Implementation of Hands-on Learning Module into Machine Design Curriculum via Class Project

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Multiple studies have shown that the effective way for students to learn engineering design is through a hands-on active pedagogy. Active pedagogy is one of the strategies' that is being adopted by universities to revolutionize engineering education. Project based learning is a form of active pedagogy that involves hands-on tasks, well defined project outcomes, multiple solutions to the problem at hand, and links science and engineering concepts. The major goal for this class project was to introduce into the curriculum a hands-on learning module that would enable students to understand fundamental design concepts via a question based approach. The project required the students to integrate design principles, mathematics, science, modeling, arts, and language to come up with an intricate car design. The project was broken down into segments with deliverables due every 2 weeks throughout the semester. Student groups participated in a car race on the last day of class. A total of two surveys (mid- and end- semester) were handed out to students to solicit their feedback on this active learning pedagogy and to make any necessary modifications the following semester. The major observations from the class project and student surveys are: (a) this project provided the students an opportunity to apply the mathematical/science concepts to a real world scenario, (b) it helped students in the learning process to understand important and relevant concepts, (c) provided learning opportunities outside traditional classroom, (d) provided an opportunity to integrate concepts learned in other classes, and (e) students would like hands on projects like this extended to other courses also.

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Introduction

Engineering design as defined by ABET's Criteria for Accrediting Engineering Programs, "is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic science and mathematics and engineering sciences are applied to convert resources optimally to meet a stated objective" [1]. As stated above, because of the iterative nature of design, it is essential that the curriculum integrate a component that would allow the students to apply their knowledge base in creative ways to solve open ended design problems. This leads us to the question – What are the effective pedagogical approaches that could be adopted so that students develop their design skills? Multiple studies have shown that the effective way for students to learn engineering design is through a hands-on, active pedagogy [2]–[6]. The active pedagogy includes project based learning [7] that involves hands-on tasks, well defined project outcomes, multiple solutions to the problem at hand, and links science and engineering concepts.

The goal of this project was to introduce into the curriculum a hands on learning module that enables students to understand fundamental design concepts via a question based approach. The goal was realized by a class project that required students to integrate design principles, mathematics, science, modeling, arts, and language to come up with an intricate car design. The project is based on an informed design approach [8] where students utilize prior knowledge in science and mathematics to come up with the design rather than a trial and error approach. The project is open ended in the sense that students working in groups of 3 to 4 are allowed to creatively design and fabricate a car that satisfies the requirements. This encourages pluralistic thinking in the students wherein they are free to come up with any working design and not bound by the right/wrong philosophy commonly encountered in exams [8]. Students always wonder if they would ever be required to apply the mathematical/science concepts learned in class to real world scenarios and this project provides an opportunity to do so.

Need for Project

The existing format of ME 311 Machine Design class at Fairfield University requires student groups to work on a reverse engineering project. Each group has to choose a commercially available device (for example: airsoft gun, C – clamp, fishing rod, weighing scale to name a few) and reverse engineer to determine the safety factor and expected life span using concepts learned in class. As a new faculty teaching the course for the first time, the existing format was adopted for Fall 2014 semester with an additional requirement that the students come up with at least one improvement to the existing design. The student feedback for the project from university conducted end-of-semester surveys and in class surveys conducted by the instructor was positive with students enjoying the hands-on experience. However, the current format does not provide the students an opportunity to use prior knowledge and creativity to come up with a design solution but rather justifies why the existing design is a valid one. Also since the project requires the students to break apart a device, they typically tend to go with simple devices that are cheap and easy to obtain. This means that these devices do not have intricate designs and have fewer elements.

In order to address this issue, this new project format was introduced for Fall 2015 semester wherein the students had to design, fabricate and analyze a system using the given resources. This would provide the students an opportunity to not only apply the theory learned in class but also question themselves at each stage of the design process leading to better understanding of the fundamentals. In addition it would prepare students for Senior Capstone Design Project where they are expected to do extensive design and fabrication work.

Methodology

This paper discusses the implementation of this project during Fall 2015 semester with a class size of 15 students. In order to accomplish the goal of fabricating a working car model, each student group was provided with a K'NEX building set, motors, battery pack and controllers. The student groups were free to synthesize any working design that satisfied the design requirements. The design requirements were with regards to car movement and size. The car needs to move in a straight line (forward and reverse) and make turns (left and right). Also, the car needs to fit inside a cube with dimensions 10 inch (L) * 8 inch (W) * 8 inch (H).

The project was broken down into segments with deliverables due every two weeks. The activities and deadlines are summarized in the table below.

Table 1: Project activities

Step	Activity	Due Date
1	Form groups	Week 2
2	Plan of action	Week 4
3	Chassis/axle design	Week 6
4	Drive train design	Week 8
5	Steering design	Week 10
6	Project presentation	Week 12
7	Car race	Week 12

Students were allowed to form their own groups with four students in each group. Each student in the group was required to take ownership of a certain aspect of the project. This would not only help the students communicate effectively with other group members but also get to act as a project manager. Students would participate more enthusiastically in the learning process because they assume a leadership role. The next step for each group was to prepare their plan of action. It is a flowchart/outline that indicates how they plan to carry out the design and analysis for their car. The plan of action needs to include how the car would function along with mechanism for power transmission to the wheels and steering, loads acting on the device, reasonable safety factor, predict which component might fail first, any missing information that needs to be found, and any physical testing that they plan to conduct along with list of instruments needed for the study.

Students received feedback on their submitted plan of action from the instructor and also other student groups. Students were given plan of action of a different group and each student had to provide a critical review on the assigned plan of action. Students were asked to be as clear as possible in their feedback and indicate all the positives and weakness as seen by them. The goal of this exercise was for the students to get a perspective of how others with similar knowledge and background would view their work and help improve the quality of their work. With the feedback on their plan of action, students started to work on building the car in stages. Students calculated the stresses, deflections and safety factors for each component as they built the chassis, drivetrain and steering. The class lectures covered material that the students needed to perform these calculations. After each design phase, students met with the instructor to receive feedback on their design and plan for design iterations if needed. Due to the fact that students were working in groups, it gave them a chance to see how the other team members understood and visualized their design ideas leading to better iterations as the design process progressed. Also, studies have shown that student creativity and inventiveness is boosted when students have ready access to equipment (design project kit in this scenario) [9].

Assessment

The major assessment of the project outcome was a working car that satisfied the requirements. The in class discussion problems, home works and midterms tested subject material that was closely tied to project deliverables and was also used to assess the outcomes. Two surveys were handed out to students during the course of the semester to solicit their feedback on this active learning pedagogy.

The first survey was given to students at the halfway mark of the semester. Students were asked to rate their responses on a scale of 1 to 10 with 10 indicating full agreement with the statement and 1 indicating disagreement with the statement. The questions on the mid-semester survey were:

1. The project helped me in the learning process.
2. The project helped me understand the important concepts in this course.
3. The project provided me an opportunity to apply the class material to a practical problem.
4. The project activities took the right amount of time to complete.
5. The class project was well designed with clear deliverables.
6. I enjoyed working on the class project.
7. The project gave me an opportunity to be an effective team member.
8. I feel that hands on projects like this should be extended to other courses also.

The questions on the end-of-semester survey were:

1. The project provided an opportunity to integrate concepts learned in other classes.
2. The project provided me an opportunity to learn the class material outside the classroom.
3. The hand on activities motivated me to participate more enthusiastically in the learning process.
4. The ready availability of the K'Nex kits boosted creativity and inventiveness.
5. The project deliverables were closely tied to (in sync with) the homework's and exams.
6. Other comments:

Student groups gave a short presentation on the design of their car and participated in a car race on the last class day. Student work was assessed using the following criteria:

1. The maximum size of the car needs to be 10 inch (L) * 8 inch (W) * 8 inch (H).
2. Groups need to indicate if they have used any additional parts other than the given K'Nex kits. You are allowed a budget of $25 dollars towards additional parts.
3. Car needs to be controlled using the given 3 way switches.
4. You will have a practice session for 5 minutes to get familiarized with the track.
5. Each car will be timed through the track and teams with the two best times will

participate in a final race to decide the winner.

6. Points will be deducted depending on the number of times, the car goes off track: *0 – 1*: no penalty, *2 – 4 times*: 0.5 point off and *>5 times*: 1 point off.

The grading scheme used for evaluating student cars is shown in Table 2 and the track on which the students raced against each other is shown in Figure 1.

Table 2: Car race grading scheme

Team:	*Maximum points*	
Presentation	4	
Size conformance	1	
Forward/reverse motion	2	
Steering mechanism	2	
Straight line motion	3	
Square track motion	3	
Straight line time (seconds)		
Square track time (seconds)		
Number of times off track		

Fig.1 Car race track

Discussion

Student feedback on the mid-semester survey is summarized in Figure 2. The average score on each of the outcome was greater than 8 indicating that students strongly agreed with the statements. One area needing improvement is conveying to the students clearly the project deliverables. Students indicated they prefer the instructor discuss deliverables in class rather than provide them with a handout detailing the project requirements.

Student feedback on the end-of-semester survey is summarized in Figure 3. Similar to the mid-semester survey, the average scores on all the outcomes were greater than 8 indicating strong agreement. Three students had provided their response for the *Other comments* question in this survey. They are summarized here:

- I liked the project as part of this class.
- Great project. Learned a lot.
- The project was helpful but was a bit too much work to handle.

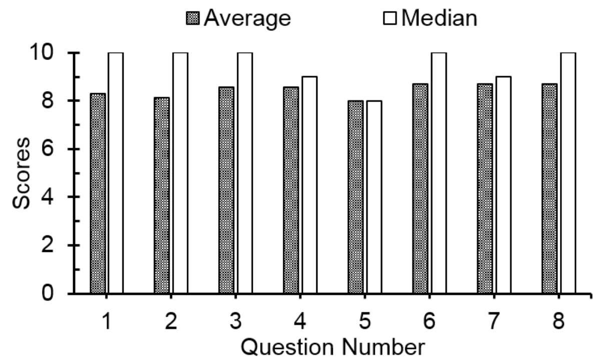

Fig.2 Mid-semester survey results

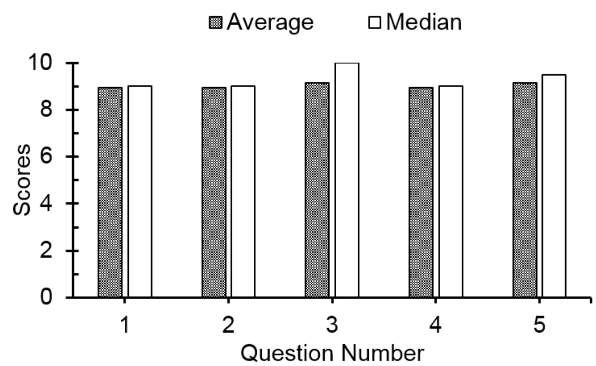

Fig.3 End-of-semester survey results

All the four student groups successfully fabricated their car and participated in a race on the last class day. The cars built by the four student groups are shown in Figure 4. Each group came up with a distinct design with different method of power transmission, wheel layout and steering mechanism. The major observations from the class project and student surveys are: (a) this project provided the students an opportunity to apply the mathematical/science concepts to a real world scenario, (b) it helped students in the learning process to understand important and relevant concepts, (c) provided learning opportunities outside traditional classroom, (d) provided an opportunity to integrate concepts learned in other classes, and (e) students would like hands on projects like this extended to other courses also.

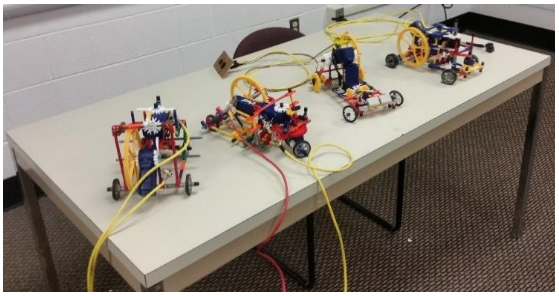

Fig.4 Cars built by student groups

As an instructor, the major challenges faced during the implementation of this project were three fold. First, structuring the lectures so that the home works and exams were closely tied to the project deliverables. This was essential so that students had the required knowledge to analyze their design at each stage of the process. Second, evaluating design of individual groups at each stage and providing feedback before the next deliverable was due. Student groups were free to synthesize any working design and hence, all the designs were unique. The instructor had to verify the analysis of each team separately and provide them feedback. Third, evaluating effectiveness of having readily available equipment (design kits) on student performance. Assessment of this outcome was done via student's performance on the home works and midterms. However, this may not be a true indicator and further ways of assessing this outcome need to be explored.

Summary

An active hands-on learning module was successfully implemented into the Machine Design curriculum at Fairfield University via a class project. The project was well received by the students and they participated thoroughly in all the activities. Students in specific liked the hands-on component and wanted it to be extended to other courses also. Future implementations of this project will be focused on ways to assess effectiveness of having readily available equipment (design kits) on student performance.

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