The Evaluation of Robotics Activities for Facilitating STEM Learning

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Abstract. We used the theory of planned behavior to predict students' intentions to choose STEM (science, technology, engineering and mathematics) in the transition from middle school to high school after participating in robotics activities. We found that students' attitudes towards STEM were not as high as expected, although most of them expressed an intention to choose future study of STEM. Then we interviewed teachers on their attitudes on the effect of robotics activities on choosing to study STEM, and checked if the activities actually led to an increase in students choosing STEM. We found positive results for both questions.

Keywords: Robotics · Theory of planned behavior · STEM

1 Introduction

Many factors discourage students from studying science, technology, engineering, and mathematics (STEM), for example the perception of STEM as boring, only appropriate for nerds [4] and not for female students [8]. The Israeli Ministry of Education is attempting to increase the number of students studying STEM. A major program, called AMT, is aimed at strengthening the learning of STEM in middle-schools [11]. The subjects taught include mathematics, physics, computer science (CS), robotics and computer security.

Attitudes concerning STEM are formed as early as middle-school [5] so students' must be influenced early. One approach is to use kinesthetic activities, such Computer Science Unplugged. Another is to use programming environments designed for young students such as Scratch and Alice. A third approach is to engage students in robotics activities. This became feasible with the appearance of LEGO® Mindstorms. Recent advances in technology have made educational robotics even more accessible. We asked whether engaging in robotics transcends fun and leads to significant positive changes in their attitudes towards STEM, as well as in their intentions to study STEM. This question is important because of the time, money and effort required for robotics activities, an investment that can be justified only if the above goals are achieved.

W. Lepuschitz et al. (eds.), *Robotics in Education*, Advances in Intelligent Systems and Computing 630, DOI 10.1007/978-3-319-62875-2_12

2 Previous Work

Students participating in the FIRST LEGO® League (FLL) competitions maintained high attitudes and achieved meaningful learning of STEM [7]. On the other hand, the learning was sub-optimal because of the pressures of the competition [6]. It follows that it is preferable to engage in robotics activities within a non-competitive curricular environment.

Two research projects investigated students' motivation to learn CS in the context of robotics activities. Markham and King [9] found that the robotics group devoted more effort when compared with non-robotics classes, and claimed that this extra effort implied increased intrinsic motivation. McGill [10] studied changes in motivation through robotics activities in a preliminary CS course for non-majors. She found an improvement in students' attitudes towards programming, but little effect on other measures such as confidence.
Our research significantly extends previous work in several ways:

- We investigated attitudes towards STEM in general and not just towards CS or robotics.
- We went beyond measuring attitudes and looked into the intentions that are engendered by attitudes; this is important because it is intentions that directly affect future behavior.
- By carrying out the research in middle-schools, we checked the effect of robotics before students make firm decisions on their future studies.

A preliminary report on this research was published in [3]. There we described the construction and administration of the questionnaire, and our conjecture that the results would lead more students to study STEM. Here we report quantitative results showing that this in fact did take place. We also report results from our interviews with the teachers.

3 Theoretical Background

The research used the theory of planned behavior (TPB) [1]. This is both a theoretical research framework and a quantitative methodology. TPB models human behavior using attitudes, subjective norms and perceived behavioral control (PBC) to predict intentions to perform a behavior, in this case to study STEM. Our research group has used TPB before within the context of educational technology [2] and it proved effective in understanding the causal links from attitudes to intentions to behavior.

Here are short definitions of the elements that appear in TPB (full definitions can be found in [3]): Behavior is the observed human action that is a response to a given situation. Intention is an indication of a person's readiness to perform a given behavior. An attitude towards a behavior is the degree to which the performance of the behavior is positively or negatively valued. Evaluation of the behavior is assumed to have two components: (1) behavioral beliefs about the consequences of the behavior, and (2) the outcome evaluation of this behavior's consequence to be positive or negative. Subjective norms about the behavior are a person's estimate of the social pressure to perform or not to perform the target behavior. Perceived behavioral control of the behavior is the extent to which a person feels that he or she can control the behavior.

TPB questionnaires are built after taking field notes and interviews. Since they are based on issues that arise in practice, the results from TPB tend to be more valid than questionnaires based solely upon the researchers' experience.

4 Methodology

4.1 Research Questions

1. (a) To what extent does participation in robotics activities influence the attitudes of students towards STEM and their intentions concerning STEM studies in the future? (b) Do they really choose STEM in high school?
2. What are the teachers' attitudes on the role of robotics' activities towards the intentions of their students to choose STEM?

4.2 Context and Populations

We investigated two contexts of robotics activities in Israeli schools: The first population consisted of participants in the FIRST LEGO® League (FLL) competitions intended for grades 4–8. The characteristics of this population were that the activities were extracurricular and the participants self-selected.

The second population consisted of middle-school students in the AMT program. Unlike the first population, their activities were part of the school curriculum and the students were selected by teachers and principals. Therefore, these students were likely to display a more diverse set of attitudes and intentions.

The control group consisted of students in the MOFET program which is also aimed at excellent students of STEM, but they focus on physics and mathematics with no robotics activities.

For the second research question we interviewed ten teachers of robotics.

4.3 Research Instruments and Data Analysis

The first year of the research was devoted to field observation and interviews; these were used to construct a 44-question TPB questionnaire. We sent more than 700 questionnaires and received back 350. We terminated our analysis after 106 questionnaires at which point additional analysis did not change the results.

Interviews with the teachers were conducted throughout the entire project.

5 Results and Discussion

5.1 The First Research Question: (a) Changes in Attitudes

We found that most students were enthusiastic towards robotics at the beginning of the year when the subject was new. They carried out the assignments given by teachers and they collaborated on the construction of robots. The FLL students collaborated more than the AMT students because they had a concrete goal. The robots often malfunctioned which led to frustration. The interviews showed that the students felt good when they received respect and support from the teachers and the school staff, as well as from their parents. The interviews revealed a problem in scheduling: robotics classes are usually given in the afternoon after all the other students have gone home.

Several questions of the TBP questionnaire dealt with the students' attitudes towards science. Their answers showed that the experience of trial and error made them feel like "real" scientists and that engaging with science in the future would be considered a success, both by themselves and by their teachers and parents. We noted that students' did not mind failing in their robotics activities and that they readily accepted the challenge of correcting their errors.

We analyzed the data from the questionnaire according to the TPB methodology we developed [2]. We divided the values calculated for each TPB predictor into quartiles (Table 1). The analysis showed that: (1) Students are roughly uniformly distributed in the quartiles for attitudes, which is somewhat disappointing. (2) Most students fall into the two middle quartiles for subjective norms, which means that they can be influenced to choose STEM by the school and home environments. (3) The relatively high scores for perceived behavioral control mean that students feel that they can control their future choices to study STEM. (4) The scores for intentions are very high, indicating that they are likely to choose STEM.

Table 1. Results of the TPB questionnaire (n = 106)

	Attitudes	Subj. Norms	PBC	Intentions
First quartile	27	12	34	58
Second quartile	24	36	33	32
Third quartile	31	53	37	12
Fourth quartile	24	5	2	4
Total	106	106	106	106

While the attitudes were not as high as we expected, the results for the subjective norms are of particular importance, because they show that students can be motivated by the respect and support they receive from their teachers and parents. The PBC results show that the students feel that they can control their choice of STEM at high school.

The high scores for intentions were consistent with the answers to a question about the student's intentions to study STEM that was asked at the beginning of the questionnaire before the TPB items.

5.2 The First Research Question: (b) Do Students Choose STEM?

From one of the cities in which the activities took place we obtained the numbers of students in the AMT and MOFET programs. In 2012, before robotics activities were introduced, only 10% of the students chose STEM subjects. In 2015, after robotics activities were introduced, this percentage increased to 13% and in 2016 increased again to 18%, almost double the percentage from four years before.

Table 2 gives the number of students in that city's AMT (the ones who studied robotics) and the number of students in MOFET (who did not study robotics). From 2015 to 2017, the number of students in AMT increased, exceeding the number of MOFET students.

Table 2. Number of students in 2015–17

Year	2015	2016	2017
MOFET	300	283	272
AMT	316	372	446

The AMT program has three topics: Scratch, robotics and computer security. Before AMT, Scratch was taught middle-schools, yet the numbers of students choosing STEM did not increase. We interpret the data in Table 2 as justifying the use of robotics activities, because robotics is a central topic of the AMT program, while robotics is not taught in the MOFET program. Since AMT students are *not* self-selected, this strengthens the claim that robotics was significant in their decision to study STEM.

5.3 The Second Research Question

Most of the teachers said that their students enjoyed engaging with robots to the extent that many did not want to go home at the end of the activities. We believe that this enjoyment positively influences motivation. The FLL teachers from outside the school had difficulties controlling their students, but this was improved by assigning teachers from the school to assist. The teachers said that students are more motivated and responsible than they are in regular classes. In their opinion, participation in robotics activities caused students to choose to study STEM, in general, and CS, in particular, in high school. Their explanation was that students became addicted to working with robots and enjoyed programming them. They emphasized that many were students who wouldn't otherwise have chosen STEM. High school teachers explicitly said that their students recognize CS topics from middle-school CS and robotics activities.

6 Conclusions

Our research provides evidence that supports the claim that robotics activities motivate students to further study of STEM. We believe that the advantage of using robots in classrooms is that the students experience kinesthetic activities: The robots give a concrete feedback in contrast to the virtual world of a software-only environment. Moreover since the students' must learn from mistakes that lead to incorrect concrete behavior of the robots, engaging with robots imitates game-like learning that attracts students and this in turn reduces the fear from STEM. Students obtain experience similar to that of scientists and this encourages them to study STEM. We found that students, as well as their parents and teachers, consider science professions as success in life, and we believe that robotics activities can mediate this success.

Acknowledgments. This research was supported by the Israel Science Foundation (grant 912/13).

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