AC 2012-3665: LEARNING THROUGH GUIDED DISCOVERY: AN ENGAGING APPROACH TO K-12 STEM EDUCATION

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Learning Through Guided Discovery: An Engaging Approach to K-12 STEM Education

Abstract

The Guided Discovery approach is a process in which students are encouraged to reinvent. The popular saying "don't reinvent the wheel" is counterproductive in the context of learning as it attempts to impart knowledge through discoveries and inventions of other people. Real learning occurs when learners are immersed in authentic situations and are allowed to figure out the solutions and experience an aha! moment and discover critical knowledge themselves. This paper presents the implementation of guided discovery approach using robotics at five elementary schools and presents the results of a study focused on measuring the effectiveness of this approach to introduce STEM to students.

260 elementary school students (4^{th} graders) from five elementary schools in Southern California participated in this study. The study involved students being introduced to STEM using robotics. This initiative titled Robotics Education through Active Learning (REAL) trains teachers to conduct weekly sessions (90-120 minute-sessions) for 20-25 weeks in their classrooms with the support of Cal Poly Pomona faculty and students. The study culminated in a robot rally in which all participants from various schools attended and demonstrated their robots in various events. A survey was conducted after the event and the responses were analyzed and compared against a control group consisting of 66 students. The theory of planned behavior was used to predict students' plans for future STEM education. The results of this study suggest that the robotics program based on the guided discovery approach is successful. The success of this program led to a follow-up study to measure students' perceived math and engineering ability, difficulty, STEM attitudes, and intentions to obtain good math grades. The second study indicated that many of the positive outcomes of this program persisted six months later.

Background

Science, technology, engineering, and mathematics (STEM) education in the United States continues to garner national concern.[1] A National Academies committee report notes inefficiency in preparing students for the workplace and higher education.[2] Of particular concern is the low numbers of college graduates in STEM fields who will help the U.S. retain its global lead in science and technology.[2] In response to these concerns, educators have been developing innovative strategies to introduce STEM education earlier in the education timeline.[3-4]

The objective of this research is to test the effectiveness of a guided discovery approach in promoting STEM education through the use of robotics among students who are nationally underrepresented in STEM. The research question driving this investigation is whether a discovery based approach and a hands-on robotics program will improve students' STEM attitudes, math performance, and intentions to pursue STEM education and careers. The theory of planned behavior[5] was used to guide the measurement of students' STEM education outcomes.

A Guided Discovery Approach to STEM Education

Traditional approaches to STEM education can result in disinterested students who may not pursue college-level STEM education and a competitive and hostile educational environment.[6] We propose that a guided discovery approach is more effective in engaging diverse students in learning STEM concepts. This engagement will result in increased STEM knowledge and academic self-efficacy among diverse elementary students.

Bruner's[7] guided discovery approach posits that any subject can be taught effectively in some intellectually honest form to any child at any stage of development. A constructivist approach to learning and teaching is based on the notion that learners construct their own knowledge rather than knowledge being transferred into learners' brains.[8-10] Learners' construction of knowledge is based on their past knowledge, the timeliness of new knowledge, and the learner's ability to understand the connections. This process forces learners to either modify existing knowledge or develop new knowledge. Learning experiences based on constructivism are reflected in popular instructional strategies such as inquiry based learning[11-12], problem based learning (PBL) [13-14], simulation based learning[15-17], experiential learning[18], service learning[19], and scenario based learning.[20-21]

All constructivist instructional strategies share several commonalities and an experienced educator using the PBL approach may very well use guided discovery principles. However, our instructional strategy is to ensure that we use guided discovery as our core principle, and design all our lessons and activities based on that intentionally. We selected the guided discovery approach because it is well-established in the literature as an effective approach to learning and it provides a positive learning environment for all students to learn significant STEM content in an engaging way.[22-23]

A guided discovery approach also benefits students, particularly girls and racial minorities, by providing the experience of learning as a process rather than promoting the perception of "innate ability." Research suggests that when students see other students executing tasks 'without difficulty' they assume they do not possess the necessary innate ability to go into a STEM field.[24] It is necessary for students to learn that these skills are developed over time as a process and that intelligence is incremental rather than innate.[25-26]

In guided discovery there is an appropriate level of guidance that allows students to experience virtually all the characteristics of pure discovery and it happens within realistic time frames. We have implemented a guided discovery approach that is seemingly unstructured and chaotic but internally well structured and logical. Our guided discovery approach allows students to personalize the concepts. Our premise is that without deeper understanding of foundational skills essential for STEM education, most students will never develop serious interest in STEM.

Example - Circumference of a circle

A brief example of a classroom-tested successful guided discovery process at an elementary school using robotics is determining the circumference of a circle. The guided discovery approach contrasts the traditional approach of using direct teaching where the fact is stated and the students are expected to memorize the formula and use it in problem solving. Imagine this scenario:

> Students build a basic robot that goes exactly 3 feet so that it can perform a delicate operation without falling off the table top, and the robot must perform this operation consistently. At this point students are not lectured or provided the formula for the circumference of a circle. They are only presented with a real problem that has serious consequences - less than 3 feet means the task is not accomplished, and more than 3 feet means destruction of the robot.

Testing on the ground prior to testing on the tabletop

Most students initially took the easiest approach: using time. They made the robot go forward for a few seconds, observed the robot's behavior, measured the distance, and either increased or decreased the time accordingly. After several attempts they realized they are unable to make the robot go exactly the same distance each time. In fact during this process most students made a table and started noting their observation at each run. This was something that was not even part of the learning objective but students realized they needed a way to organize the data.

After trying out every possible option some students figure that using time is not the best way to solve the problem. They discover that this has something to do with the rotation of the wheels. Even though they are on the right track the answer is still elusive as they don't know how many rotations are needed. They keep trying various numbers and someone may stumble on the correct answer accidently in which case we change the distance (e.g., from 3 feet to 4 feet) and they start all over again. At this point students realize there has to be a better way to do this and finally they discover that they have to determine how far the robot goes for one rotation of the wheel. Although there is some direct instruction at the tail end, the formula is presented in the context only after the students have discovered the principle that they need to figure out a way to find the circumference of the wheel.

Robotics Education through Active Learning (REAL)

Robotics is increasingly being considered as the Fourth essential R (after the three Rs, Reading, wRiting and aRithmetic). Robotics is a truly multi-disciplinary field that combines mechanical, electrical, electronics, control engineering, and computer science. Learners, who are immersed in the activity, acquire important skills in math and science without realizing that they are intensively engaged in the learning process. Robotics offers a unique platform that allows students to experience discovery through imagining, designing, building, programming, and controlling their own creation. However, if not structured, robotics can become another boring course. The robotics curriculum needs to be exciting, age-appropriate (for elementary school students), mapped to state and national math standards but also progressively challenging and engaging as students advance to higher grade levels.

The REAL Initiative is currently offered as a once a week in-class course for 90-120 minute sessions for 20-25 weeks (see Table 1). Engineering professors and students visit each classroom once a week and help lead the robotics session. Furthermore, our curriculum introduces the required infrastructure of innovation: motivation, self-esteem, critical thinking, and team work along with the classical parameters of grades and state standards. This is not an after-school club activity for interested students only. This involves all the students in a classroom irrespective of their background or interest level.

To ensure robotics is used as a means to provide context for difficult to understand abstract math and science concepts, we have developed a curriculum using a guided discovery approach. Each week students learn a new aspect of robot design, which reflects several topics in STEM. Table 1 shows a sample curriculum for a 25-week robotics program. All students who go through the program visit the University.

The Robot Rally - The annual robot rally is a culminating event in which students from all participating schools come to the University and take part in various challenges. Students are evaluated on their teams' performance (sumo robot wrestling and obstacle course), robot design, and team work. Students also get a chance to tour the engineering labs, and eat in the cafeteria, creating a lasting impression of college life.

Table 1. Sample Robotics Curriculum

Week	Topics	Activities
1-2	Introduction to Robotics, Engineering Terminology and NXT micro controller. Understanding sensors, DC and Servo motors.	Students identify and use the components to build to simple machines. Learn to operate NXT brick. Connect each sensor (ultra sonic, touch, light and sound) to the brick and conduct experiments. Connect motors to NXT and operate.

3-4	Construction techniques, interfacing sensors and motors to micro controller. Clockwise and counter clockwise rotation. Relationship between degrees and angles. Units; CM & Inch.	Build a three wheeled robot
5-7	Introduction to programming, programming logic, developing logic and writing the sequence of instruction in plain English, developing flow chart. Circumference of a circle; Parts of a circle – chord, radius, perimeter; Formula for circumference; The value of PI.	Program three wheeled robot. Measure diameter; Using the stop clock to determine the time it takes to go certain distance (approach using time); Measure the circumference of the wheel (experimental approach); Calculate the circumference using π (analytical approach); Perform task (robot required to travel certain speeds and distances); Write a program to park the robot between two robots.
8-9	Introducing the concept of ***loop*** in programming to perform repeated operations. What is light? Wave lengths. Learn to use light sensor to identify various colors. Introducing the concept of conditional statement, ***If… then*** to program. Algorithm for following a line.	Write a program to make your robot to go in a square**.** Experiment with light sensor to read various colors, compare readings; Write a program to identify black color and stop the robots; Write a program to keep the robot in an area whose boundary is marked by black/white color (students given a diagram)
10	Learn to use ultra sonic sensor to identify obstacles; Combine ultra sonic and light sensor to perform specified tasks.	Determine the distance between the robot and obstacles; Write a program to identify an object within certain distance and stop; Write a program so robot can roam around in an area avoiding obstacles.
11-12	Learn to use touch sensor for navigation, identification and strategy. What is sound? Units for sound.	Experiments with touch sensor. Clap on move, clap on stop robot.
13-14	Data collection, table, graphs and average. Understanding distance (displacement), speed and velocity.	Write a program to make the robot go as fast as possible to cover a specified distance. Using a stop watch, note down the time. Calculate the speed.
15	Gears, gear ratio, power transmission; Gear terminology – driving gear, driven gear, pinion, bevel gear, helical gear, rack & pinion, work gear.	Make a simple gear transmission; Use gear to make the robot go faster; Calculate gear ratios
16-17	Simple machines – Lever, wheel & axle, pulley, inclined plane	Build a compound machine using all specified individual simple machines
18	What is power? Units of power	Determine the power of robot experimentally
19	Engineering Design Process – Sketching	Brainstorm and sketch various robot configurations. Design a robot for a specified obstacle course or sumo wrestling.
20-24	Putting it all together - Design the robot to perform all specified tasks	Build and program the robot to navigate an obstacle course and take part in sumo wrestling
25	**REAL – Cal Poly Pomona Robot Rally**	

Theory of Planned Behavior

The goal of the REAL Initiative is the increase the number of students who pursue STEM education and careers. The best way to predict future behavior is to examine ones current behavioral intentions[5]. The theory of planned behavior (TPB) has proven effectiveness in predicting behaviors related to several social problems, particularly health behaviors, and thus is a promising theory for predicting participation in STEM education. The theory posits that specific attitudes toward a behavior, social norms, and perceived control over a behavior are the most accurate predictors of behavioral intentions, which is the best predictor of actual behavior[5].

Specific Attitudes - Specific attitudes toward the behavior are predicted from the interactive effects of beliefs about the action, including positive and negative consequences of the action, and evaluation of those consequences (how beneficial or costly they are perceived to be). For example, if being a female who is good at math has negative consequences, such as rejection from male peers, and the consequences are perceived to be costly, then the attitude regarding math is going to be negative and behavioral intentions to perform well in math and pursue further math education will be low.

Social Norms - Social norms are predicted from an interaction between beliefs regarding whether the action is socially appropriate and evaluations of those beliefs regarding whether those social norms are important to follow. For example, if being a female who is good at math is not socially normative and the female believes social norms are important to follow, such as to avoid social rejection, then behavioral intentions to perform well in math and pursue further math education will be low.

Perceived Behavioral Control - Ajzen and Fishbein[5] conceptualized perceived control as the "person's belief as to how easy or difficult the performance of the behavior is likely to be"[27]. The greater the ease in which a person can perform the behavior, the more likely the behavior will occur. If females find math to be very difficult, then pursuing an education and career in math will be unlikely unless other variables intervene.

Researchers have used the TPB[5,28-29], and its predecessor, the theory of reasoned action[30] to predict education-related behaviors. Butler[31] found that attitudes toward science and social norms regarding science were significant predictors of elementary and middle school students' intentions to complete their laboratory and non-laboratory science assignments, readings, and projects. Crawley and Black[32] showed that attitudes, norms, and perceived control significantly predicted 8th through 11th graders' intentions to enroll in a high school physics class. Davis and colleagues[33] found the TPB to be an accurate model in predicting African American high school students' intentions to complete high school, which predicted graduation three years later. Davis and colleagues further reported the strongest predictor of intentions to graduate was perceived control, followed by social norms, and attitudes. In contrast, Koballa[34] found that attitudes toward taking elective science courses and social norms were the best predictors of junior-high school girls' intentions to enroll in at least one elective physical science course, although perceived control was not measured in this study testing the theory of reasoned action. Meece and colleagues[35] demonstrated the importance of perceived control, or self-efficacy beliefs, in their study showing that expecting to perform well in math was the best predictor of future math grades.

Thus, to use the TPB as a theoretical framework, participants' specific attitudes about math and engineering, teachers' social norms regarding students' math and engineering performance, and perceived behavioral control and self-efficacy (or ability to perform well) in math and engineering were assessed to predict behavioral intentions for pursing math and engineering education and careers.

Hypotheses

***Hypothesis 1*:** Participants in the robotics program will have more positive scores on perceptions including math ability (1a), engineering ability (1b), math difficulty (1c), and engineering difficulty (1d) compared to students not in the robotics program.

***Hypothesis 2*:** Participants in the robotics program will have more positive scores on attitudes including math attitudes (2a), engineering attitudes (2b), and robotics attitudes (2c) compared to students not in the robotics program.

***Hypothesis 3*:** Participants in the robotics program will report more supportive social norms than students not in the robotics program.

***Hypothesis 4*:** Participants in the robotics program will report greater behavioral intentions for future math and engineering activities than students not in the robotics program.

***Hypothesis 5*:** Participants in the robotics program will report positive outcomes such as enjoying programming (5a), enjoying building robots (5b), and enjoying the Robot Rally opportunities (5c).

Hypothesis 6: Participants in the robotics program will have better math performance than students not in the robotics program.

***Hypothesis 7*:** The theory of planned behavior constructs (perceived ability, attitudes, and social norms) will predict behavioral intentions regarding math and engineering education for both program participants and non-participants, such that positive self-perceptions of ability, positive attitudes, and positive social norms will predict greater behavioral intentions.

Study 1 Method – Participants

Participants (N = 260) included 4th grade students from five elementary schools in southern California. The comparison group consisted of 86 students from two of the five schools and the experimental group (program participants) included 174 students from all five schools. There were 125 (49.8%) males, 126 (51.2%) females, with students representing the following racial/ethnic groups: 39.4% Latino (n = 99), 22.7% Asian (n = 57), 18.7% Caucasian (n = 47), 8% Multiracial (n = 20), 8% Other (n = 20), 2% Black (n = 5), and 1.2% American Indian (n = 3).

Materials

The questionnaire included several self-report measures of students' perceptions, attitudes, social norms, behavioral intentions, program specific questions, and math performance. Unless otherwise stated, all Likert-type scales were rated on a 1 (*very strongly* disagree) to 6 (*very strongly agree*) scale.

Perceptions. *Perceived math ability* was assessed with two items including "I am often nervous when I have to do math" and "Many times when I see a math problem I just 'freeze up.'" The items were correlated (r = .499, p = .01), thus were combined to create a mean score. A similar measure for *perceived engineering ability* was used with the additional item "I have never been as good in engineering as I am in other subjects" (α = .693).[36] *Perceived math difficulty* was assessed with four items such as "Learning how to do better in math is easy for me" and "I have always done well on math assignments" (α = .844). Four similar items were used to measure *perceived engineering difficulty* (α = .881). Perceived ability items were based on work by Parsons and colleagues[37] and perceived difficulty items were modeled after measures by on Sparks, Guthrie, and Shepherd.[38]

Attitudes. *Math attitudes* was assessed with five items such as "I will use math a lot when I grow up" and "Learning math is a waste of time" (α = .789). A similar measure of four items was used to assess *engineering attitudes* (α = .758). *Robotics attitudes* was assessed with six items such as "Building robots is fun" and "I think working with robots is interesting" (α = .852). Attitudes items are based on measures used by Parsons and colleagues[37,39] and Aiken.[36]

Social Norms. To assess students' perceptions of *social norms* regarding their teachers' expectations, the following three items were used: "My teacher thinks I will get a good grade in math", "My teacher thinks I am good at math", and "My teacher thinks I am good at engineering" (α = .742).[38]

Behavioral Intentions. Three items assessed participants' planned commitment to math and engineering. One item stated, "I will get a good grade in math this year" and was rated on a Likert-type scale. Two items "Do you want to study engineering when you go to college?" and "Do you think you will have a job in engineering some day?" were asked with response options of "No," "Maybe," or "Yes." The maybe responses were recorded into the "No" category to allow for analysis of dichotomous values.

Robotics Program. Program participants were asked to evaluate how well their robot program worked, with four statements such as "My robot program worked right away" and "My robot program failed a few times before it succeeded" (α = .564). Participants were also asked to report their preferences for programming versus building robots. There were four items including "I enjoy building things," "I enjoy programming with computers", "I would rather build something than program something," and "I would rather program something than build something." The two building items were correlated ($r = .244$, $p = .01$), thus were combined into a mean score. The programming items were not correlated, thus they were kept as two single-item measures. Participants who attended the Robot Rally competition were asked to rate their preferences for each opportunity at the event including going to a university, doing the sumo wrestling competition, doing the obstacle course, working with a team to win, meeting students from other schools, and eating in the university cafeteria. The six items were rated on a Likert-type scale from 1 (*I really hated it*) to 6 (*I really liked it*; α = .687).

Math Performance. All students completed an 11-item math test with questions on geometry and other math relevant to 4th grade standards. Sample items included "A right angle has 90 degrees," "The diameter of a circle is the length of the line through the center and touching two points on its edge." These items were marked as "True" or "False" with a possible total score of 11.

Design and Procedure

The design is a post-test only questionnaire with a comparison group of students selected from the same grade level, same teachers, and same school. Comparison group participants were selected from two schools and are similar to the experimental group in terms of age, gender, race/ethnicity, socioeconomic background, and academic performance. When necessary, analyses are restricted to a school-match comparison to control for academic achievement. Experimental group participants completed the questionnaire during class time at the end of the 25-week robotics program. Comparison group participants completed the questionnaire at the same time during the school year as the experimental group participants to account for maturation.

Study 1 Results

To test *hypothesis 1* that participants in the robotics program will have more positive scores on perceptions compared to students not in the robotics program, a series of independent samples *t*-tests were computed. In support of *hypothesis 1a* experimental group participants had higher perceived math ability (M = 4.81, SD = 1.03) than comparison group participants (M = 4.46, SD = 1.19), $t(257) = -2.451$, $p = .015$. There were no differences by condition for perceived engineering ability (*hypothesis 1b*). There was support for *hypotheses 1c* and *1d* for math and engineering difficulty, such that participants in the experimental group believed they could overcome math (M = 4.14, SD = 1.11) or engineering (M = 3.86, SD = 1.15) difficulty contrasted with the comparison groups' math (M = 3.40, SD = 1.14) and engineering (M = 3.53, SD = 1.15) difficulty, math: $t(258) = -4.999$, $p = .001$, engineering: $t(257) = -2.138$, $p = .033$.

Support for *hypothesis 2* indicated that participants in the robotics program had more positive attitudes than comparison group participants. Specifically, experimental group participants had more positive math attitudes (M = 4.56, SD = 1.10) than the comparison group (M = 4.07, SD = 1.24), $t(258) = -3.223$, $p = .001$, supporting *hypothesis 2a.* Participants in the experimental group had marginally more positive engineering attitudes (M = 4.41, SD = 1.07) than the comparison group (M = 4.15, SD = 1.17), $t(257) = -1.794$, $p = .074$, providing marginal support for *hypothesis 2b.* Finally, experimental group participants had more positive robotics attitudes (M = 5.10, SD = 1.00) than comparison group participants (M = 4.46, SD = 1.01), $t(255) = -4.841$, p = .001, supporting *hypothesis 2c.*

In support of *hypothesis 3*, participants in the robotics program (M = 4.49, SD = 1.01) reported more supportive social norms than students not in the robotics program (M = 3.99, SD = .95), $t(258) = -3.861$, $p = .001$.

In support of *hypothesis 4*, a logistic regression showed that condition was a significant predictor of future intentions to study engineering in college, $\chi^2(1) = 5.308$, $p = .021$, $\beta = -.806$, $p = .028$, with 77.4% correct classifications. Among students in the control group, only 11 (4 girls) or 14% said they planned to study engineering in college. Among students in the experimental group, 46 (19 girls) or 26.6% said they planned to study engineering in college.

A logistic regression showed that condition was a significant predictor of future intentions to obtain a job in engineering, $\chi^2(1) = 4.33$, $p = .037$, $\beta = -.910$, $p = .05$, with 86.2% correct classifications. Among students in the control group, only 6 (1 girl) or 7.5% said they planned to get a job in engineering. Among students in the experimental group, 29 (7 girls) or 16.8% said they planned to get a job in engineering.

Overall, there were no differences by condition for math grade intentions. However, when experimental and control group participants were matched by school to control for general academic performance, the difference was significant. Participants in the robotics program had higher intentions to get good math grades (M = 4.90, SD = 1.21) than participants in the comparison group (M = 4.28, SD = 1.39), $t(85) = -2.05$, $p = .043$.

To test *hypothesis 5* that participants in the robotics program will report positive outcomes, a one-sample *t*-test was computed to compare the experimental group's mean to the scale midpoint of 3.5, since comparison group participants did not complete program specific measures. The tests showed that participants enjoyed programming with computers (*hypothesis 5a*), (M = 3.95, SD = 1.08), $t(172) = 5.41$, $p = .001$; enjoyed building robots (*hypothesis 5b*), (M = 4.66, SD = 1.10), $t(171) = 13.78$, $p = .001$; and enjoyed the Robot Rally opportunities (*hypothesis 5c*), (M = 5.08, SD = .743), $t(156) = 26.72$, $p = .001$. Thus hypothesis five was fully supported.

Hypothesis 6 predicted that participants in the robotics program will have better math performance than students not in the robotics program. Overall, there were no differences by condition for math test performance. However, when experimental and control group participants were matched by school to control for general academic performance, the difference was significant. Participants in the experimental group had higher math test scores (M = 8.47, SD = 1.83) than participants in the comparison group (M = 6.95, SD = 1.63), $t(89) = -4.06$, $p = .001$.

In support of *hypothesis 7*, the theory of planned behavior constructs predicted behavioral intentions of getting a good math grade for both experimental and comparison group participants, $F(3, 240) = 48.92$, $p = .001$, $R^2 = .379$. Specifically, positive self-perceptions of math ability (β = .213, $p = .002$) and positive social norms (β = .415, $p = .001$) predicted future plans to get a good math grade. Interestingly, math attitudes were only a significant predictor for participants in the experimental group, $\beta = .190$, $p = .008$.

In support of *hypothesis 7*, the theory of planned behavior constructs predicted behavioral intentions of studying engineering in college for both experimental and comparison group participants, $F(3, 247) = 26.64$, $p = .001$, $R^2 = .244$. Specifically, positive self-perceptions of engineering ability (β = .245, $p = .001$) and positive engineering attitudes (β = .328, $p = .001$) predicted future plans to study engineering in college. Interestingly, social norms were not a significant predictor in this model.

In support of *hypothesis 7*, similar results were found for intentions to obtain a job in engineering, $F(3, 248) = 17.80$, $p = .001$, $R^2 = .177$. Specifically, positive self-perceptions of engineering ability (β = .188, $p = .01$) and positive engineering attitudes (β = .310, $p = .001$) predicted future plans to obtain a job in engineering. Interestingly, social norms were not a significant predictor in this model.

Study 1 Discussion

Overall the majority of hypotheses were supported, indicating the REAL Initiative was successful in improving students' math and engineering perceptions, math and engineering attitudes, perceptions of teachers' social norms, math and engineering behavioral intentions, and math performance. Students also indicated they enjoyed the program through their report of positive attitudes toward robotics, programming, and building robots, and the culminating robot rally event.

Hypothesis 1 was mostly supported in that participants in the robotics program had more positive scores on perceptions including math ability, overcoming math difficulty, and overcoming engineering difficulty compared to students not in the robotics program. There were no differences by condition for perceived engineering ability.

Hypothesis 2 was mostly supported in that participants in the robotics program had more positive attitudes toward math and robotics, and marginally more positive attitude toward engineering compared to students not in the robotics program.

Hypothesis 3 was fully supported since participants in the robotics program reported supportive social norms. That is, students perceived their teachers to be supportive of their success in math and engineering more so than students not in the robotics program.

Hypothesis 4 was fully supported such that participants in the robotics program reported greater behavioral intentions to improve future math grades, pursue engineering education, and pursue an engineering career, compared to participants in the comparison group.

Hypothesis 5 was fully supported in that participants in the robotics program reported positive outcomes such as enjoying programming, enjoying building robots, and enjoying the Robot Rally opportunities.

Hypothesis 6 was fully supported such that participants in the robotics program had better math performance than students not in the robotics program.

Hypothesis 7 was supported indicating the theory of planned behavior is an adequate model for predicting STEM related behavioral intentions for both program participants and non-participants. Some predictors were more important than others. The best predictors of math grade intensions were perceived math ability and social norms, and math attitudes were a significant predictor only for the experimental group. The best predictors of intentions to study engineering in college and intentions to get a job in engineering were perceived engineering ability and engineering attitudes, but not social norms.

Study 2 Long-Term Follow-Up

Given the success of the program as indicated by Study 1 results, we wanted to see if the positive outcomes would persist after the robotics program ended. Currently most schools do not have the resources to continue the robotics program once the investigators move on to a new cohort of students. There are exceptions, however, in that schools have fundraised to purchase robotics kits and continue the programs on their own, particularly if one or more teachers have been actively involved in the robotics curriculum. The long-term impact of the program will determine whether continuing to invest in the new robotics curriculum is worthwhile.

Study 2 Method – Participants

The sample consisted of 5^{th} grade students who completed the REAL Initiative in the previous school year (six-months prior) and a matched comparison group (N = 131). The sample included two elementary schools, each with one treatment group classroom and one comparison group classroom, resulting in 65 students (two classes) in the treatment group and 66 students (two classes) in the comparison group. The sample included 57 girls (46%) and 67 boys (54%), with a racial/ethnic representation of a Latino majority (n = 83, 69%), Asian Americans/Pacific Islanders (n = 14, 12%), and less than 10% each of African American, Caucasian, multiracial, and other racial groups.

Materials

The materials were similar to those in Study 1; however the questionnaire was shorter by necessity. The constructs measured in Study 2 included: perceived math and engineering ability, perceived math and engineering difficulty, math and engineering attitudes, social norms, and intentions to obtain good math grades.

Design and Procedure

The design and procedure were identical to Study 1. Comparison group participants were selected from the same grade level, same teachers, and same school, and they completed the questionnaire at the same time during the school year as the experimental group participants to account for maturation.

Study 2 Results

Results indicated students participating in the REAL Initiative maintained their significant gains in math attitudes, perceptions of teacher support, and intentions to get good math grades. Students who completed the robotics program had more positive attitudes toward math (M = 4.82, SD = .86) than the comparison group (M = 4.48, SD = .90), $t(129) = 2.23$, $p = .028$; perceptions that their teachers are supportive of their success in math ($M_{exp} = 4.08$, $SD_{exp} = .92$; $M_{con} = 3.73$, $SD_{con} = .93$), $t(128) = 2.18$, $p = .031$); and greater intentions to earn good grades in math ($M_{exp} = 4.83$, $SD_{exp} = 1.09$; $M_{con} = 4.29$, $SD_{con} = 1.40$), $t(123) = 2.40$, $p = .018$. There were no differences by school or gender indicating all student participants benefitted from the robotics program.

Similar to Study 1, the theory of planned behavior constructs predicted behavioral intentions of getting a good math grade for both experimental and comparison group participants, $F(3, 120) = 34.48$, $p = .001$, $R^2 = .463$. Specifically, positive math attitudes ($\beta = .216$, $p = .006$) and positive social norms ($\beta = .415$, $p = .001$) predicted future plans to get a good math grade. Positive self-perceptions of math ability was a marginally significant predictor ($\beta = .171$, $p = .084$).

Study 2 Discussion

Results from Study 2 indicated that many of the positive outcomes of the REAL Initiative persisted six months later. Robotics participants had more positive attitudes toward math, perceived their teachers to be supportive of their math and engineering education, and intended to earn good math grades during the current school year. The theory of planned behavior was again a good model to predict students' behavioral intentions, showing the importance of self-efficacy, attitudes, and social norms in supporting STEM education intentions.

Overall Discussion

This research met its objective by demonstrating that a guided discovery approach is effective in promoting STEM education through the use of robotics among students who are nationally underrepresented in STEM. The hands-on, engaging robotics program improved students' STEM attitudes, math performance, and intentions to pursue STEM education and careers. Students participating in the 25-week REAL Initiative had more positive outcomes than comparable students participating in the schools' standard STEM curriculum.

The results of Study 1 and the positive outcomes shown in the follow-up (Study 2) suggest the REAL Initiative is a successful program to promote STEM education early in the educational pipeline. By developing STEM education programs that are locally sustainable by schools, and are aligned with state and national STEM education standards, the U.S. can move toward developing a more diverse STEM workforce.

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