AC 2009-193: THE IMPACT OF INTRODUCING ROBOTICS IN MIDDLE- AND HIGH-SCHOOL SCIENCE AND MATHEMATICS CLASSROOMS

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The Impact of Introducing Robotics in Middle and High School Science and Mathematics Classrooms

Abstract – The Center for Pre-College Programs at the New Jersey Institute of Technology was established to provide students with high quality science, technology, engineering and mathematics (STEM) education and mentorship activities, in an effort to help students see the rewards of careers in STEM and increase students’ interest in pursuing a career in these fields. Students who participate in the centers’ programs are better prepared to pursue and successfully graduate in STEM majors, especially engineering. The Center also conducts training institutes that provide teachers with pre-engineering curriculum to better prepare students to enter engineering degree programs. The curriculum focuses on pre-engineering skills and teachers are trained to use instructional strategies that support connections between standards-based science, mathematics and real world engineering. The current paper describes 1) a new training program to introduce students and teachers to engineering and information technology through the use of robotics, 2) the curriculum developed to train middle and high school Science and Mathematics teachers to use robotics and 3) results of data collected during the first year including students’ and teachers’ attitudes toward engineering, teachers’ concern about using robotics in their classroom and their preparedness to teach the robotic curriculum.

Index Terms – Pre-engineering Curricula, Robotics, Attitudes toward Science, Mathematics and Engineering, Knowledge about engineering careers.

The United States currently has a shortage of qualified workers in the science, technology, engineering and mathematics (STEM) fields that will continue at least into the next decade\textsuperscript{1,2}. For the long-term economic health of this country it is important that more students undertake studies and pursue careers in these fields because as evidenced by the U.S. Government’s H1-B visa program, it has become necessary to recruit skilled professionals in these fields from other countries to meet the current needs of the American work force\textsuperscript{3}.

There are several reasons more students are not interested in pursuing careers in STEM fields. The most crucial reason is a lack of academic preparation in middle and high school\textsuperscript{4}. Many students are not exposed to topics in these fields at all during their K-12 studies; for some, particularly those from underrepresented populations in urban school districts, their only interaction with technology is using a personal computer for word processing and other non-technical tasks. Although students are taught about mathematics and science, most students are relatively uninformed about technology and the field of engineering. Research indicates that most parents, teachers and school counselors do not discuss engineering as a possible career with students because they also do not know much about engineering themselves or what engineers do\textsuperscript{5-7}.

Many K-12 teachers have not been trained to incorporate engineering and technology topics into their classroom lessons and there is a lack of high-quality curricular materials in these areas. As a result, students are not exposed to the engineering and technology resources used to develop strategies for solving problems in the real world. But research has shown that even students who are adequately prepared and initially choose engineering often do not persist. While proper
academic preparation may be essential for success in engineering, it appears that students’ attitudes to engineering and opinions about engineers prior to beginning college are also important. Often students drop out in good standing, with grades similar to students who persist in engineering, but have significantly poorer attitudes to engineering; less positive perceptions of engineers; enjoy mathematics and science less; place a lower value on engineering compared to other majors; and hold negative stereotypes about engineers (e.g. engineers are nerds) or exaggerated positive stereotypes about engineers (e.g. engineers are geniuses). Therefore, in addition to being better prepared in math and science, potential college students need to be more well-informed about engineers and careers in engineering not just so more students choose engineering as a major but also so more students succeed in engineering.

The Pre-Engineering Instructional Outreach Program (PrE-IOP) at NJIT’s Center for Pre-College Programs was established as part of a three-year project funded by the New Jersey Commission on Higher Education to inform students, teachers, parents, and school counselors about careers in engineering. The objective of the program was to increase the number of students who enroll in engineering schools in New Jersey, particularly those from groups traditionally underrepresented in engineering. The PrE-IOP training programs provided middle and high school teachers with pre-engineering curriculum that not only better prepares students to study engineering but helps increase their attitudes towards, and interest in, engineering careers. The curriculum, aligned with New Jersey Content Standards and national standards such as ISTE’s National Educational Technology Standards for Students (NETS for Students) and ITEA’s Standards for Technological Literacy (STL), focuses on pre-engineering skills and includes instructional strategies that emphasize connections between science, mathematics and real-world engineering. Survey instruments were developed to measure Teachers’ Attitudes to Engineering and Knowledge of Engineering Careers and Students’ Attitudes to Mathematics, Science and Engineering, Knowledge of Engineering Careers and self-efficacy for engineering skills.

To help more students appreciate the role of technology and engineering in today’s society, and increase the number of students interested in pursuing careers in STEM fields, particularly those in generally underrepresented populations, the Center for Pre-College Programs has developed a new program centered on the unifying topic of robotics using biomedical engineering applications. Engineering design activities are powerful tools for the integration of science, mathematics and technology and for engaging a broad population of students. Because of its multidisciplinary nature, the study of robotics in the classroom can be a valuable tool for the practical, hands-on application of concepts across various engineering and science topics. Multiple fields of science, such as biology and medicine, and engineering, from electrical engineering (sensors and motors) to mechanical engineering and physics (gears, axles and hinges) are combined with information technology (the programming languages that help support and control robotic devices) to form a teaching tool that enables students to recognize direct links between their science courses and engineering in the real world.

The emphasis on biomedical engineering applications is especially important because many of the applications of robotics tend not to be aligned with the interests of a significant portion of the student population, namely females. Fields such as medicine, dentistry and law have seen significant increases in women entering their profession because women tend to be motivated by a desire to contribute to society. Engineering and related scientific and mathematical tools are
seldom seen as a means to enhance society. However, more students, particularly females, are beginning to recognize that biomedical engineering, defined as using traditional engineering principals to solve problems in biology and medicine provides for an overall enhancement of health care, which of course is an effective way to help people and improve society\textsuperscript{23}.

The new robotic curriculum, Medibotics: The Merging of Medicine, Robotics and Information Technology, incorporates grade-appropriate prototypes of robotic surgeries developed for biomedical engineering students at NJIT\textsuperscript{24} into the pre-engineering curriculum previously developed for the Pre-Engineering Instructional Outreach Program using LEGO\textsuperscript{TM} Mindstorms Kits for Schools and Robolab software. For example, degenerative disk disease is a medical condition in which the spinal disks become worn and frail, making movement a painful and tiring process. Spinal disk replacement (SDR) surgery uses the SB Charite Artificial Disk, a polyethylene sliding core in between two cobalt chromium endplates, that replicates the human spinal disk, to replace the damaged disk. A high school level prototype for Spinal Disk Replacement Surgery uses an Oreo cookie to simulate the end plates and the inner core. Students learn to construct and program a robot to perform three functions: detect a damaged disk, remove the disk, and replace it with a substitute (the Oreo). To accomplish this task, the robot will need three components: a clamp, crane and infrared sensor. The clamp would act like fingers in removing and replacing the disk in the correct and precise location in the spine. The crane would move the clamp up and down to retrieve and replace the disk. The infrared sensor would aid in detecting the definite location of the damaged disk and when the surgery was complete it would also help ensure if the disk was the right fit and placed in the correct location.

The remainder of the current paper summarizes the results of data collected during the first year including students’ and teachers’ attitudes toward engineering and knowledge of engineering careers, teachers’ concern about using robotics in their classroom and their preparedness to teach pre-engineering curricula using robotics.

Measures

Attitudes to Mathematics, Science and Engineering and Knowledge of Engineering Careers

Surveys were used to measure teachers’ and students’ attitudes to mathematics, science and engineering, knowledge of engineering careers and self-efficacy for engineering skills\textsuperscript{5,7,18}.

- **Attitudes to Mathematics, Science and Engineering:** Students agree or disagree with statements about scientists (scientists help make peoples’ lives better), mathematics (It makes me nervous to think about taking mathematics classes), engineers or engineering such as “engineers are nerds”, or “I would like a job designing robots” on a five-point scale where 1 indicates strong disagreement and 5 indicates strong agreement. Students can also indicate they do not know. I do not know responses are not counted for purposes of calculating mean attitude scores. Teachers agree or disagree with many of the same statements in addition to statements such as “If one of my students excels in mathematics or science, I suggest engineering as a possible career.”

- **Knowledge of Engineering Careers:** A multiple-part open-ended question asks respondents to “Name five different types of engineers” and to “give an example of the work done by each type.” Each type of engineer is coded “1” for correct and “0” for incorrect. Possible
total scores range from zero to five. Each example of the work they do is coded “2” for completely correct, “1” for partly correct, and “0” for incorrect. Possible total scores range from zero to ten.

- **Self-Efficacy for Engineering Skills:** For students, self-efficacy for engineering skills is a self-reported measure of self-confidence for skills necessary to succeed in engineering such as being good at solving problems in more than one way. For teachers, self-efficacy for engineering is a self-reported measure of how well they think they can help prepare students for a career in engineering. Teachers indicate if they know about summer or after school programs to help students prepare for careers in engineering or whether they know where to find information about careers in engineering. Self-efficacy is measured on a five-point scale where 1 indicates low self-efficacy and 5 indicates high self-efficacy.

*Teachers’ Concerns about Implementing the Robotics Curricula in their Classrooms*

Teachers’ concerns about integrating the pre-engineering curricula into their classrooms using robotics were measured using The Teachers’ Concerns Questionnaire (TCQ) adapted from the Concerns Based Assessment Model (CBAM). Repeated administrations of the TCQ are used to identify teachers’ concerns and track changes in their concerns as they engage in educational reforms, focusing on how they progress through seven stages of concern: Awareness, informational, personal, management, consequences, collaboration and refocusing.

*Teachers’ Readiness to Teach*

At the end of their training program teachers completed an 18 item Readiness to Teach Questionnaire (RTQ). The RTQ requires teachers to indicate how ready they feel they are to teach lessons on the topics from their particular workshop on a scale from 1 to 4 where 1=“I would have to start from scratch”, 2=“I would need more training to teach this topic”, 3=“I would have to look at my notes to do this”, and 4=“I can teach a lesson on this topic tomorrow”. For example, one item asks ‘How ready are you to teach integrating sound sensors into robot designs?’

*Teachers*

Twenty middle and high school (ten each) mathematics and science teachers attended a two week training program during the summer of 2007. Teachers completed the Attitudes to Engineering Survey before the beginning of the program; the Teachers’ Concerns Questionnaire before the beginning of the program, during the first day of the program and at the end of the program; and finally the Readiness to Teach Questionnaire at the end of the program.

To evaluate the impact teachers’ participation in the programs had on students, the teachers were also asked to have their students take the Student version, Attitudes to Mathematic, Science and Engineering at the beginning of the school year before using the pre-engineering, robotics curricula in their classroom (pre-data), and again at the end of the school year (post-data). Only eight teachers returned the students’ surveys at the beginning of the school year as requested.
The teachers were also asked to complete the Attitudes to Engineering Survey and the Readiness to Teach for a second time and the Teachers’ Concerns Questionnaire for a fourth time toward the end of the 2007-2008 school year after using the robotics curricula. Although all 20 teachers were contacted, only the eight teachers who returned the student surveys completed the teacher surveys at the end of the school year. Two of the teachers explained that although they were very interested in the program and they learned a great deal, their school never provided them with a LEGO™ kit so they were not able to implement the robotics curricula and therefore did not return the student attitude surveys at the end of the school year. As a result complete student data are available from only six teachers of equal gender, from mostly urban schools, the exceptions being one from an all girl Catholic school.

Summaries of the pre-data for all 20 teachers are presented as a qualitative, formative evaluation of their training (i.e. the workshop). Summaries of the teachers’ post data for the teachers who completed all the required data are also provided but no tests of significance from pre-to-post were performed due to the small sample size.

Attitudes to Engineering

Overall, the teachers were fairly positive about engineers and engineering as a career, even before the beginning of the program. Most agreed that “skills learned in engineering are useful in everyday life.” They all disagreed with the statement “I would not like any of my students to be engineers.” All but one teacher indicated that they knew at least one of their students was considering studying engineering in college. At the end of the school year all eight teachers agreed “If a student excels in mathematics and/or science, I suggest engineering as a possible career.”

The average attitudes to engineering score for all 20 teachers before the beginning of the summer program was 3.7. The average for the eight teachers who completed the attitudes survey at the end of the school increased to 4.1. Even the two teachers who were not able to implement the robotics curricula appeared more positive about engineering. Other open-ended feedback from these two teachers indicated that although they could not introduce robotics in their classroom they still introduced the pre-engineering concepts in the curricula to their students.

Engineering Preparation Self-efficacy

Before the summer workshop began, most teachers were somewhat informed about how to help prepare their students to consider engineering as a possible career. Most agreed they knew ‘where to find the necessary information to help their students if they wanted to become engineers’ but most disagreed with the statement ‘I have all the information I need to help prepare any of my students who may want to be an engineer.’ Only a few indicated they knew of summer programs to help students learn more about careers in engineering. Average Engineering Preparation scores were low, only 3.2. The average for the eight teachers who completed the attitudes survey at the end of the school increased to 4.3 indicating they are much more informed as a result of participating in the Medibotics program.
Knowledge of Engineering Careers

Only 60% (n=12) of the teachers were able to correctly identify five different types of engineers before the beginning of the program. Three (15%) did not identify any and the other five teachers (20%) were able to identify only a few types. Of the 12 teachers who were able to correctly identify five different types of engineers, less than half were able to give correct examples of the kind of work done by all five types. Some gave no examples at all.

At the end of the school year seven of the eight teachers who completed the Attitudes to Engineering survey were able to correctly identify five different types of engineers and give at least partially correct examples of the work done by each type. Two were able to provide completely correct examples of the type of work done by the five different types of engineers.

Teachers Concerns about Implementing the Curriculum

The three sets of responses to the Teachers’ Concerns Questionnaire completed by all 20 teachers were examined. The analysis indicated that initially, before the program, teachers’ concerns focused on increasing their awareness of engineering topics and gathering information about using robotics in their classroom and their concerns did not change before the first day of the program. By the end of the summer program the teachers’ concerns had begun shifting toward whether the new curriculum would help their students learn math and/or science, expressing fewer personal and management concerns about the time commitments required to implement the new curriculum. Analysis of the responses from the six teachers who had implemented the robotics curricula in their classrooms indicted that they had entered the consequences stage where teachers begin to think more about the impact the program is having on their students and were beginning to think about how they could collaborate with other teachers.

Teachers Readiness to Teach

Teachers completed the Readiness to Teach at the end of the summer program. Average scores ranged from 3.1 to 3.4. A majority of the responses indicated 3=‘I would have to look at my notes’. Only one teacher gave any responses that indicated 1=‘I would have to start from scratch’. Less than 25% of the responses indicated 2=‘I would need more training to teach this topic’. For many items, at least 50% of the teachers indicated 4=‘I can teach a lesson on this topic tomorrow.’

Teachers were asked to complete the Readiness to Teach again toward the end of the school year after teaching the robotics curricula in their classroom. Average responses for the six teachers who implemented the robotics curricula and returned their students’ attitudes surveys changed slightly from 3.2 at the end of the training program to 3.0 at the end of the school year. This small decrease is not significant and probably reflects the fact that not all teachers were able to cover all topics in the curricula.
Students

Unfortunately because only six of the 20 teachers (two middle and four high school) returned students’ pre- and post- attitude surveys the sample size for the student analyses is much smaller than anticipated. The most appropriate and most powerful statistical analysis is a repeated measures analysis of variance controlling for differences between teachers. Therefore any students who did not complete the attitude survey at both the beginning and end of the school year are lost to the analysis and reduce the sample size further to a total of 112. For the two middle school classes there were 24 students from a mathematics class and 16 students from a science class. For the four high school classes there were 17 10th and 11th graders in a geometry class, 15 10th and 11th graders in a science lab, 24 9th and 10th graders in an algebra class, and 14 9th grade girls in a science class. As a result the total sample of students was approximately 55% female.

The middle and high school versions of the attitudes survey are slightly different as each was designed to be age appropriate. The middle school version makes more references to mathematics and science using examples of what engineers do like “designing robots” and the high school version talks more explicitly about engineering. In addition to an overall measure of attitudes (TOTAL), each version of the survey has subscales that measure different aspects of students’ attitudes towards engineering for example: interest in engineering as a career (INTEREST), negative perceptions and stereo-types about engineering and engineers (NEGATIVE), positive perceptions of engineers or the advantages of engineering (POSITIVE), ideas about gender equality in pursuing a career in engineering (GENDER) and general statements about engineers and engineering (GENERAL). To help compensate for the small sample size only the subscales mentioned above, that the two versions have in common, are examined so that the two grade levels could be combined and analyzed together.

The knowledge of engineering question and the scoring protocol are the same for each version so this question can also be examined for all students. Because summarizing proportions of students who were able to identify different types of engineers or who report that their teachers had performed specific tasks in the classroom produces count data rather than a measure on an interval scale, chi-square tests of independence were used to test for significant changes from the beginning to the end of the school year.

On the survey, students are asked how often any of their math, science or technology teachers had presented engineering principles as part of their classroom teaching. The frequencies with which students indicated any of their teachers did so are summarized in Table I. Students’ responses changed significantly from the beginning to the end of the school year ($X^2_3=92.1$, $p<.01$). Many more students reported that their teachers had presented engineering topics as part of their classroom teaching at the end of the school year.
### TABLE I
**Students Indicating Any of Their Teachers Presented Engineering Principles as Part of Their Classroom Teaching**

<table>
<thead>
<tr>
<th></th>
<th>Never</th>
<th>1-2 times</th>
<th>3-10 times</th>
<th>More than 10 times</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Beginning</strong></td>
<td>56%</td>
<td>33%</td>
<td>9%</td>
<td>1%</td>
</tr>
<tr>
<td><strong>End</strong></td>
<td>10%</td>
<td>16%</td>
<td>45%</td>
<td>29%</td>
</tr>
</tbody>
</table>

### Attitudes to Engineering

Repeated measures analysis of variance techniques were used to test for significant differences in students’ attitudes to engineering from the beginning to the end of the school year. Average responses to each of the subscales examined and the overall total scale are summarized in Table II.

### TABLE II
**Summary of Changes in Students’ Attitudes to Mathematics, Science and Engineering During the School Year**

<table>
<thead>
<tr>
<th>Subscale</th>
<th>INTEREST</th>
<th>POSITIVE</th>
<th>NEGATIVE*</th>
<th>GENDER</th>
<th>GENERAL</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Beginning</strong></td>
<td>Mean (SD)</td>
<td>2.3 (.54)</td>
<td>3.7 (.57)</td>
<td>2.3 (.51)</td>
<td>4.2 (.61)</td>
<td>3.6 (.57)</td>
</tr>
<tr>
<td><strong>End</strong></td>
<td>Mean (SD)</td>
<td>3.2 (.49)**</td>
<td>4.0 (.53)</td>
<td>1.9 (.49)**</td>
<td>4.4 (.57)</td>
<td>3.9 (.55)**</td>
</tr>
</tbody>
</table>

* The items for this subscale are phrased negatively so a lower mean is desirable. These items are reverse scored for calculating the TOTAL scale so that a higher overall mean is desirable.

Significant increases were found in students’ overall attitudes toward engineering (TOTAL scale) and for each of the subscales except gender equity. Students were more interested in engineering, had more positive perceptions of engineers and engineering as a career, had less negative perceptions about engineering but did not appear to change their attitudes about whether “women were equally good at mathematics and science” or whether “women could succeed in engineering as easily as men”.

### Engineering Self-Efficacy

Average responses to the Engineering Self-Efficacy Scale and both of its subscales (Enjoyment and Technical Skills) are summarized in Table III. Significant increases were found in students’ overall engineering self-efficacy (TOTAL scale) and both subscales. Students were more confident in the kind of skills they would need to study engineering in college or become engineers and indicated they enjoyed performing mathematics and science tasks more.
TABLE III
SUMMARY OF CHANGES IN STUDENTS’ ENGINEERING SELF-EFFICACY DURING THE SCHOOL YEAR

<table>
<thead>
<tr>
<th>Subscale</th>
<th>SKILLS</th>
<th>ENJOYMENT</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beginning</td>
<td>Mean (SD)</td>
<td>3.2 (.78)</td>
<td>3.2 (.69)</td>
</tr>
<tr>
<td>End</td>
<td>Mean (SD)</td>
<td>3.6 (.73)*</td>
<td>3.5 (.66)*</td>
</tr>
</tbody>
</table>

* p<.05

Knowledge of Engineering Careers

Responses to both parts of the Knowledge of Engineering Careers question were summarized and are displayed in Tables IV and V. Significant changes were found from the beginning to the end of the school year. Almost half the students (47%) were not able to correctly identify any type of engineers and only 4% were able to correctly name five different types (See Table IV). By the end of the school year almost all the students were able to correctly name at least one type of engineer and almost half were able to name three or more types ($X^2_3=66.1$, p<.01).

TABLE IV
STUDENTS’ RESPONSES TO KNOWLEDGE OF ENGINEERING QUESTION, PART 1, NAME FIVE DIFFERENT TYPES OF ENGINEERS.

<table>
<thead>
<tr>
<th>Number Correct Responses</th>
<th>0</th>
<th>1-2</th>
<th>3-4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beginning of School Year</td>
<td>47%</td>
<td>37%</td>
<td>12%</td>
<td>4%</td>
</tr>
<tr>
<td>End of School Year</td>
<td>3%</td>
<td>49%</td>
<td>32%</td>
<td>16%</td>
</tr>
</tbody>
</table>

At the beginning of the school year, less than 40% of the students gave any correct examples of the kind of work done by the types of engineers they named (See Table V). None of the students scored 10 points which means that even students that were able to correctly identify five different types were not able to give completely correct examples of the kind of work done by each type, some of their answers were only partly correct. By the end of the school year most students (93%) were able to give at least some partly correct examples of the type of work done by the different types of engineers they named which is a significant increase ($X^2_3=82.7$, p<.01).
TABLE V
STUDENTS RESPONSES TO KNOWLEDGE OF ENGINEERING QUESTION, PART 2, GIVE AN EXAMPLE OF THE WORK DONE BY EACH TYPE.

<table>
<thead>
<tr>
<th>Number of Points</th>
<th>0</th>
<th>1-3</th>
<th>4-6</th>
<th>7*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beginning of School Year</td>
<td>63%</td>
<td>18%</td>
<td>14%</td>
<td>5%</td>
</tr>
<tr>
<td>End of School Year</td>
<td>7%</td>
<td>22%</td>
<td>58%</td>
<td>11%</td>
</tr>
</tbody>
</table>

* None of the students scored more than 7 points out of a possible 10

Conclusions

Before beginning the program, teachers were concerned about implementing the new curricula which is to be expected, but by the time they completed the program they were feeling more confident and eager to help their students. By the end of the school year, after they had some real classroom experience with the new curricula, those that completed the concerns questionnaire had fewer concerns and were beginning to think about how they could collaborate with other teachers.

Teachers’ attitudes toward engineering, their knowledge of careers in engineering and the information they had to help students interested in studying engineering increased as a result of participating in the Medibotics program.

Students’ attitudes toward engineering, their knowledge of careers in engineering and their self-efficacy for engineering type skills increased significantly from the beginning to the end of the school year. Although poor teacher compliance resulted in a small sample the current results are encouraging. Changes in teacher accountability are being made for the second year of the program and another evaluation will be conducted next year.

References


