Improving First-Year Engineering Students' Design and Teamwork Skills

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***Abstract*— In this paper, we introduced design education concepts to a first-year engineering course. The new content was added to an existing project to help students make more informed decisions in their project. The project was a team-based project in which students were asked to build a wind turbine. Students were supposed to design and build the turbine structure. Before students started building the structure, they were introduced to the design concepts and engaged in in-class activities including concept generation and concept reduction. Students perceptions of the usefulness of the new content/lecture was overall positive. There were no significant differences between the two weeks of activities based on the student response. The most frequent positive comments were related to group activities. Students also liked clear instructions and sketching of the design. Positive student feedback was more frequent than negative ones, indicating they do not agree on the negative aspects of the lectures/activities. One of the frequent negative feedback was related to busy PowerPoint slides.**

Keywords—design education, team-based learning, project-based learning, first-year engineering

I. Introduction

The overall objective of the current study is to revisit the content of an existing engineering pipeline course at the college of engineering in a minority serving institution and tailor it to provide early engineering design and team-working skills to the students at freshman level. In the previous scenario, these topics were taught later in their curriculum and this created several problems in their learning of these concepts. Learning engineering design earlier is especially beneficial for first-generation and under-represented minority college students who do not have college educated friends and families to guide them.

This is a required course for all first-year engineering students and is being offered in two parts: lecture and lab. While initially some hands-on techniques were implemented in the lab, there are some disconnections between some of the ideas that are being taught in the lecture and what students are doing in the lab. We modified an existing project in the lab part of the course to introduce design education and improve team-based and project-based learning in the course.

Since design is a central aspect of engineering practice [1], it is imperative that engineering students develop design skills, and become more like experienced engineering practitioners [2]. The sooner engineering students being exposed to design education and practice, the more time they will have to be more like expert designers. There are important differences between expert and novice designers. Expert designers spend more time on the design task than novices [2]. Novice designers perceive the design task as a well-structured problem [3] and immediately engage in making decisions to solve the problem [4]. In contrast, expert designers tend to delay making design decisions to understand [5] and frame the problem [6] as well as do research and gather information [7] to generate concepts and design ideas [4]. Thus, novice designers work with a few ideas and do not spend time and effort to explore alternatives [8] while expert designers tend to generate different ideas before making decisions and implement them [9]. When evaluating different options, novices do not critically evaluate their design decisions [10] while expert designers conduct experiments and use systematic troubleshooting to find and correct flaws in their solution [11].

II. Research Purpose and Question

The main purpose of redesigning the first-year engineering course activity was to get the first-year engineering students familiar with engineering design earlier in their education. This study was conducted to answer the question of "What are the students' perception on design education consisting of direct instruction followed by a hands-on activity in teams"?

III. Methods

A. Course Settings and Design Project

All engineering students at a minority serving higher education institution are required to take Introduction to Engineering course. It is a three-credit hour course that most students complete in their first year at the university. Typically, 500 students are enrolled in the course in both Spring and Fall semesters. The course focuses on hands-on design projects and problem solving. The course has a lecture and a lab component. The course is offered in two lecture sections (about 250 students per lecture). In Spring 2018, 16 lab sections (about 25 students per lab) were offered. In the lab, students work in teams of 4 to 6 (depending on the project). There are four main projects in the course: Excel, Solar, Wind Turbine, and Robotics. The wind turbine project has the greatest potential to focus on developing design skills. We modified the content of the wind turbine project (for weeks 1 and 2 of the project) for two of the lab sections. In the wind turbine project, students spend 5 weeks (3

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hours per week) on the wind turbine project. The breakdown of 5 weeks of the projects are:

Week 1: Learn CAD software, Solidworks

Week 1, modified for 2 sections:

- 20-minutes lecture on engineering design
- 40 minutes individual activity on listing possible materials that can be used to build the turbine structure, listing their pros/cons, and sketch a possible design for the turbine structure (see Fig. 1 for sample student work)
- Learn CAD software, Solidworks

Week 2: Design the blade in the CAD software and 3D print the blades (see Fig. 2.a)

Week 2, modified for two sections:

- 10 minutes, review of the design lecture
- 40 minutes: work in groups to compare, rank, and combine (if necessary) the sketches drawn in the previous week, and decide on a final structure design
- Design the blade in the CAD software and 3D print them

Week 3: Design and build the turbine structure (see Figure 2.b)

Week 4: Test performance of the wind turbine (testing power of the blade and stiffness of the structure)

- For the power test, a fan is used to simulate the wind for the wind turbine to generate power. Students record the generated power, voltage, and current. The generated power depends on how well the students designed the blades (see Fig. 2.c).
- For the structure stiffness test, the structure is loaded transversely (simulating wind loading) using weights attached to a string that pull the structure back, and its deflection is measured. The less deflection (stiffer), the better (see Fig. 2.d).

Week 5: Presentation

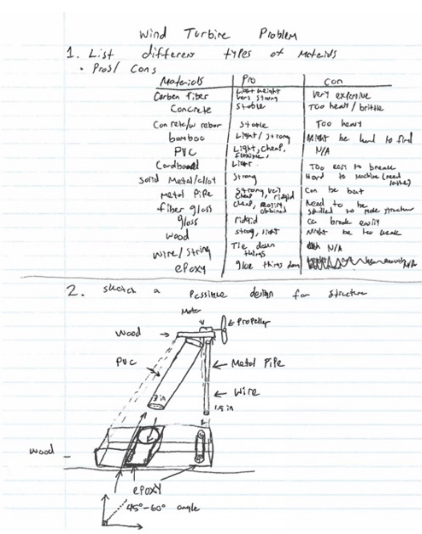
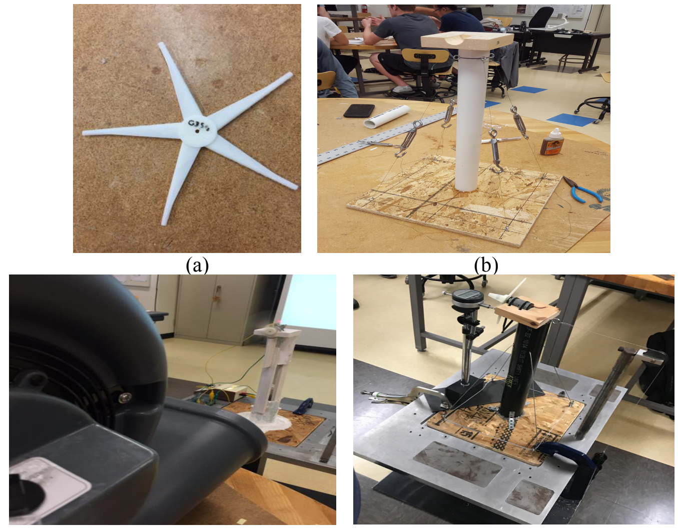


Fig. 1. Sample student work in week 1 of the project.



(a) (b) (c) (d)

Fig. 2. a. sample 3d printed blades; b. sample wind turbine structure; c. power test; d. stiffness test.

B. Participants

In total, 48 students were enrolled in the two modified sections of the lab. 23% of students were female and 15% were Hispanic. 83% of the students were freshmen and 44% of students were living on-campus. 15% of the students were working on-campus and 31% of the students were working off-campus. At the end of weeks 1 and 2, students were asked to fill out a quick anonymous evaluation sheet about the lecture and activity. In total, 46 students filled out the evaluations for weeks 1 and 2.

C. Evaluation and Analysis

The evaluation sheet for week 1 contained one likert-style scale and three open-ended questions:

- How useful was today's lecture/activity in helping you design the wind turbine structure? (5-point scale ranging from very low to very high)
- What did you like in today's lecture/activity?
- What did you NOT like in today's lecture/activity?
- What would you like to see added or think is missing in today's lecture/activity?

In week 2 evaluation, in addition to these four questions we also asked students to rate the lecture in week 1 again and indicate if their rating has changed.

Descriptive statistics were used to evaluate the usefulness of the lectures/activities for the students. Since there was no explicit lecturing on design process in the other sections, it was not possible to ask and compare student responses on the usefulness of the lecture. To measure the consistency and usefulness of the two weeks lectures/activities, the student ratings of week 1 and 2 were compared using t-test (for mean comparison), median comparison test, and Mann-Whitney U test (for comparing the distributions). The open-ended questions were coded using thematic analysis and open-coding [22].

IV. Results and Discussion

A. Likert-scale questions

Fig 3. shows the distribution of students' answers to the three likert-scale questions asked students about their overall perception of the lecture and activity about week 1 (asked both in week 1 and week 2), and week 2. Overall student feedback for both weeks was positive. 50% students rated week 1 high or very high, 41% medium, and only 9% low. 61% of students rated week 2 high or very high, 34% rated medium, and only 4% low. Compared to week 1, week 2 evaluation has shifted toward the positive end as more students selected high usefulness for the lecture/activity. Students re-evaluation of week 1 in week 2 does not show any overall improvement as mean remained the same (see Table I). There was no statistical difference between week 1 and week 2 means (t-test p-value>0.05) or medians (p-value>0.5). In addition, Mann-Whitney U test revealed that there was no difference between the distribution of week 1 and week 2 feedback.

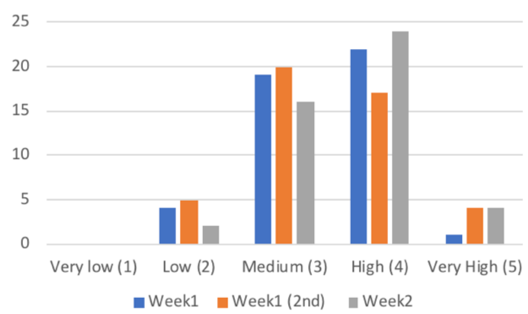


Fig. 3. Distribution of students' responses to overall usefulness of the session

TABLE I. Statistics for the Usefulness of the Session

Statistics	Week 1	Week 2	Week 1 (2nd)
Mean	3.43	3.65	3.43
Median	3.5	4.00	3.00
Standard Deviation	0.69	0.71	0.81
T-test (p-value)	0.14		
Median test (p-value)	0.36		
Mann-Whitney U Test (p-value)	0.17		

B. Open-ended questions

The students' responses were coded by open coding. The responses were categorized based on the emerging themes which were named as a) Overall Characterization, b) Instruction, and c) Content. Also, the number of responses that were given to each question in both weeks was interpreted. Table II indicates the number of responses given to each question. As shown in Table II, the students' positive comments outnumbered the negative comments. Also, the negative comments were less frequent. Thus, it was concluded that students agreed more on positive aspects of the lectures/activities than the negative ones.

TABLE II. Number of Student Comments

Category	Liked	Did not Liked	Thought missing
Overall	27	11	0
Instruction	67	22	36
Content	44	14	16
Total	141	47	52

The details of each question and each category is presented below.

*1) **What students liked.*** The coded student responses brought up three categories: a) Overall Characterization, b) Instruction, and c) Content.

a) Overall Characterization. The students described the lecture/activity of week 1 as overall good, informative, and giving insight about the project that they would be working on. Also, they found the week 1 lecture/activity helpful, useful, motivational, engaging them into the project, and clear. In addition, one student liked that the lecture was short.

The students liked the lecture/activity of week 2 even better than the lecture/activity of week 1. They characterized the week 2 as good/very good, helpful, great, and liked that the lecture part was short.

b) Instruction. In week 1, the students mainly liked the sketching the wind turbine structure, and brainstorming on design mainly for materials and building the turbine, and discussion activities for solving problems. Also, they stated that the time arrangement was good for the whole session; they liked the organization of the session (including short lectures and hands-on activities) and practicing design. The students also liked the PowerPoint presentation that was used by the instructor as much as seeing a wind turbine example that the instructor made use of during his instruction.

In week 2, the students provided more positive comments on instruction than they did for week 1. Majority of the students liked group work in which they had discussions on project design and designing/creating blades. They mentioned that they liked the communicating and socializing with others, being active in the class, straight forward and clear instructions, and the PowerPoint presentation that was used in this week as well. They found it detailed enough and easy to understand.

c) Content. About week 1, most of the students mentioned that they liked to be given guideline for the design which includes considering different ideas to start the project, doing research on materials, and how to pick a design for the project. Some students mentioned that they liked to see a guideline that they can use while planning any project. Some other parts of the content that students mentioned were problem solving and some real-world problems of engineers, the difference between novice and experienced engineers in their approach, and general information and ideas about the class and project during the instruction. About week 2, the students liked being informed on how to design and create wind turbine blades, and guideline for the project. Also, one student mentioned that he/she liked learning a new topic.

In summary, students thought the lectures and activities were helpful. They liked the group activities, straight forward and clear instructions, sketching of the turbine structure, and guidelines for design and project planning. Here are some examples of the answers to the question of what they liked: *"The time we had to sketch our ideas to explore possible materials that can be used.", "The fact that we had time to collaborate on our design.",* "I liked the content of the slide show with the process of solving problems".

2) ***What students did NOT like.*** We analyzed the student responses based on the same themes that emerged in the previous question: a) Overall Characterization, b) Instruction, and c) Content.

a) Overall Characterization. For week 1, some students commented that they found the lecture long, boring, repetitive, and slow. One student found the lecture on wind turbines short. For week 2, only two students mentioned that the overall session was boring and useless.

b) Instruction. About week 1, a few students mentioned that they found the instruction not very engaging/interactive/collaborative, and some other students mentioned that they did not like sketching activity, reviewing materials in detail, and too much focus on PowerPoint during lecture part. A few students thought that the PowerPoint presentation slides were confusing, busy, and containing too much information but not enough photos.

About week 2, only six students mentioned different aspects of instruction–it was difficult to figure out the optimal blade, they did not have enough time to work on project, they sat too long during the session, and they did not like designing base for the wind turbine, there was lack of lecture and they did not like to be divided into subgroups while working on project.

c) Content. For week 1, only six students commented about the parts of content which they did not like. They did not like the amount of materials to cover in one session, lack of information on materials for design and about the project (What is it about? Why is it necessary?), insufficient guideline for the project, and confusing diagrams. One student mentioned that he/she doesn't like any lecture. For week 2, there were only three comments for the content–there was not a lot of information, there was a lack of talk about the wind turbine and structure, and lack of details on how to design the blades.

In summary, the most common and frequent comments in both weeks were related to lack of details in the content and too busy PowerPoint slides. Examples from the students' answers to the question of what they did not like in the lecture/activity are: *"Not much activity/movement going on.", "The first half was pretty boring."*

3) ***What students thought should be added.*** We analyzed the student comments based on two emerging themes: a) Instruction, and b) Content.

a) Instruction. For week 1, most of the students mentioned that there should be more examples of working wind turbines made by students. Some students mentioned that there should be more audiovisual components during the lecture for the materials and design process, more group work and discussion on group projects and each students' design and material selection, example of the test process for wind turbines, more sketching activities, more practice on design process, and examples of past failed projects. Also, it was mentioned that there should be more thought-provoking questions and less instructor lecture.

For week 2, the students mainly wanted to see more examples of wind turbines and blades. Also, they stated that there should be more time to work on the design process. Some other comments were about instruction to include more guidance and help about the lab and designing blades.

b) Content. About week 1, some students stated that they would like to have more and clear information on wind turbine, more information on design process, and the real-world problems, materials that can be used, and guidelines for design project. About week 2, a few students mentioned that there should be more information on angle of attack, structure and materials, how to plan an effective design, and turbine support structures. They also thought that there should be more design topics and more photos should be used in the lecture.

In summary, students would like to see more examples of blade design, structure design, and design process. They also indicated interest in more information about wind turbine design and design process in general. Examples of working wind turbines was another frequent comment. Some examples of students' answers to the question of what is missing or what should be added to the lecture/activity are listed here: *"Would have liked to understand move on how the best structure was and see it in action.", "More examples of blades maybe", "I wish there was more interesting (attention getting ways) like gifs or animations."*

V. Conclusion

In this paper, we analyzed student feedback after adding design education lectures and activities to a team project in a first-year engineering course at a minority serving higher education institution. Overall, student feedback to directly lecturing design process and design activities was positive. Number of positive comments were also greater than negative comments. Students comments were coded by open coding method. Three categories were emerged from the codes: overall characterization, instruction, and content. Students thought the lectures and activities were helpful. They liked the group activities, sketching of the turbine structure, and guidelines for design and project planning. Students agreed more on the positive aspects of the lectures and activities. When it came to what students didn't like, there were no consensus (no frequent responses). Some negative comments were related to lack of details in the content and too busy PowerPoint slides. Students would like to see more examples of blade design, structure design, design process, and working wind turbines. They also indicated interest in more information about wind turbine design and design process in general.

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