum, the different aged students also responded differently to the process of construction. The younger students opened robotic kits right away and both members of the team were involved in taking out pieces, turning them, manipulating them, and seeing how they could fit together. Middle school students looked at the kit for much longer before opening them or touching any of the pieces. Younger students rarely read beyond the first page of instructions before diving in, while the middle school students would often read the entire instruction booklet, would often take only one piece out at a time, and were much more hesitant to try out how pieces would fit together.

Creative Builds

As the STEM lab curriculum progressed, builds became more creative and complicated. Some labs intentionally gave students choices, and students were given opportunities to design their own robots. When students were challenged to do their own creative build of any design they wanted, there were, again, differences observed between the ages. Younger students received the challenge and met it with excitement and creativity. Students stated things such as: “We get to build whatever we want!”, “'I made a rescue helicopter and now I’m going to make a whole rescue team,” and “I made a swing set with people.” By contrast, the older students stated they did not have any ideas, saying things like, “I don’t know what to build.” They asked how to make a ladybug, when the sample was a very similar butterfly, and another student made a table. Overall, the middle school students displayed less creativity and risk-taking, and struggled when not provided with explicit instructions.

Introducing STEM and robotics was intended to be a natural situation to help students learn resilience. Learned helplessness had been displayed by students in other academic areas, but it was hoped that the hands-on construction opportunities would provide a fun setting to foster resilience across grades. Initially, learned helplessness was observed particularly with older students. Many groups in the middle school grades would immediately ask for assistance without trying on their own first. One group stated, “I want to make a car and make it move, but I don’t know how, and you have to show me and help me.” Meanwhile, when the younger ages wanted to build a car or tractor, they would try on their own before asking for help. However, with time, the older students began to display more resiliency. One of the middle school students shared, “We had the idea of a clock. But then we gave it up because we couldn’t find a way to make two moving hands.” In later STEM labs, gears were introduced to show how to make independent moving objects, and at that time, that same group did go back to make the clock they had originally planned. While students gave up quickly when confronted by a challenge in the first instance, it was exciting to observe in future weeks the connection to deeper learning and the effort the students put forth to retry their original idea of the clock build. This was an important example to those students that they could accomplish their goals with the right information and effort.

Synthesis/Application Builds

The next level of robotics builds involved application and synthesis builds. It was during these builds that students needed to account for a changing situation and appropriately change their build to reflect the new scenario. Students displayed a fluidity in thought process to create new ideas that correctly responded to the changing scenario. It was interesting to observe that in this situation there was less of a difference between age groups, and in some groups, the older students excelled more than the younger students. Some quotes from the younger students were, “I love seeing the frog change, so I made the cave bigger” and “I want to make a tree but had to use yellow because there were the only ones bent that looked more like a branch.” The middle school students also showed flexibility in their thought with statements such as, “I’m Jamaican so I’m making a Jamaican front and he needs a coconut tree” and “I want to make a rock, but we don’t have brown. [Partner:] We can improvise and make a rock shape.” It was with these builds that all grades showed rich social-emotional discussions, as they had to work together to agree on their build, and showed a willingness to try new things with the conceptual confines of the scenario.

As the robotics curriculum concluded, students summarized their experiences with some wonderful quotes and observations. Third through fifth grade students shared thoughts and feelings such as, “I want to build all the time. I have lots of ideas still in my head,” “I like doing things with my friends, even when we don’t get along. In this class you need a partner, and I like that,” and “I like that I can find different ways to do things. I can make it my own.” Middle school students shared thoughts such as, “I didn’t know my brain could do this,” “I had to be okay with being confused, but I didn’t like it,” and “I thought all this would be too hard, and I didn’t want to do it. But you made me. And I actually got it to work.” The enthusiasm of the younger students remained throughout the entire STEM curriculum. It was most exciting that the middle school students began to make some positive shifts in their thinking and showed enjoyment and appreciation for the robotics program by the end.

Conclusion

The students at STBCA represent an urban, minority demographic group who had not previously had access to educational robotics. Students did not have robotics at home, and some had no experience with construction toys at all. Introducing the students at STBCA to educational robotics provided an opportunity to observe their attitudes, perceptions, and mindsets. In this unique case where a single teacher could deliver the robotics curriculum from third to eighth grade, trends in student attitudes and mindsets across age groups became apparent over time. Research by Dweck and colleagues identified that students who had a growth mindset also had high resilience, persistence, adopted new problem-solving approaches, and had higher STEM scores. Meanwhile, students who identified as having a fixed mindset were more pessimistic, gave up more easily when faced with difficulty, were performance rather than mastery motivated. Similar attitudes were observed in the STBCA students as they were given challenges in the robotics curriculum. Younger students were generally more eager to try on their own, express creativity, and problem-solve. Older students displayed helpless attitudes initially and difficulty with creativity, but did display shifts in attitude and perceived ability as the curriculum progressed.

The results of the PERTS mindset survey showed lower mean mindset scores than had been reported in the literature, and most grades had students who identified as having strong fixed or growth mindsets. Some students who presented strong resistance and helpless attitudes toward the initial robotics challenges began to gain confidence and shift their attitude over time. These observational cases suggest that success with robotics could influence student self-beliefs. As research has found student mindsets can be shifted, future research could be done to evaluate student mindsets before and after a robotics curriculum that incorporates a mindset intervention treatment. Given the range of mindset beliefs present across all age groups, shifting mindsets using educational robotics could be a valuable long-term benefit for students. When the robotics curriculum was initially planned, it was known that the access to robotics for the first time would begin to bridge an access gap for these traditionally underserved students. However, it became clear through observation that the challenges introduced through robotics were helping the STBCA students catch up for lost time in robotics and STEM topics, but in self-beliefs and mindset as well.

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