AC 2010-49: STUDENT ATTITUDES TOWARDS DESIGNING EXPERIMENTS

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Student Attitudes towards Designing Experiments

Abstract

The broad objective of this research is to contribute to our understanding of how mechanical engineers learn to design and conduct experiments. Specifically, this study investigated undergraduate student attitudes towards the design of open-ended experimental projects, and how these attitudes are different among freshmen, juniors and seniors. Freshman, junior, and senior mechanical engineering students all were given the same open-ended experimental design problem as part of required laboratory courses. The objective of the assignment was to design, construct, and conduct an experiment to determine the relationships between factors that affect the forces on a wooden beam that supports the weight of a person. Pre- and post-surveys were administered regarding student attitudes towards the problem. The surveys were statistically analyzed to identify similarities and differences within and between the student groups. Focus groups were also conducted to supplement the survey data.

Before designing the experiment, the freshmen and juniors differed in their attitudes towards the experimental design but felt the same afterwards. The freshmen were more frustrated and felt negatively towards the assignment initially. Pre/post analysis revealed no significant change in the freshman's negative attitudes. Initially, the juniors expressed positive feelings. However, after designing and performing the experiment, the juniors liked the assignment less. Their positive attitudes decreased to match the freshmen. The junior and senior attitudes were similar before designing the experiment. However, unlike the juniors, the seniors became more positive after the assignment was complete.

The unexpected effects of the experimental design experience that occurred with the junior students are of interest. The juniors initially felt they understood how to design an experiment but after performing it, they did not. On the pre-survey, 95% felt the task description was adequate compared to only 43% in the post-survey. Before completing the experiment, 19% of the juniors did not like the open-ended nature but 62% did not like the open-ended nature after performing the experiment. Finally, 14% of the juniors were frustrated with the lack of direction of the assignment before performing the experiment and 62% were frustrated after performing the experiment. It was observed from the focus group that initially the juniors were not affected negatively by the task, but ended up completing the assignment with a sense of opposition. The results suggest that the juniors initially thought it would be easy to design an experiment, but discovered that they did not know how to proceed. It is suggested that this may be attributed to the nature of the science laboratory courses taken by freshmen and sophomores at this institution, which consist largely of cookbook experiments. The results of this investigation indicate a need for exposure to engineering experimental design processes sooner in the student's academic career.

Introduction

The goal of this research is to contribute to our understanding of how students learn to design experiments. This study focuses specifically on student attitudes towards an open-ended design project because attitudes are important to issues of self-efficacy and persistence to complete difficult assignments. At many universities, undergraduate mechanical engineering students take chemistry, physics and other science courses in which experiments have cookbook instructions and fill in the blank answers. These experiments do not contribute to experimental design skill development. They may in fact hinder it because performing experiments is not the same as designing them. Many students come to engineering laboratory courses expecting step-by-step experiment directions and, as this study will show, many of those students are therefore frustrated with the open-ended nature of experimental design.

A goal of academic institutions is to prepare their students for the 'real world' with adequate skills and knowledge. Much criticism is centered on the engineering curriculum, particularly its neglect of engineering design[1]. In order to assess the various methods to teach design, we first must identify the student's attitudes towards open-ended design problems. Engineering design problems are often characterized as ambiguous, ill-defined, and having multiple solutions that can satisfy a problem's requirements.[2] Engineering design differs from mathematics or science problem solving in three primary ways: design is a goal-oriented activity[3], the "stopping point" is neither systematic nor definitive, and the process is repetitive in which the designer incrementally advances upon a particular solution[2-4].

Subjects

The subjects of this study included freshman, junior, and senior mechanical engineering students in a department of mechanical engineering at a state-supported flagship university. This subject sample was used due to convenience. During the time of data collection, each group of students was enrolled in a required mechanical engineering laboratory course. There were 30 freshman students enrolled in ENCP 101, Introduction to Engineering, and in their first semester of the engineering program. The 21 juniors included were enrolled in EMCH 361, Measurements and Instrumentation, generally taken in the sixth semester. There were 42 senior students in the last semester of their engineering program enrolled in EMCH 467, Mechanical Engineering Laboratory.

Methodology

A quasi-experimental approach was used for this research, in which the students in the freshman, junior and senior year were all given the same assignment. Specifically, the three groups of students were given an open-ended engineering problem. Each group was also administered the same two surveys, pre and post, regarding their attitudes towards the problem. The surveys were then statistically analyzed to identify similarities and differences within and between the groups.

The student assignment was to design, construct, and conduct an experiment to determine the relationships between factors that affect the forces on a wooden beam that supports the weight of a person. An example of this assignment is located in the Appendix. All students were given the

same assignment document, with the exception that due dates were adjusted to fit the timing of the course.

The protocols developed to collect data from the students included two surveys (pre and post) and a set of focus group questions. The surveys were used to document the students' attitudes towards the open-ended problem description. They contained Likert scale questions that were scaled strongly disagree, disagree, agree, and strongly agree. These questions were used as feedback of the students' attitudes towards the design problem.

The pre-survey was administered to the students after the problem description was handed out. The students were asked to complete the pre-survey based on their impression of the assignment and their previous knowledge of designing experiments. The students were then asked to produce an experimental design report detailing their experiment as part of their laboratory coursework. After completing the first report, the students conducted their experiments based on their documented ideas. The students were grouped based on similarities in their experimental design reports (materials, variables, etc.) when they conducted their experiments. Following the implementation of their experiments, the students produced a final design report to present their findings. The students then completed the post-survey and focus group.

The pre-survey consisted of 10 Likert scale questions that can be seen in Table 1. Each question used in the pre-survey was given a letter for simplicity during analysis. Demographic information collected in the pre-survey was gender, age, previous year enrollment, and previous coursework. This information was collected and used to describe the subject groups.

TABLE 1 PRE-SURVEY QUESTIONS WITH CORRESPONDING ANALYSIS LETTERS

Before designing the experiment:	
A	I have a good understanding of how to design experiments.
B	I feel the task description was adequate.
C	I understand the purpose of the experiment.
D	I understand the physical set-up that I will need to use.
E	I can identify all of the variables to be manipulated, responding or controlled.
F	I can plan a procedure including all of the steps necessary to perform the experiment.
G	I feel confident that my experimental design report will be thorough.
H	I feel the task description did not contain enough information to design an experiment.
I	I like the open-ended nature of this assignment.
J	I am frustrated with the lack of direction of this assignment.

The post-survey contained 21 Likert scale questions: the 10 questions from the pre-survey and an additional 11 Likert scale questions. The post-survey questions can be seen in Table 2. The lettered questions were those asked in both the pre- and post-survey while the numbered questions were asked only in the post-survey. The additional post-survey questions were asked in two sets. The first six required the students to be retrospective to while performing the experiment. The remaining five were asked about their then current attitudes. To check the validity of the surveys, positive and negative forms of the same questions were asked. For example see questions B and H in Table 2.

TABLE 2 POST-SURVEY QUESTIONS WITH CORRESPONDING ANALYSIS LETTERS AND NUMBERS

While performing the experiment:	
1	I discovered that I did not understand the purpose of the experiment.
2	I changed the experimental set-up from what was planned.
3	I used different measurement instruments from what was planned.
4	I modified the experimental procedure from what was planned.
5	I used different data tables from what was plaed.
6	I discovered that my experimental design was not thorough.
After performing the experiment:	
A	I have a good understanding of how to design experiments.
B	I feel the task description was adequate.
C	I understand the purpose of the experiment.
D	I understand the physical set-up that I will need to use.
E	I can identify all of the variables to be manipulated, responding or controlled.
F	I can plan a procedure including all of the steps necessary to perform the experiment.
G	I feel confident that my experimental design report will be thorough.
H	I feel the task description did not contain enough information to design an experiment.
I	I like the open-ended nature of this assignment.
J	I am frustrated with the lack of direction of this assignment.
After performing the experiment, I discovered:	
7	Designing the experiment before performing it was helpful.
8	Other students had better designs than I did.
9	Performing the experiment before designing it would have been helpful.
10	I have a good understanding of how to design experiments.
11	I am well prepared to design experiments in the future.

Focus group interviewing with each group of students was conducted to supplement the pre- and post-survey questions and check the reliability of the surveys. The focus group questions were: (1) How do you design an experiment, (2) What steps did you use in designing your experiment, (3) How well did your plan or procedure work, (4) How did you determine your variables, (5) How did you select measurement tools, (6) What problems did you have with this experiment, (7) What did you change about your experiment, (8) What types of experiments have you done, and (9) What skills/knowledge are most important to have to design experiments? Each class of students was divided into two focus groups and asked each question listed above. The focus groups were allotted twenty minutes during their regular lecture meeting times. The sessions were recorded and then transcribed.

Results

A summary of the data for the Likert scale attitude questions from the pre- and post-surveys can be seen in Tables 3 through 8. In order to compare across groups with different sample sizes, the results were normalized by the total number of surveys per group (30 freshman, 21 junior, 42 senior) and multiplied by 100. Table 3 shows the results of the freshman pre-survey Likert scale questions. The freshmen felt they had a good understanding of how to design experiments and the physical set-up they would use. They also reported they understood the purpose, could identify all the variables, plan a procedure, and felt confident in presenting their experimental design. The majority felt the task description was adequate but were frustrated with the lack of direction of the assignment while roughly half liked the open-ended nature of the assignment.

TABLE 3 FRESHMAN PRE-SURVEY LIKERT SCALE RESULTS

Question	Strongly Disagree	Disagree	Agree	Strongly Agree
I have a good understanding of how to design experiments.	0%	13%	80%	7%
I feel the task description was adequate.	0%	41%	55%	3%
I understand the purpose of the experiment.	10%	20%	60%	10%
I understand the physical set-up that I will need to use.	3%	10%	70%	17%
I can identify all of the variables to be manipulated, responding or controlled.	3%	24%	62%	10%
I can plan a procedure including all of the steps necessary to perform the experiment.	0%	27%	63%	10%
I feel confident that my experimental design report will be thorough.	0%	27%	63%	10%
I feel the task description did not contain enough information to design an experiment.	0%	57%	40%	3%
I like the open-ended nature of this assignment.	7%	50%	37%	7%
I am frustrated with the lack of direction of this assignment.	7%	31%	55%	7%

Table 4 shows the results of the freshman post-survey Likert scale questions. After designing and performing the experiment, the freshmen reported they understood how to design an experiment, understood the purpose, could identify all the variables, felt confident in presenting their design, changed their set-up, and felt well prepared to design experiments in the future. A majority of the freshmen felt the task description was adequate, liked the open-ended nature, and were not frustrated with the lack of direction. They did not use different measurement tools, modify their experimental procedure, use different data tables, or feel other students had better designs. The freshmen also reportedly discovered their experimental design was thorough. All of the freshmen agreed/strongly agreed that they understood the physical set-up, could plan a procedure, and that designing the experiment before performing it was helpful. Additionally, all of the freshmen disagreed/strongly disagreed with the statement "while performing the experiment, I discovered that I did not understand the purpose of the experiment." At least 90% of the freshmen agreed/strongly agreed that they have a good understanding of how to design experiments and feel well prepared to design experiments in the future.

TABLE 4 FRESHMAN POST-SURVEY LIKERT SCALE RESULTS

Question	Strongly Disagree	Disagree	Agree	Strongly Agree
I have a good understanding of how to design experiments.	0%	13%	70%	17%
I feel the task description was adequate.	0%	33%	63%	3%
I understand the purpose of the experiment.	0%	17%	83%	0%
I understand the physical set-up that I will need to use.	0%	0%	63%	37%
I can identify all of the variables to be manipulated, responding or controlled.	0%	17%	63%	20%
I can plan a procedure including all of the steps necessary to perform the experiment.	0%	0%	87%	13%
I feel confident that my experimental design report will be thorough.	0%	23%	57%	20%
I feel the task description did not contain enough information to design an experiment.	7%	53%	40%	0%
I like the open-ended nature of this assignment.	10%	30%	47%	13%
I am frustrated with the lack of direction of this assignment.	10%	47%	43%	0%
I discovered that I did not understand the purpose of the experiment.	23%	77%	0%	0%
I changed the experimental set-up from what was planned.	13%	13%	50%	23%
I used different measurement instruments from what was planned.	27%	43%	27%	3%
I modified the experimental procedure from what was planned.	10%	30%	47%	13%
I used different data tables from what was planed.	17%	37%	40%	7%
I discovered that my experimental design was not thorough.	13%	60%	27%	0%
Designing the experiment before performing it was helpful.	0%	0%	80%	20%
Other students had better designs than I did.	0%	55%	45%	0%
Performing the experiment before designing it would have been helpful.	20%	70%	10%	0%
I have a good understanding of how to design experiments.	0%	7%	83%	10%
I am well prepared to design experiments in the future.	0%	10%	80%	10%

Table 5 shows the results of the junior pre-survey Likert scale questions. The juniors agreed that they had a good understanding of how to design experiments. They also felt they understood the purpose and physical set-up, could identify all the variables, could plan a procedure and liked the open-ended nature. However, they were frustrated with the lack of direction of the assignment. The majority of the juniors also felt confident in presenting their design report while all felt the task description did not contain enough information to design an experiment.

TABLE 5 JUNIOR PRE-SURVEY LIKERT SCALE RESULTS

Question	Strongly Disagree	Disagree	Agree	Strongly Agree
I have a good understanding of how to design experiments.	5%	24%	71%	0%
I feel the task description was adequate.	0%	5%	90%	5%
I understand the purpose of the experiment.	0%	14%	71%	14%
I understand the physical set-up that I will need to use.	0%	14%	71%	14%
I can identify all of the variables to be manipulated, responding or controlled.	0%	19%	71%	10%
I can plan a procedure including all of the steps necessary to perform the experiment.	0%	24%	71%	5%
I feel confident that my experimental design report will be thorough.	0%	43%	52%	5%
I feel the task description did not contain enough information to design an experiment.	5%	95%	0%	0%
I like the open-ended nature of this assignment.	0%	19%	71%	10%
I am frustrated with the lack of direction of this assignment.	5%	81%	14%	0%

Table 6 shows the post-survey Likert scale results for the junior students. After turning in their lab reports, the juniors indicated they understood how to design experiments and the purpose of the experiment. They were able to identify all the variables, plan a procedure, and felt the task description was not adequate. They reported that while performing the experiment, they changed their set-up but did not use different measurement instruments from what was planned. After performing the experiment, they felt designing it before performing it was helpful. The majority of juniors felt confident in presenting their design, disliked the open-ended nature, and was frustrated with the lack of direction of the assignment. The majority also modified their experimental procedure and felt other students had better designs but felt well prepared to design experiments in the future. Roughly half the juniors used different data tables and reportedly discovered their experimental design was not thorough. All of the juniors understood the physical set-up while at least 90% of them agreed/strongly agreed that they understood the purpose, could identify all the variables, and could plan a procedure with all the necessary steps to perform the experiment. At least 90% of the juniors disagreed/strongly disagreed that they did not understand the purpose of the experiment and that they used different measurement instruments than what was planned while performing the experiment.

Table 7 shows the pre-survey Likert scale results for the senior group. The students had a good understanding of: how to design experiments, the purpose of the experiment and the physical set-up. They were not frustrated with the lack of direction and the majority liked the open-ended nature of the assignment. The juniors felt the task description was adequate, could identify the variables, plan a procedure and felt confident in presenting their design.

TABLE 6 JUNIOR POST-SURVEY LIKERT SCALE RESULTS

Question	Strongly Disagree	Disagree	Agree	Strongly Agree
I have a good understanding of how to design experiments.	0%	14%	86%	0%
I feel the task description was adequate.	10%	48%	43%	0%
I understand the purpose of the experiment.	5%	0%	86%	10%
I understand the physical set-up that I will need to use.	0%	0%	76%	24%
I can identify all of the variables to be manipulated, responding or controlled.	0%	5%	81%	14%
I can plan a procedure including all of the steps necessary to perform the experiment.	0%	5%	95%	0%
I feel confident that my experimental design report will be thorough.	10%	24%	67%	0%
I feel the task description did not contain enough information to design an experiment.	0%	86%	5%	10%
I like the open-ended nature of this assignment.	10%	52%	29%	10%
I am frustrated with the lack of direction of this assignment.	5%	33%	38%	24%
I discovered that I did not understand the purpose of the experiment.	29%	67%	0%	5%
I changed the experimental set-up from what was planned.	5%	24%	57%	14%
I used different measurement instruments from what was planned.	19%	76%	5%	0%
I modified the experimental procedure from what was planned.	0%	33%	48%	19%
I used different data tables from what was planed.	5%	43%	43%	10%
I discovered that my experimental design was not thorough.	0%	48%	43%	10%
Designing the experiment before performing it was helpful.	5%	10%	62%	24%
Other students had better designs than I did.	0%	43%	48%	10%
Performing the experiment before designing it would have been helpful.	10%	57%	24%	10%
I have a good understanding of how to design experiments.	0%	24%	76%	0%
I am well prepared to design experiments in the future.	10%	24%	67%	0%

TABLE 7 SENIOR PRE-SURVEY LIKERT SCALE RESULTS

Question	Strongly Disagree	Disagree	Agree	Strongly Agree
I have a good understanding of how to design experiments.	0%	10%	83%	7%
I feel the task description was adequate.	2%	19%	71%	7%
I understand the purpose of the experiment.	0%	10%	69%	21%
I understand the physical set-up that I will need to use.	0%	7%	67%	26%
I can identify all of the variables to be manipulated, responding or controlled.	0%	21%	67%	12%
I can plan a procedure including all of the steps necessary to perform the experiment.	0%	14%	71%	14%
I feel confident that my experimental design report will be thorough.	2%	21%	55%	21%
I feel the task description did not contain enough information to design an experiment.	7%	64%	29%	0%
I like the open-ended nature of this assignment.	2%	39%	49%	10%
I am frustrated with the lack of direction of this assignment.	19%	55%	24%	2%

Finally, Table 8 shows the senior post-survey Likert scale results. All the seniors understood the physical set-up while roughly half modified their procedures and used different data tables after performing the experiment. Ninety percent of the seniors disagreed/strongly disagreed that they did not understand the purpose of the experiment. At least 90% of the seniors agreed/strongly agreed they could plan a procedure and all agreed/strongly agreed they understood the physical set-up of the experiment. The seniors were mainly not frustrated with the lack of direction after completing the assignment and the majority liked the open-ended nature of the assignment. While performing the experiment, they did not use different measurement instruments and the majority felt they did not change their experimental set-up. After performing the experiment, the seniors did not feel other students had better designs but 98% agreed/strongly agreed that designing the experiment before performing it was helpful. The majority also felt the task description was adequate and well prepared to design experiments in the future.

TABLE 8 SENIOR POST-SURVEY LIKERT SCALE RESULTS

Question	Strongly Disagree	Disagree	Agree	Strongly Agree
I have a good understanding of how to design experiments.	2%	7%	79%	12%
I feel the task description was adequate.	2%	29%	60%	10%
I understand the purpose of the experiment.	0%	14%	67%	19%
I understand the physical set-up that I will need to use.	0%	0%	48%	52%
I can identify all of the variables to be manipulated, responding or controlled.	0%	12%	48%	40%
I can plan a procedure including all of the steps necessary to perform the experiment.	0%	5%	74%	21%
I feel confident that my experimental design report will be thorough.	0%	26%	60%	14%
I feel the task description did not contain enough information to design an experiment.	14%	69%	14%	2%
I like the open-ended nature of this assignment.	7%	26%	50%	17%
I am frustrated with the lack of direction of this assignment.	21%	57%	17%	5%
I discovered that I did not understand the purpose of the experiment.	40%	50%	10%	0%
I changed the experimental set-up from what was planned.	26%	31%	38%	5%
I used different measurement instruments from what was planned.	31%	45%	17%	7%
I modified the experimental procedure from what was planned.	17%	29%	43%	12%
I used different data tables from what was planed.	21%	31%	36%	12%
I discovered that my experimental design was not thorough.	36%	48%	17%	0%
Designing the experiment before performing it was helpful.	0%	2%	83%	14%
Other students had better designs than I did.	12%	63%	24%	0%
Performing the experiment before designing it would have been helpful.	19%	60%	12%	10%
I have a good understanding of how to design experiments.	0%	17%	74%	10%
I am well prepared to design experiments in the future.	0%	20%	66%	15%

Discussion

Pre/Post Analysis

The results discussed above provided general attitudes towards the experimental design experience, but statistical analysis was necessary to find any significant changes in responses to the survey questions. The pre and post Likert scale responses for each group of students were statistically tested for a change in the median using MiniTab 14 statistical software and the Mann Whitney test.

Analyzing the ten common pre/post responses with the Mann Whitney test, there was not statistical significant changes in the freshman's attitudes from before designing to after performing the experiment. Three statistically significant pre/post changes in the junior responses were found. These were associated with the following questions: (a) I feel the task description was adequate, (b) I like the open-ended nature of this assignment, and (c) I am frustrated with the lack of direction of this assignment. From pre- to post-survey, the junior responses for the first two questions listed decreased in agreement, while the answers to the third increased in agreement. The juniors felt they understood how to design an experiment but after performing it, only 43% felt the task description was adequate compared to 95% in the pre-survey. Before completing the experiment, 19% of the juniors did not like the open-ended nature but 62% did not like the open-ended nature after performing the experiment. Finally, 14% of the juniors were frustrated with the lack of direction of the assignment before performing the experiment and 62% were frustrated after performing the experiment. It was observed from the focus group that initially the juniors were not affected negatively by the task, but completed the assignment with a sense of opposition. The juniors were asked what the hardest part of designing an experiment was and some responses included: "analyzing the data", "the whole thing was frustrating", and "it was a pain and doesn't make sense right now."

Two statistically significant pre/post changes in the senior responses were found. These were associated with the following questions: (a) I understand the physical set-up that I used and (b) I identified all of the variables to be manipulated, responding, or controlled. From pre- to post-survey, both scaled responses of the two listed questions increased in agreement. From the focus group, the seniors felt they understood how to design an experiment better and appreciated the context of the assignment because it related to the 'real world' better than other laboratory assignments. The seniors generally liked the design an experiment assignment.

Comparison Between Groups

After comparing within each group, analysis was completed across groups. Comparison between the freshmen and seniors resulted in three significant findings from the following questions: (a) Before designing the experiment, I understand the purpose of the experiment, (b) Before designing the experiment, I am frustrated with the lack of direction of this assignment, and (c) While performing the experiment, I changed the experimental set-up from what was planned. The freshman students agreed more with the second and third questions and the seniors agreed more with first question. Both groups felt the task description was adequate while 20% more seniors felt they understood the purpose. The freshmen and seniors both liked the open-ended nature of the assignment, but the 36% more freshmen were frustrated with the lack of direction before performing the experiment. Both the freshmen and seniors understood the physical set-up for the assignment but 30% more freshmen changed their set-up while performing the experiment.

Analysis between the freshmen and juniors resulted in four significant changes all from the pre-survey and none from the post-survey. These significant changes had the he header "Before designing the experiment" and were as follows: (a) I feel the task description was adequate, (b) I feel the task description did not contain enough information to design an experiment, (c) I like the open-ended nature of this assignment, and (d) I am frustrated with the lack of direction of this assignment.

The junior students agreed more with the first and third questions while the freshman agreed more with the second and fourth questions. The freshmen and juniors both felt they understood how to design an experiment but 36% more juniors felt the task description was adequate. Thirty-eight percent more of the junior students liked the open-ended nature of the assignment while 48% more freshmen were frustrated with the lack of direction before designing the experiment.

Before designing the experiment, the freshmen and juniors differed in their attitudes towards the experimental design but felt the same afterwards. The freshmen were more frustrated and felt negatively towards the assignment initially. After designing and performing the experiment, the juniors liked the assignment less. Their positive attitudes decreased to match the freshmen, whose pre/post analysis revealed no significant change.

The results indicate the freshmen were more frustrated with the lack of direction of the assignment and this was also supported by the focus groups. An example of freshman statement from the focus group is "It was too open-ended and I like steps or some type of task instead of just the open ended." Another freshman student stated, "I don't know what I tested for, to be

very honest with you. I was just going through the motions and I had no idea what was going on." The majority of the juniors were also frustrated with the lack of direction, but not as much as the freshmen initially. From the focus group, a junior student said, "It was overwhelming at first, just the open-endedness of it. I've never had an assignment where you design whatever you want." More of the junior students liked the open-ended natured and stated that "it is more applicable to real life situations."

Comparison between the junior and senior students resulted in five significant changes in scaled responses all from the post survey. The first two questions have the heading "After performing the experiment," the third and fourth questions have the heading "while performing the experiment," and the final question heading reads "after performing the experiment. The questions are as follows: (a) I feel the task description was adequate, (b) I was frustrated with the lack of direction of this assignment, (c) I changed the experimental set-up from what was planned, (d) I discovered that my experimental design was not thorough, and (e) I discovered other students had better designs than I did. The senior students agreed more that the task description was adequate while the junior students were more frustrated, changed their experimental set-up more, and felt their experimental design was not thorough.

The junior and senior student analysis did not reveal any significant changes in the pre-survey questions. Before designing the experiment, the two groups both agreed they understood how to design an experiment and felt the task description was adequate. They also liked the open-ended nature and were not frustrated with the lack of direction before designing the experiment. While performing the experiment, 28% more juniors changed their set-up and 35% more discovered their experimental design was not thorough. After designing and performing the experiment, 26% more seniors felt the task description was adequate. Also, 33% more juniors felt other students had better designs than themselves. The junior and senior attitudes were similar before designing the experiment. After performing, the senior attitudes became more positive while the junior attitudes became more negative towards open-ended experimental design.

Conclusions

This research explored student attitudes towards an open-ended design project. The students were surveyed about their attitudes towards design before and after completing the open-ended experimental design problem. Their general attitudes were statistically analyzed and significant differences between the classes were found.

The most unexpected effects from the experimental design experience occurred with the junior students. Before designing and performing the experiment, 95% of the juniors agreed/strongly agreed that the task description was adequate. After completing the assignment, only 43% agreed/strongly agreed; more than half of the group changed their opinions during the course of the experiment. Another change amongst the junior students similarly revolved around their opinion of the open-ended nature of the assignment. Before beginning, 19% of the juniors did not like the open-ended nature and 62% did not like it afterwards. Forty-three percent more juniors who liked the open problem initially changed their minds after designing the experiment. After performing the experiment, 60% of the freshmen and 67% of the seniors liked the open-ended nature while 43% of the freshmen and only 22% of the seniors were frustrated with the

lack of direction from the task description. Many of the juniors negatively changed their feelings towards the experimental design experience unlike the freshmen and seniors.

The freshman students were the most frustrated initially with the assignment, but the juniors were most frustrated afterwards. In general, the seniors felt they learned from the experience and liked the assignment. Almost all of the freshmen felt they had a better understanding of how to design experiments, along with 67% of the juniors, after completing the assignment. The juniors felt they understood how to design experiments, could design in the future, and liked designing before performing the experiment but thoroughly disliked the open-ended nature and task description.

It is suggested that these findings may be attributed to the nature of the science laboratory courses taken by freshmen and sophomores at this institution, which consist largely of cookbook experiments. The results of this investigation indicate a need for exposure to engineering experimental design processes sooner in the student's academic career.

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2. Adams, R. & Atman, C.J., "Characterizing engineering student design processes: An illustration of iteration," Proceedings of the Annual American Society for Engineering Education Conference, 2000.
3. Gero, J.S., "Design prototypes: A knowledge representation schema for design," AI Magazine, 11 (4), pp. 26-36, 1990.
4. Eekels, J. & Roozenburg, N.F., "A methodological comparison of the structures of scientific research and engineering design: Their similarities and differences," Design Studies, 12 (4), pp. 197-203, 1991.

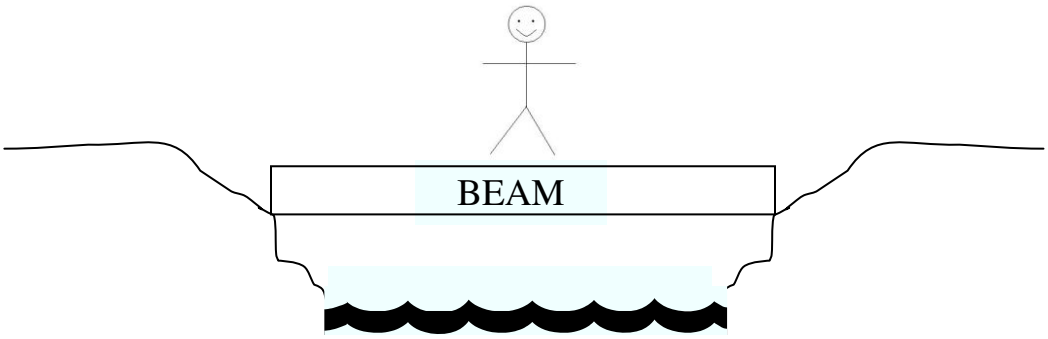
Appendix

"Design-a-Lab" Project

Fall 2008

TASK DESCRIPTION

You are to design, construct, and conduct an experiment to determine the relationships between factors that affect the forces on a wooden beam that supports the weight of a person. The forces come from the person and the end supports.



REPORTS

You will report your progress with two reports. The first report is an individually-written Experimental Design Report that includes the following sections:

- Objective: Describe the purpose of the experiment.
- Instrumentation: Describe the planned physical set-up, equipment and measurement instruments. Include a schematic or sketch of the set-up.
- Procedures: Describe the factors and variables that will be controlled, changing and responding. Describe the planned experimental procedures. Include one or more data collection tables.

Your second report is a team-written Final Report that includes the following sections:

- Objective: Describe the purpose of the experiment.
- Instrumentation: Describe the actual physical set-up, equipment and measurement instruments. Include a schematic or sketch of the set-up.
- Procedures: Describe the factors and variables that were controlled, changing and responding. Describe the actual experimental procedures.
- Results: Describe the data you collected. Include data tables and graphs of the results.
- Discussion: Describe the trends in the data, and sources and magnitudes of errors,
- Conclusion: Restate significant findings, make recommendations for future work.

SCHEDULE AND DEADLINES

- Friday, Sept. 12: Experimental Design Report Due.
- Monday, Sept. 15: Design, construct, and run experiment, and write report.
- Monday, Sept 22: Final Report Due.