AC 2007-1684: IMPACT OF TEACHING ENGINEERING CONCEPTS THROUGH CREATING LEGO-BASED ASSISTIVE DEVICES

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Impact of teaching engineering concepts through creating LEGO-based assistive devices

Abstract

LEGO robotics is not all that new to the classroom. Teachers have used the toolset to teach STEM subjects in exciting and hands-on ways. Sure students appear to be more engaged and appear to be learning, but how does such a curriculum impact students’ attitudes and knowledge? How do you design such a curriculum of robotics to also appeal to female students? These are questions this study attempts to answer. The study involves a 15-hour robotics unit that has groups of students design, construct, and test an assistive device they create using the LEGO robotics toolset. The curriculum was designed to address specific standards from the Massachusetts state curriculum frameworks. The assistive device theme was chosen to appeal to both males and females for whom engineering has, traditionally, not been appealing. The curriculum was then taught by a pair of teachers who had been trained in the LEGO toolset and curriculum in a two-week summer professional development workshop, which addresses yet another question. Can a teacher novice to LEGO robotics effectively teach such a curriculum with just two weeks worth of training? To answer these questions, the teachers from the summer professional development workshop (n=12, female=6, male=6) were interviewed and given knowledge surveys before and after the workshop, and a seventh grade classroom of Boston Public School students (n=24, female=14, male=10) were given attitude and knowledge surveys before and after the unit. The attitude survey assessed the students’ perceptions of both science and engineering while the knowledge survey assessed questions modified from the Massachusetts Comprehensive Assessment System (MCAS). The results of the study revealed significant achievement on the knowledge assessment and, somewhat surprisingly, a much more significant increase in the females’ perception of the usefulness of engineering as opposed to the males’.

Introduction

Engineering not only makes the technology around us possible, it is also an amazing way to put the knowledge we have to a real and practical use. Engineering in the classroom allows students to see the value of what they are learning, apply their knowledge to contexts that make sense to them, and be free to create and explore the world around them. Massachusetts recently included engineering and technology frameworks in the entire K-12 curriculum as required material[1]. Currently, students are being tested on engineering and technology content on the MCAS (Massachusetts Comprehensive Assessment System) test; however, very few of these students are getting any formal instruction related to the engineering/technology frameworks. Two reasons for this are, one, there are very few middle school teachers with any formal training in engineering or technology, and, two, very little curricula designed to teach the content outlined in the Massachusetts state curriculum frameworks. If engineering is going to be taught in the classroom, teachers will undoubtedly require an engineering curriculum and some preparation prior to teaching the curriculum. This study looks at a pair of teachers and an engineering curriculum to see the impact they have on 7th grade students. This teaching pair attended a two-week summer professional development program specifically designed to prepare them to teach the engineering curriculum. The teachers were given pre- and post-knowledge and confidence
surveys and were interviewed to gage their preparedness. Student knowledge and attitude survey results were used to assess the success of the curriculum as well as the professional development.

**Curriculum Development**

The engineering curriculum used in this study was developed by the researcher to specifically address the engineering and technology standards outlined in the Massachusetts state curriculum frameworks. The curriculum could not include all the standards, but did address the following major strands: the engineering design process, communication technologies, manufacturing technologies, bioengineering technologies\(^1\). These four major strands were put together in a 15-hour curriculum unit that, in the first six lessons, had hands-on “training” sessions designed to have the student teams learn the LEGO robotics toolset and begin working with the engineering design process. The final sessions charge the students with designing, building, and testing an assistive device out of the LEGO robotics toolset that will assist someone with a disability. This theme was chosen not only because it addressed the bioengineering technologies strand of the frameworks, but because national statistics and research show that girls prefer science that can relate more closely to themselves, the human body, or helping people or animals\(^{2-5}\).

The decision to design the curriculum around the use of an open-ended LEGO design project was based on the educational methodology of constructionism\(^6\). Papert describes this educational methodology based on the theory of constructivism. Piaget pioneered research in the theory of constructivism and described the process a learner goes through to acquire knowledge as one where he or she actively constructs knowledge. Papert took this idea a step further and stated that the construction of knowledge is enhanced when the learner actively constructs a real-world or virtual-world (in the case of computer programming) artifact. The hands-on, project-based nature of constructionist learning activities has proven beneficial to students learning and attitudes\(^2,7-11\).

Neither constructionism nor constructivism defines a clear model for how lessons should be created or taught. Bybee’s\(^{12}\) 5E learning cycle model is one based within constructivism and when applied to a hands-on design project, embodies many of the major tenets of constructionism. The 5-E model was used as the framework for designing the lessons in the engineering curriculum. The five steps are as follows: Engage, Explore, Explain, Elaborate, and Evaluate. Each lesson aims to engage the students and capture their attention and interest, while getting them to start thinking about the topic and access any previous knowledge they may have. Then the explore phase provides the students an opportunity to start “playing” with the materials and develop hypotheses and discover new things. During the explain phase, students explain the results of their exploration and the teacher helps facilitate this explanation with the vocabulary related to the topic. The elaborate phase requires the students to apply this new knowledge to new problems. The final design and construction of the LEGO assistive device will be the elaborate phases of the curriculum. Students testing their designs and reflecting on their function is the evaluate phase. During this phase, the teacher is also assessing students’ learning of the topics.
Teacher Professional Development

This new engineering curricular unit will only be successful if the teachers implementing it do so effectively. Teachers often have difficulty introducing new technology and new curriculum and find they struggle managing their time and student questions efficiently\textsuperscript{13}. Research also shows that without proper training and development, teachers may perceive such curriculum and changes negatively which, in turn, affects how they teach\textsuperscript{14}. The implementation of this engineering unit faces similar challenges. The teachers recruited to teach this curriculum in the Boston Public schools are mostly math, science, and technology teachers. These teachers do have strong math and science backgrounds; however, most of them, including the technology teachers, do not have any formal training in engineering. With this in mind, the research team created a professional development workshop to teach the teachers the technology, the included engineering principles, and give them an opportunity to teach the unit.

The professional development workshop for the teachers is outlined in more detail in an earlier publication outlining some of its successful features as voiced by the participating teachers\textsuperscript{15}. The workshop was designed based on research in the field. Hopkins\textsuperscript{16} reported that for hands-on, project-based classroom activities, the teacher must have the hands-on experience themselves so they know how it is done before they bring it to their students. However, this type of experience alone is not enough. One-time technology workshops do not address all the needs of the teacher and can end up being a waste of time\textsuperscript{17}. Loucks-Horsley\textsuperscript{18} states the most common issue for teachers after professional development is how they actually implement what they learned in an actual classroom. One way to address this is by providing an ongoing support structure for the teachers which has proven critical for many such workshops\textsuperscript{18-20}. Another method would be to include a practicum portion to the workshop where the teachers are able to teach the unit with the instructors from the professional development workshop present. Both of these were incorporated into this professional development.

The professional development was a two-week summer workshop. In the first week, the teachers went through the curriculum lesson by lesson as though they were students. In addition to learning by doing the curriculum, the teachers were given additional lessons on specific engineering principles and pedagogical techniques to assist them in teaching the unit. During the second week, the teachers had an opportunity to teach the entire unit to students. Local middle school students were brought in for 3 hours each morning. In the afternoon, the teachers had a chance to discuss and debrief as a group with the instructors and prepare for the next day. The teachers expressed the value of being able to teach the lessons alongside other teachers for the week. They said that they were able to learn from what other teachers were doing and were able to gain confidence in their teaching as they noticed that they were doing things well\textsuperscript{15}. Also in the follow-up interviews, the teachers expressed how important it was for them to get a chance to experience the curriculum hands-on prior to teaching it.
Research Methodology

Data Collection

In order to determine if the engineering curriculum and professional development are effective ways of implementing engineering concepts, the researcher looked at both teacher and student outcomes. For this study, the researcher was interested in whether or not the students were learning the intended strands from the state curriculum frameworks, whether or not this unit impacted the students attitudes towards science and engineering, and whether or not the professional development sufficiently prepared the teachers to teach the engineering unit.

The teachers took pre- and post- content tests before and after the professional development workshop (see Appendix A). They also took a pre- and post- confidence survey to assess how confident they were with engineering and technology (see Appendix B). The teachers were also interviewed approximately one month after the workshop and before they began teaching the unit in their classroom.

The students also took pre and post content tests and attitude surveys before and after their in-class experience with the curriculum. The content test included modified questions from the Massachusetts Comprehensive Assessment System (MCAS). The test questions (see Appendix C) addressed the standards included in the engineering curriculum, however, the content of these standards was presented in the curriculum in an informal manner. No written assessments were administered during the lessons. The attitude survey was adapted from Robinson’s science attitude survey[21] assessed their attitudes towards science and engineering as well as how they perceived engineers and engineering as a profession (see Appendix D).

Participants and Setting

Two classrooms each with a team of two teachers were initially chosen for the research study. However, one of the teams was unable to acquire all the necessary consent forms from their class. The one classroom that participated was a Boston Public School seventh grade classroom. The class was a typical, culturally diverse inner city Boston Public School. There were 28 students in the classroom; however, only 24 students fully completed the pre- and post-tests. The class participated in the research in the spring of 2006.

The team of two teachers (Helen and Derek) both participated in the two-week summer professional development workshop mentioned earlier. Helen had been teaching middle school science for the past four years and had an undergraduate degree in Chemistry. Derek was a fairly special case in this situation. He had an undergraduate degree in aeronautical engineering and was in his first year as a technology specialist at the school. Although Derek had such a strong engineering background, Helen was the lead teacher and led many of the lessons. Nevertheless, this teacher team is quite unique and is a validity threat to illustrating the effectiveness of the professional development workshop. To counter this, the data from all the participating teachers will also be considered. The unique teacher team does not necessarily pose a validity threat to the effectiveness of the engineering curriculum as the teachers did indeed follow the curriculum as it was designed.
Results and Discussion

Teacher Professional Development

The goal of the knowledge and confidence surveys and interviews were to see if the teachers were prepared to teach the engineering curriculum. A few of the highlights from the data will be shown here. Further details of the results can be found in an earlier publication on the research[15]. The results from the knowledge survey showed a significant (p<.05, n=12, male=6, female=6) increase in scores in the post-test as compared to the pre-test. Figure 1 below illustrates how each teacher performed. Helen’s and Derek’s data points are labeled. Helen improved from a score of 7 to a score of 9, while Derek scored the max (12) on each test. One interesting note on the three highest scorers whose scores did not change was that they were all technology teachers.

![Graph of teacher (n=12, female=6, male=6) performance on pre- and post-engineering content test. Trendline represents points where teachers would have scored equally on both (above line represents positive change, below line represents negative change)](image)

The confidence survey results complement the findings from the knowledge survey. The question regarding the teachers’ confidence in their knowledge of engineering principles changed significantly (p<.05, n=12, female=6, male=6) from 2.17 to 2.92, which is .75 points on a four point scale[15]. Likewise, the teachers’ confidence in teaching engineering principles increased, but this increase was not statistically significant.

The interviews with the teachers also supported that the professional development workshop was effective in preparing them to teach. Helen felt prepared to teach the unit and noted that her only difficulty may be with troubleshooting some of the more advanced computer programming issues that may come up. Helen stated that the “step-by-step” nature of the professional
development gave her the confidence to bring the unit into her classroom. Derek when referring to the curriculum stated, “this one I am willing to try out because I have already been taught through it and had the chance to practice it, so I think that is the key feature to feeling prepared.” He also noted that during the practicum “we were still under supervision and still had someone to fall back on the first time around,” which provided a safe space for him to try it out before taking it to a classroom full of students.

The knowledge and confidence surveys along with the interview data verify the professional development workshop did sufficiently prepare the teachers to teach the engineering curriculum. The teachers’ belief that they know the engineering principles and can teach them increased and was present during the interviews, which is an important factor in a teacher following through and effectively implementing curriculum[22]. The knowledge survey data clearly demonstrated that there was something for the teachers to learn regarding the content within the Massachusetts technology curriculum standards. In all but one case the teachers either increased or got the same score on their post-test. For each of the eight cases where the teachers scored less than 8/12, they positively increased their score. Also important to note is that the only perfect score (12) was achieved by the teacher with a Bachelor’s of Science in engineering. This is clearly not enough data to make any sort of formal conclusions, but does provide some preliminary evidence that teaching an engineering curriculum may require teachers to take engineering classes above and beyond a professional development workshop as described in this study.

**Student Outcomes**

It appears from the teacher data that they were prepared to teach the curriculum, but was it sufficient to impact the students’ learning and attitudinal outcomes. The attitude survey did not provide many statistically significant changes in student attitudes or perceptions. It did show significant (p<.05, n=24) change in two items. Item 10 (see Appendix D) asked the students if they thought engineers spent most of their time with computers. This perception changed significantly, where after participating in the curriculum the students did not feel that this is how engineers spent most of their time. Item 12 asked students if they thought the skills learned in engineering were useful in everyday life. For this question there was a significant interaction (p<.05) between the change in attitude and student gender. The female students mean score on the pre-survey was 3.43 (n=14) and jumped to 4.36(n=14) in the post-survey (on a 5-point scale), while the male students mean score actually dropped from 3.60 (n=10) to 3.50 (n=10). The drop in male scores was not statistically significant. A majority of the other items showed an improvement in student attitudes, but were not statistically significant.

The engineering content pre- and post-tests showed significant (p<.05, n=24) positive change. As mentioned earlier, the content tests were based on MCAS test items that were modified to elicit further detail into the student’s understanding. The content of these items was only informally addressed in the curriculum. The mean scores jumped from 14.5 on the pre-test to 24.3 on the post-test. Figure 2 illustrates the increase and also highlights that both male (n=10) and female (n=14) students showed significant positive increases. The mean score for each of the four items on the test increased, however, the second item (see Appendix C) regarding the manufacturing process did not change significantly (p<.05). This is also the standard that was most poorly incorporated into the curriculum unit.
Figure 2 Mean engineering content test scores

While the attitude survey results did not show significant gains across the board as the researcher may have intended, it was promising to see the significant change in female’s attitudes towards the usefulness of engineering. A causal relationship cannot be claimed, but the assistive device theme may have proven appealing for the female students. The attitude survey results along with the content scores support the claim that the professional development workshop opportunity did sufficiently prepare the teachers to teach the engineering curriculum. The students appear to be prepared to be tested on these items as mandated by the Massachusetts state curriculum standards.

Conclusions

While there was not enough data to make formal conclusions, the results from both the teacher surveys and interviews and student surveys begin to illustrate that the two-week professional development program was effective in preparing the teacher team in teaching a new engineering curriculum. Teaching an open-ended, hands-on, technology-centric curriculum can often be challenging for teachers and produce questionable student outcomes. This small study provides some encouragement that such a curriculum can be implemented given a strong professional development model and teacher support. The small size and scope of this study cannot prove anything; however, it may provide a stepping-stone for future research that may expand upon and complement the results here.
Bibliography


Appendix A
Robotics: Assistive Design for the Future Teacher pre-survey

Name:________________________ Date:________________

(Please check one box for each)

How confident are you of your knowledge of engineering principles?

- Very confident
- Moderately confident
- Slightly confident
- Not confident

How confident are you of your ability to teach engineering principles?

- Very confident
- Moderately confident
- Slightly confident
- Not confident

How confident are you of your computer skills?

- Very confident
- Moderately confident
- Slightly confident
- Not confident

How confident are you of your ability to teach computer principles and skills?

- Strongly disagree
- Disagree
- Indifferent
- Agree
- Strongly agree

I feel comfortable not knowing the answer to a student’s question.

- Strongly disagree
- Disagree
- Indifferent
- Agree
- Strongly agree

I feel I have the background content knowledge to teach an engineering/technology class to middle school students.

- Strongly disagree
- Disagree
- Indifferent
- Agree
- Strongly agree

I am confident I will be able to get all I need from this professional development workshop and be well prepared to lead a robotics unit with my students?

- Strongly disagree
- Disagree
- Indifferent
- Agree
- Strongly agree
Robotics: Assistive Design for the Future Teacher post survey

Name: ___________________________ Date: ____________________
(Please check one box for each)

How confident are you of your knowledge of engineering principles?

☐ Very confident
☐ Moderately confident
☐ Slightly confident
☐ Not confident

How confident are you of your ability to teach engineering principles?

☐ Very confident
☐ Moderately confident
☐ Slightly confident
☐ Not confident

How confident are you of your computer skills?

☐ Very confident
☐ Moderately confident
☐ Slightly confident
☐ Not confident

How confident are you of your ability to teach computer principles and skills?

☐ Strongly disagree
☐ Disagree
☐ Indifferent
☐ Agree
☐ Strongly agree

I feel comfortable not knowing the answer to a student’s question.

☐ Strongly disagree
☐ Disagree
☐ Indifferent
☐ Agree
☐ Strongly agree

I feel I have the background content knowledge to teach an engineering/technology class to middle school students.

☐ Strongly disagree
☐ Disagree
☐ Indifferent
☐ Agree
☐ Strongly agree

I am confident I got all I need from this professional development workshop and am well-prepared to lead a robotics unit with my students?

☐ Strongly disagree
☐ Disagree
☐ Indifferent
☐ Agree
☐ Strongly agree
Appendix B
Teacher Pre- and Post- Knowledge Assessment
Engineering Problems

ID Number: ________________________________ Date: _______________

**Question 1**
Please explain the best you can the steps of the engineering design process (write on the back of this page if necessary).

**Question 2**
Please draw three orthographic projections of the object in the upper right hand corner.

![Diagram of an object with orthographic projections](image)

**Question 3**
Using as many of the words below as you can, briefly describe how one communication system works (ie a telephone, a digital camera plugged into a computer, radio, etc). You can also draw a picture and label it with the words below.

Source, Encoder, Transmitter, Receiver, Decoder, Storage, Retrieval, Destination
Appendix C

Student content knowledge pre/post test (after school program)

Engineering Problems

School Name: _______________________________ Date of Birth ________________

Gender: Male / Female Grade: 6th / 7th / 8th / other _________

Question 1

Fill in the blanks

The steps below were left out of the Engineering Design Process chart. Fill in each blank in the chart with the correct step.

A. Redesign
B. Research the Need or Problem
C. Communicate the Solution
D. Select the Best Possible Solution
E. Construct a Prototype

ENGINEERING DESIGN PROCESS

Step 1
Identify Problem or Need

Step 2

Step 3
Develop Possible Solutions

Step 4

Step 5

Step 6
Test and Evaluate the Solutions

Step 7

Step 8
Question 2
Draw a line to match one of the corporate departments on the left to a task they would most likely do on the right.

<table>
<thead>
<tr>
<th>Department</th>
<th>Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering</td>
<td>plan the pricing and promotion of a product</td>
</tr>
<tr>
<td>Marketing</td>
<td>inspect raw materials to ensure product quality</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>ship finished products to warehouses and stores</td>
</tr>
<tr>
<td>Distribution</td>
<td>send designs out to have prototypes constructed</td>
</tr>
<tr>
<td>Quality Control</td>
<td>set up a system of machines to increase production</td>
</tr>
</tbody>
</table>

Question 3
Draw in the missing Top View in the orthographic drawing below.
Question 4

Using as many of the words below as you can, briefly describe how a robot with a LEGO light sensor communicates information from the environment to control its’ movement. You can also draw a picture and label it with the words below.

Source, Encoder, Transmitter, Receiver, Decoder, Storage, Retrieval, Destination
Appendix D

Robotics: Assistive Design for the Future Student pre/post attitudes survey

Teacher Name: ___________________ Date of Birth ___________________

Gender: Male / Female Grade: 6th / 7th / 8th / other ____________

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Not Sure</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. I enjoy science. ..........................................................</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>2. The science instruction that I have received will be helpful for me in the future. ..........................................................</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>3. I am good at science. ..........................................................</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>4. I usually understand what we are doing in science class. ....</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>5. Science is difficult for me. ..........................................................</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>6. I will probably take more advanced science courses available to me in high school. ..........................................................</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>7. Engineers often don’t have very good social skills. ......................</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>8. Engineering would be a highly interesting job for me. ..............</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>9. Engineers spend little time dealing with other people ..........</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>10. Engineers spend most of their time working with computers ..........................................................</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>11. Engineers rarely get involved in business. ..........................................................</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>12. Most of the skills learned in engineering would be useful in everyday life ..........................................................</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>13. Engineers are frequently those individuals who were regarded as “nerds” in high school. ..........................................................</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>14. I would consider a career in engineering ..........................................................</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

15. What grades do you usually get in science?  
(please circle only one)
- Mostly Ds (below 70) .......................................................... | 1
- Mostly Cs (70-80) .......................................................... | 2
- Mostly Bs (80-90) .......................................................... | 3
- Mostly As (90-100) .......................................................... | 4
- Not sure .......................................................... | 5

16. How much effort do you put in your science work?  (please circle only one)
- I don’t try at all .......................................................... | 1
- I do just enough to get by .......................................................... | 2
- I give an average amount of effort .......................................................... | 3
- I try pretty hard, but not as hard as I could .......................................................... | 4
- I work as hard as I can .......................................................... | 5

17. What best describes you?  
(please circle only one)
- American Indian or Alaskan Native .......................................................... | 1
- Asian or Pacific Islander .......................................................... | 2
- Black, non-Pacific Islander .......................................................... | 3
- Hispanic .......................................................... | 4
- White non-Hispanic .......................................................... | 5

Survey of Attitudes Toward Engineering (Robinson, 1999) (http://www.sweptstudy.org/instruments.html)