AC 2007-1137: THE EFFECTS OF STOMP ON STUDENTS' UNDERSTANDINGS OF AND ATTITUDES TOWARD THE ENGINEERING DESIGN PROCESS

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The Effects of STOMP on Students' Attitudes and Understandings toward the Engineering Design Process

Abstract

At Tufts University there exists an engineering educational outreach program called the Student Teacher Outreach Mentorship Program. This program is designed to take engineering students and place them in K-12 outreach to act as mentors for teachers and students. Previous research conducted on the program showed that participation in the program helped students develop much needed citizenship and communication skills. Administrators of the program have long hypothesized that the program also assists in the development of deeper understandings of engineering related concepts. The following research is a preliminary study supporting just such a claim. Through a series of attitudinal surveys, knowledge assessments, and observations focused on the individuals' experience and the engineering design process, the effects of a teaching experience.

Introduction

Engineering is an active discipline and therefore should be taught actively. At the undergraduate level, this active aspect is typically lost among the countless hours spent within the classroom, learning through lecture, reading, and abstract thinking. Over the past two decades, engineering education has begun to move away from employing passive teaching methodologies toward more active approaches. This movement is guided by published principles [1], theories [2-4], and guidelines [5, 6] that assert that good practice in undergraduate education requires a strong emphasis on experiences.

One such method to elicit experience is through the use of educational outreach opportunities. Over the past decade or so, educational outreach opportunities in engineering have been rapidly on the rise. Current programs include development of classroom materials [7-9], outreach activities on and off campus [10], holding sponsored engineering contests [11], and performing professional development workshops for K-12 teachers.[12] These programs, although designed with specific individual purposes, are all built on four main principles: to provide undergraduate engineering students with a situated service learning experience [13], to increase students' awareness and interest in technology [14], to provide all individuals with the skills to function in and around technology [15], and for students to gain a sense of citizenship as engineers.

The following paper will investigate the origins behind why such a strong emphasis should be placed on experiential learning and then show preliminary results to the effects on attitudes and understandings of the engineering design process by one such outreach program, the Student Teacher Outreach Mentorship Program (STOMP). The engineering design process is defined using the Massachusetts State Standards (Figure 1). The engineering design process is used in this study based on its uniqueness to engineering.

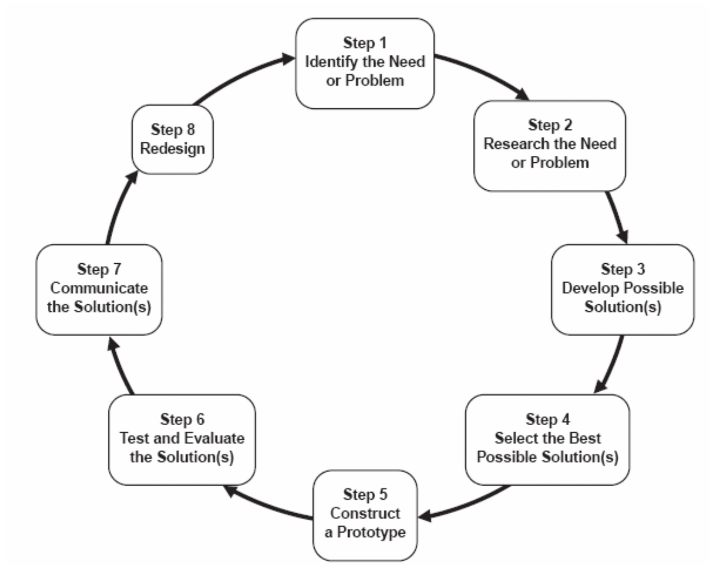

Figure 1: The engineering design process (Massachusetts Department of Education, 2001).

Theoretical Support

The theory of experiential learning has its origins in the philosophical experiential works of John Dewey. Combined with cognitive development [16] and social considerations [17, 18], Kolb [19] theorized that experiential learning is the "the process whereby knowledge is created through the transformation of experience. Knowledge results from the combination of grasping and transforming experience." Experience, in itself, is just another word for situational learning. Within a situational learning environment is the opportunity for situated cognition. Situated cognition environments are designed to model an authentic context, which normally involves the subject-matter knowledge or is closely related to an ultimate application. The result is an effective and efficient transfer of knowledge.[2] Situated learning environments, therefore, place the focus on learning occurring when specific combinations of activities, context, and culture are supplied for the learner and are made visible.[4] Social interactions incurred from situational learning environments are vital to the learning process. As stated in Bandura's Social Learning Theory, "Learning would be exceedingly laborious, not to mention hazardous, if people had to rely solely on the effects of their own actions to inform them what to do".[17] This can easily be achieved through active approaches, but is difficult to achieve within a typical lecture style classroom.

A means to achieving active experiential approaches is to use what Edgerton [20] describes as pedagogies of engagement. Pedagogies of engagement supply a missing collaborative component to higher education allowing students to understand content as opposed to learning content. This approach encourages engagement of students through cooperation and situational learning, to ultimately produce resourceful, engaged workers and citizens as opposed to memory banks of abstract knowledge.[20] This idea can be used either within a classroom [21] or in non-classroom based service-learning experiences.

The approach of this research is to employ an outreach program as a non-classroom based pedagogy of engagement. A number of non-outreach opportunities outside the classroom for engineering students have been studied to determine if they do indeed encourage intentional learning goals and active reflection by the student on what he or she learns throughout the experience.[22-25] These opportunities range from volunteer community service to field education, such as internships and co-ops.[26] Research has shown that these experiences not only allow students to gain a sense of civic responsibility, but that they also help students to develop professional teamwork and communication skills, assist in identifying career paths, prepare students for the demands of their future practice, and supply direct academic benefits by giving them a playing field to exercise their classroom knowledge.[25, 27] In other words, they enable students to "learn how to learn" in ways that are highly applicable in their future work environments and that are not otherwise attainable in classroom learning.[28] This study is a step in the direction of showing that educational outreach in engineering produces the same results.

Research Methods

In a pilot study conducted at Tufts University, two separate groups of undergraduate students were analyzed to determine the effects of the STOMP program on student understandings and attitudes. The study separates, using a control group, what is gained through other outlets and pinpoints the direct effects of STOMP participation (Note: This study does not account for the self-driven motivation of some students to want to participate in STOMP). The experimental group consisted of 12 students involved in STOMP. The control group consisted of 7 students involved in an introductory engineering course titled *Prototyping Home Robots*. Sample sizes were intentionally small so as to preserve as much of the population for the future final study. Through the use of these two groups of students, a comparison was made to determine a possible correlation between student understandings of the engineering design process and participating in STOMP.

Student Teacher Outreach Mentorship Program (STOMP)

STOMP is an engineering educational outreach program founded at Tufts University in 2001.[29] The program takes engineering students and places them in an educational outreach situation in order to act as mentors to teachers wishing to learn how to teach engineering concepts.[29] The main goals of the program, therefore, are to support K-12 educational settings in implementing engineering activities and curricula, provide engineering students with an opportunity to engage in public service through educational support,[30] and to foster technological literacy in the general public. To accomplish these goals, the program prepares these students to become “experts” within the classroom as well as how to be mentors for engineering novices like teachers. The main focus, therefore, in training STOMP participants is to reinforce the engineering design process as a ways and means for K-12 students and teachers alike to gain an understanding of engineering as a whole.

Prototyping Home Robots Course

Prototyping Home Robots is an introductory mechanical engineering course at Tufts University. This course is designed to introduce robotics and the engineering design process, through the use of LEGO and complementary programming languages.

Data Collection & Analysis

To monitor the students changes in attitude and understanding of the engineering design process, three instruments were used - surveys, knowledge assessments, and observations - for both the experimental group and control group. These tools will be tested for validity through this study.

a) *Surveys*: A set of two surveys consisting of both Likert scale and open response questions were administered to each participant in both the experimental and control groups. A pre-survey (Appendix I) was completed prior to each student entering the Fall 2006 semester. The survey focused strictly on personal background. A supplementary retrospective post-survey (Appendix II) was then administered at the end of the semester to identify their attitudes toward engineering and their confidence in explaining/conveying math, science, and technology content to a member of the general public. Knowledge of particular areas and standards were included in the survey to test if they factored into the participants scores. This method was used to more accurately display their changes. Pre- and post surveys were used in this study as a means for students to self-assess their abilities.

b) *Knowledge assessments*: Each student was administered a pre-assessment as well as a post-assessment designed to focus on the engineering design process (Appendix III & IV). These knowledge assessments consisted of open-ended questions with space for a written response. Assessments were developed to be broad with no specific concepts (i.e. tension, torque, etc…) tested, because each participant had a different experience that can only be generalized around the engineering design process. The engineering design process represents a basic idea in which all ideas used within the K-12 environment can be built on. The knowledge assessments were designed in such a way to encourage each student to explain in great detail their understanding of the process rather than a prescribed response. Knowledge assessments were used as a means to understand the participants' understandings of the engineering design process.

c) *Observations*: During the time that the students were involved in the study, both groups were observed within their setting (STOMP location or *Prototyping Home Robots* classroom) in order to monitor their behaviors within their situation.

Both sets of surveys and knowledge assessments were not tested prior to this study. A main purpose of this pilot study was to determine the appropriateness and to validate these tools on accurately identifying attitudes and understandings of the participants.

A rubric was developed for the pre- and post-knowledge assessments to determine if each students' knowledge and understandings of the engineering design process changed. Pre- and post-surveys were tallied by one rater to identify if each student's attitudes and confidence changed over the course of their participation. General regression analysis using the results of the post-survey data and knowledge assessment data will also be analyzed to determine connections between self-assessed background knowledge and direct knowledge of the engineering design process.

Observations were used simply to provide insight as to how changes might have occurred. To maintain anonymity of each individual, aliases were used. The research was conducted on a strictly volunteer basis and no benefits were offered to the participants. The only benefit implicit in the study was to help continue the program and/or class running.

Results

The pilot study analyzed 12 STOMP participants and 7 *Prototyping Home Robots* participants at Tufts University over the course of the Fall 2006 semester. Pre-survey analysis of all the participants showed that the majority of the participants were caucasian (69%) and female (63%). The female population is not surprising considering Tufts boasts a 32 percent female engineering student body (twice the national average). Perhaps, also, participation in STOMP may make engineering more attractive for female students.

Students were at varying points in their schooling (16% seniors, 21% juniors, 26% sophomores, and 37% freshmen). The majority of the students at the time of the study had identified themselves as mechanical engineering majors (63%) [also identified were environmental (5%) and general engineering (32%)]. Also the majority of the STOMP participants were involved in an engineering society (67%) or had previous outreach experience (75%) as opposed to the *Prototyping Home Robots* students (29%).

Table I: Average participant self-analysis of their knowledge

0 – not very knowledgeable; 5 – very knowledgeable	Experimental			Control		
	Before	**After**	**Change**	**Before**	**After**	**Change**
National And State Mathematics, Science and Technology/Engineering Standards	2.27	2.82	0.55	2.57	3.14	0.57
Integrating engineering into K-12 science and math classrooms	2.09	3.82	1.73	2.86	3.86	1.00
Determining the relevant design features in building a project	2.82	3.73	0.91	2.14	4.43	2.29
The engineering design process	3.00	4.00	1.00	3.00	4.43	1.43
The types of considerations that must be taken into account when evaluating a solution to an engineering problem	2.91	3.91	1.00	2.57	4.14	1.57

The retrospective attitudinal and confidence analysis showed that the experimental and control groups were relatively similar in both their attitudes and confidence. Retrospective self-ratings of knowledge in specific areas related to engineering were similar ranging from a difference of 0.77 to 0 on a scale of 0 to 5. As seen in Table I, both groups made positive changes in every category analyzed. Experimental participants showed the most change in their ability to integrate engineering into K-12 science and math classrooms and showed the least improvement in knowing the national and state mathematics, science and technology/engineering standards. The control group also showed the least change in knowledge of the educational standards, but showed the most improvement in determining the relevant design features in building a project.

Table II: Average participant self-analysis of their attitudes and ability level (averages determined by giving levels numerical values in parentheses).

	Experimental		**Control**	
	Before	**After**	**Before**	**After**
How would you rank yourself in mathematics and science knowledge?	intermediate (2.08)	intermediate (2.25)	intermediate (2.00)	intermediate (2.00)
How would you rank yourself in engineering knowledge?	novice/intermediate (1.58)	intermediate (2.08)	novice/intermediate (1.57)	Intermediate (2.00)
Confidence towards your ability to teach/convey engineering concepts.	slightly confident (2.33)	moderately confident (3.08)	slightly confident (2.14)	moderately confident (3.00)
Attitude toward the subject of engineering.	positive (3.09)	positive (3.27)	positive/very positive (3.43)	very positive (3.71)
Attitude toward engineering classes.	positive (3.00)	positive (2.91)	positive (3.00)	positive (3.14)
Attitude toward your college experience as a whole.	positive (3.18)	positive (3.18)	positive (3.17)	positive (3.33)

Analysis of participant attitudes and ability level surrounding the area of engineering and the engineering design process revealed the groups as being virtually identical (Table II). Each aspect analyzed stayed the same or showed an improvement over the course of the study. The only difference apparent in the analysis was an overall more positive attitude of the control group toward the subject of engineering throughout the study.

Table IIIa: Knowledge assessment scores for the experimental group

STOMP

	Pre-Knowledge Assessment	**Post-Knowledge Assessment**	**Normalized gain**
Stacy	11	10	-11%
Mary	6	15	64%
Janet	13	15	29%
Ashley	6	12	43%
James	5	9	27%
Ian	6	4	-14%
Paul	10	10	0%
Lucy	11	9	-22%
Carol	4	4	0%
Robert	6	6	0%
Janice	8	10	17%
Beth	6	6	0%
AVG	**8.00**	**9.17**	10%

Analysis of the pre- and post-knowledge assessments completed by both the experimental and control groups showed a wide range of changes over the course of the semester (Tables IIIa & b). Participants in the experimental group showed an average positive change in their knowledge of the engineering design process of 1.27. Individual changes had a rather vast range from 9 to -2. Only 3 out of 11 experimental participants showed a negative change during the course of the study.

Table IIIb: Knowledge assessment scores for the control group

EN-10

	Pre-Knowledge Assessment	Post-Knowledge Assessment	Normalized gain
George	12	9	-38%
Kimberly	6	6	0%
Alice	8	4	-33%
Sue	5	9	27%
Melissa	5	9	27%
Bill	9	7	-18%
Jason	8	7	-8%
AVG	**10.71**	**7.29**	-37%

Participants in the control group showed an average negative change of -0.13. More than half (4 out of 7) participants showed a decrease in their knowledge of the engineering design process. Changes ranged from 4 to -4.

Discussion

From the attitudinal and confidence surveys, it is evident that the experimental and control groups are similar in nature. Both groups have identified themselves to be on a similar ability level, similar confidences toward engineering related concepts, and similar positive attitudes toward engineering.

The groups do differ slightly on which areas they improved most. The control group improved the most in determining the relevant design features in building a project; as opposed to the experimental group which improved most on their ability to integrate engineering into K-12 science and math classrooms. These results are easily explained when the focus and design of each group is investigated. The *Prototyping Home Robots* class is designed to introduce students to the engineering design process and help them learn how to go about solving an engineering problem. STOMP on the other hand, is designed to encourage students to revisit and rethink what they learned within their classrooms to assist them in integrating this knowledge into a K-12 situation. New knowledge on how to solve a problem is not learned through STOMP; rather knowledge learned previously is revisited and practiced in order to understand it more clearly.

From the knowledge assessments it would appear that the experimental group increased their understanding of the engineering design process. The key to the improvement may lie within the requirement of STOMP participants to communicate the design process in basic steps to younger students. This encourages them to examine more fully questions like how to breakdown problems, how to encourage students to ask questions about a presented challenge, how to convey the merit of brainstorm ideas, how to take information from a failed test and incorporate it into a redesign, and so forth. This aspect is unique to participating in educational outreach. The control group that did not have this aspect actually produced a minute degradation of understanding about the engineering design process from the knowledge assessments. Self-reported assessments form the retrospective survey produced an opposite effect. It is difficult to believe that a class that introduces engineering design as a subject produces a degradation in students' understanding of the subject putting in jeopardy the validity of the assessments. A re-evaluation of the knowledge assessments used in the study will be conducted before future research to determine the incongruity between the students' self-reported gains and the measured gains from the knowledge assessments.

Observational data of the experimental participants showed a high number of students contemplating their answers and constantly attempting to elaborate on their explanations to the K-12 students. Control group students did not require the need to re-evaluate what it was that they learned about the engineering design process. Discussion about the topic was at most elaborated simply within their group consisting of no more than 3 students.

Results are not conclusive at this time due to the incongruity in the data as well as the small sample size. It can however be at least initially implied that the results do show the possibility of participation in STOMP as being beneficial towards understanding the engineering design process.

Conclusions & Future Work

Educational outreach in undergraduate engineering education has an opportunity to be an extremely beneficial experience for participants, teachers, and students. It cannot be surmised that such an experience will be beneficial for all students. Working with K-12 students and teachers can be a terrifying notion to many resulting in more harm than good for the K-12 system; however, this study indicates the possibility of implementing such a program as being beneficial for some. The pilot study in essence then can be slated as a success. For those students who did participate, on average the teaching experience increased their understandings of the engineering design process and positively changed attitudes and confidences toward engineering. The pilot study also identifies the need for many changes to be applied in order to produce more salient results. The future of this project will require the involvement of a larger population spanning out to multiple universities in order to obtain statistically significant results as well as results that can be applicable to situations outside of Tufts University. Knowledge assessments must be redesigned so as to remove any gender bias that may exist as well as to ensure equivalence between questions on the pre- and post assessments. Modifications are currently being worked on using participant feedback. Participant feedback will also be collected to determine their interpretation of the items before administering the surveys. Future assessment of the surveys and knowledge assessment will be performed using a group of experts in the field ensuring interrater reliability. With the changes made, the results should show ultimately how beneficial or not participation in a program like STOMP really is.

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Appendix I: Pre-Survey

Participant Information:

This information will be separated from your survey answers and is only to gather background data about the range of participants in the study. Your answers will remain confidential. All questions are optional.

Name: __________________________ Date: __________________________

Date of Birth: ________________ Gender (circle): Male Female

Ethnic Background (check most applicable):

- ___ Caucasian
- ___ African American
- ___ Asian and Pacific Islander
- ___ Hispanic
- ___ American Indian
- ___ Other ______________________
- ___ Prefer Not To Answer

School currently attending: ____

Major (if applicable): _____________________ Projected Graduation year: _____________

I am involved in (check all that apply and specify in space provided):

- ___ STOMP ____
- ___ An Engineering Society ____
- ___ An Introductory Engineering class ____
- ___ An internship or co-op ____

Have you ever participated in service learning (educational outreach, internship, co-op, community service, etc…) before?

☐ no ☐ yes If yes, when and where? ____

TO BE FILLED OUT BY THE INVESTIGATORS

Alias: ______________________________ ID#: ________________________________

Appendix II: Post-Survey

This is a retrospective survey which allows you to self-identify your knowledge, attitudes and confidence before your experience (involvement in STOMP, an engineering society, an internship, etc…) and after your experience.

Name: ___________________________ Date: ___________________________

Please rate your knowledge of the following topics before and after your experience:
(1 = not at all knowledgeable 5 = very knowledgeable)

Before		After
1 2 3 4 5	National and State Mathematics, Science and Technology/Engineering Standards	1 2 3 4 5
1 2 3 4 5	Integrating engineering into K-12 science and math classrooms	1 2 3 4 5
1 2 3 4 5	Determining the relevant design features in a building project	1 2 3 4 5
1 2 3 4 5	The engineering design process	1 2 3 4 5
1 2 3 4 5	The types of considerations that must be taken into account when evaluating a solution to an engineering problem	1 2 3 4 5

How would you rank yourself in mathematics and science knowledge?

Before:
- ☐ novice
- ☐ intermediate
- ☐ expert

After:
- ☐ novice
- ☐ intermediate
- ☐ expert

How would you rank yourself in engineering knowledge?

Before:
- ☐ novice
- ☐ intermediate
- ☐ expert

After:
- ☐ novice
- ☐ intermediate
- ☐ expert

Confidence toward your ability to teach/convey engineering concepts:

Before:
- ☐ Very confident
- ☐ Moderately confident
- ☐ Slightly confident
- ☐ Not confident

After:
- ☐ Very confident
- ☐ Moderately confident
- ☐ Slightly confident
- ☐ Not confident

Attitude toward the subject of engineering:

Before:
- ☐ Very Positive
- ☐ Positive
- ☐ Negative
- ☐ Very Negative

After:
- ☐ Very Positive
- ☐ Positive
- ☐ Negative
- ☐ Very Negative

Attitude toward engineering classes:

Before:
- ☐ Very Positive
- ☐ Positive
- ☐ Negative
- ☐ Very Negative

After:
- ☐ Very Positive
- ☐ Positive
- ☐ Negative
- ☐ Very Negative

Attitude toward your college experience as a whole:

Before:
- ☐ Very Positive
- ☐ Positive
- ☐ Negative
- ☐ Very Negative

After:
- ☐ Very Positive
- ☐ Positive
- ☐ Negative
- ☐ Very Negative

Check all the options that would describe your specific experience:

- ☐ positive
- ☐ beneficial
- ☐ useful
- ☐ worth-while
- ☐ good but not great
- ☐ educational
- ☐ negative
- ☐ waste of time
- ☐ useless
- ☐ pointless
- ☐ eye opening
- ☐ other: ______________________

Appendix III: Pre-Knowledge Assessment

1. How would you proceed in beginning this project?

2. Here are two example pencil boxes built by other companies. Critique the following designs. What are the advantages and disadvantages of both? What, if any, changes would you make? Which do you like better and why?

3. If given the following materials options to build the pencil box, which option would you choose and why?
    a. LEGO bricks
    b. Straws and tape
    c. Wood
    d. Metal rods, nuts and bolts

4. After building your first prototype, you test the box and it falls apart. What do you do next?

Appendix IV: Post Knowledge Assessment

1. How would you proceed in beginning this project?

2. Here are two example **CARS** built by other companies. Critique the following designs. What are the advantages and disadvantages of both? What, if any, changes would you make? Which do you like better and why?

3. If given the following materials options to build the car, which option would you choose and why?
   a. An assortment of LEGO pieces
   b. Straws and tape
   c. Wood
   d. Metal rods, nuts and bolts

4. After building your first prototype, you test the car and it falls apart. What do you do next?