AC 2011-511: USING A PROJECT-BASED LEARNING APPROACH TO TEACH MECHANICAL DESIGN TO FIRST-YEAR ENGINEERING STUDENTS

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Abstract

The Rowan University Mechanical Engineering program has recently adopted a new curriculum, based on more than a decade of experience and lessons learned. One important change was the increase in time allotted for project-based learning in each of the core areas: thermal-fluid sciences, mechanical design, and system dynamics/control. A major shortcoming of the previous curriculum (and of most traditional curricula) was that students were not exposed to “real” mechanical engineering content until the second semester of sophomore year – by this time many students had switched out of mechanical engineering altogether. To remedy this, and as an aid to retention, we have implemented a true mechanical design course in the first semester of freshman year. Since most mechanical design courses do not require differential equations, placement of the course into the freshman year seemed appropriate. In addition, the Rowan mechanical design course has two ambitious hands-on design projects that (it was hoped) would engage students and improve retention. This paper will describe the results of placing a mechanical design course so early in the curriculum, and will provide details on how the course was tailored to suit students recently arrived from high school.

Introduction and Background

The Rowan University Mechanical Engineering program has recently rolled out a new curriculum, which incorporates many of the lessons learned in its fourteen years of existence. The first year of the old curriculum was similar to that of most engineering programs, with mathematics and basic science courses predominating. All discipline-specific design courses came later in the curriculum, beginning in the second semester of the sophomore year. The old and revised first semester of the first year is shown in the table below.

<table>
<thead>
<tr>
<th>Table 1: Original and Updated First Semester Freshman ME Curriculum</th>
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<tbody>
<tr>
<td>Semester-hours are shown in right hand columns</td>
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<tr>
<td>1996-2009</td>
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<tr>
<td>--------------------------------</td>
</tr>
<tr>
<td>1 Calculus I</td>
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<tr>
<td>2 Adv College Chem I</td>
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<tr>
<td>3 College Composition I</td>
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<tr>
<td>4 Freshman Engineering Clinic I</td>
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<td>5 General Education Elective</td>
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<td>Total</td>
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There were two major concerns with the old approach. First, students were not exposed to challenging, hands-on design problems until much later in the curriculum, usually the third year. Because of this, it was felt that most of their first two years were spent in a “context-free” manner, learning mathematics, basic sciences and engineering sciences without seeing any practical application.
Second, the ME faculty were concerned with student retention after the freshman year. While retention numbers at Rowan are relatively high (between 80-85% after freshman year) it was felt that introducing discipline-specific design content earlier in the curriculum could raise these numbers. At most universities Mechanical Design is taught at the sophomore or junior level. This is not strictly necessary, however, since traditional Mechanical Design courses do not require high level mathematics. In fact, most (if not all) Mech Design courses employ trigonometry and differential calculus exclusively, with a limited amount of linear algebra in some cases. Thus, it seemed natural to move Mechanical Design to the first semester of freshman year. The author is unable to find any reference to a traditional Mechanical Design (i.e. applied kinematics) course being offered to first-year students in the literature.

Introducing design content into the freshman year is not new, of course. Throughout the 1990s many “Freshman Design” courses were introduced at universities nationwide. An example of such an effort was led by the National Science Foundation’s Gateway Engineering Education Coalition, which placed an emphasis on introducing design early in the engineering curriculum as an aid to retention\(^1\). Courses like these are intended to be general\(^2\), and give students an overall introduction to the engineering profession. As such, the design projects given in these courses are often very simple, and small-scale (e.g. a catapult\(^3\) or a darkness-activated light switch circuit), or place an emphasis on creating “paper” designs, with limited fabrication and testing\(^4\).

Some instructors have developed more challenging design projects for first-year students, e.g. the pump design and fabrication project developed by Swanbom\(^5\), et al. Owing to the number of students designing and fabricating pumps, however, the open-endedness of the project was necessarily limited. Class size at Rowan is much smaller (typically 35 students) and we are able to present students with much fewer limitations on their design projects.

**Description of the Course**

*Introduction to Mechanical Design* is a course that has been taught to third-year students at Rowan for the past eleven years. It is modeled on traditional applied kinematics courses. Sample topics include:

- Introduction to mechanisms
- Graphical linkage synthesis
- Fourbar, slider-crank, inverted slider-crank and other linkages
- Position, velocity and acceleration analysis
- Inverse dynamic analysis of linkages

Depending upon the instructor, the mechanical systems are modeled using an *a*) trigonometric/algebraic approach or *b*) a vectorial constraint equation approach. In the second approach, a system of nonlinear constraint equations is developed for each problem, which is solved using MATLAB or similar software. The author uses the second approach when teaching Mechanical Design, which led to some difficulties with the first-year students, as will be discussed.
The highlights of the course are two large-scale design projects, one given three weeks into the semester and the other given near the end. During the past ten years, the author and his colleagues have developed a set of challenging design/analyze/build/test projects for Mechanical Design, including an air compressor, a steam engine, a Stirling-cycle engine and a walking toy. For the first-year students, the author elected to give the compressor project and the walking toy project. Each will be described in more detail below.

The author chose to keep as much of the traditional course as possible, while recognizing the difference in ability between first-year and third-year students. The pace of the course was slightly slower than for third-year students, which resulted in one major topic being dropped (dynamic force analysis). Also, the time given for design projects was longer – five lab periods were devoted to each project in all. The remaining lab periods were given to instruction in CAD (SolidWorks), MATLAB and other topics.

The Compressor Project
The goal of the compressor project was for students to design, fabricate and test a small air compressor for maximum pressure and/or flow rate. The students worked in teams of three or four to size the components of the compressor using the ideal gas law for isentropic compression. They used simple mechanical design calculations to determine the torque required to develop the desired pressure. For this they assumed a static system, since they did not have enough dynamics to calculate inertial effects (which are relatively minor, considering the slow speed of the motor).

The students used a common motor and base on which to mount their compressors. The motor spun at 1100rpm and was rated to produce 0.25hp (186W). The students were able to choose the speed/torque at the driveshaft of their compressors by selecting a belt and pulley configuration, as shown in Figure 1, below.

![Figure 1: The common base and drive assembly used in the compressor project. Students were able to select the speed and torque of their compressors by placing the belt on the appropriate set of sheaves.](image-url)
It was announced at the outset of the project that two awards would be given: one for highest pressure and the other for maximum flow rate. Since these are mutually exclusive goals, most teams elected to focus on one or the other. Thus, teams that strove for high flow rate designed compressors with long stroke, and used the high speed/low torque pulley combination on the drive base. Conversely, teams that aimed at high pressure used a relatively short stroke with small volume at TDC, and the high torque pulley combination.

It must be noted that nearly all of the students began the project with no design or fabrication experience whatsoever. Thus, a significant amount of lab time was devoted to basic mechanical design issues such as screw size, pinned connections, material selection and the like. When given to third-year students, the compressor project lasts between three and four weeks. The first-year students took five weeks (of lab periods) to complete the compressor project.

![Figure 2: Student team with winning compressor](image)

*The Walker Project*

The second project was actually much simpler than the first: the students were asked to design and fabricate a walking “toy”, using a small, battery-powered motor. The links for each walker were made on an Epilog Legend 36EXT laser cutter using ¼” thick basswood or Plexiglas. The walkers were assessed for speed and traction with a race and “sumo” competition at the end of the semester. Each team was required to perform a full motion analysis of one “foot” of their walker using the techniques developed in class. This proved to be more difficult than expected for some: many teams used an eight-bar linkage similar to the “Strandbeest” of Theo Jansen.
Conclusions and Lessons Learned

First, it must be stated that, in terms of student learning and satisfaction, the course was a success. The first-year students performed nearly as well as their third-year peers on examinations and homework assignments. Each team successfully designed and fabricated an air compressor that worked (even if only for a short time). And almost every team produced a toy that walked (or “danced” in a very entertaining way). In sum, the idea of moving Mechanical Design to the first semester of the first year appears to be a sound one.

Student Feedback

At the close of the semester, the author conducted a survey to gauge the opinion of the students concerning the course. The class had a total of 56 students at the outset, and two students dropped during the semester. Of the 54 remaining, a total of 48 students responded to the survey.

First, the students were asked if they felt that they had an adequate background to take the course in the first place. A large majority of the students felt that they were well prepared in math (97.9%) and physics (93.5%). A full 100% of students felt that the pace of the course was “challenging but realistic.” And (perhaps most importantly) 90.2% felt that the course material was not too challenging for first-year students.

Students were asked to comment on the workload of the course compared with other first-year courses, and most appeared to find it reasonable, if challenging.

“The work was challenging but the amount of it wasn’t overwhelming.”
“Not too difficult, heavy workload but worth it.”
“This class was challenging for me. It was a lot of work as well. As large amount of time and effort were put into this class for me.”
“Less workload than some courses, yet realistic. I was able to complete all of my work while not falling behind in other classes.”

Judging by the last two comments (and many others like them), the student perception of workload depended heavily on which instructors they had for other courses (specifically, Advanced College Chemistry).

Next, students were asked to comment on the course content and the pace of the course. By and large, students seemed comfortable with the pace of the course. The major complaint was the use of MATLAB for solving nonlinear equations.

“More explanations of Matlab on what the programs and commands mean, that is all.”
“Computer programming/Matlab/solid works experience would make the course run more smoothly – maybe the first couple of weeks could have been devoted to practicing with the computer.”
“I felt that the pace of this course was good and had interesting content.”
“I love this course. It was both challenging but realistic and fair, as well as a lot of fun. However, I feel that we should not be asked to program before we’ve had a programming class.”
“The pace was good though I would have liked a bit more solidworks work that lead to learning new tools/functions.”
“Matlab should be introduced at a slower pace, if at all.”

The message of these comments is clear: students felt very uncomfortable having to write even simple programs without having had any prior programming experience. The author (with some misgivings) plans to remove the MATLAB content from the course and have the students use more familiar tools (e.g. Excel) for computation.

Finally, students were asked about the homework assignments, which were largely identical to the ones given to third-year students in the past. Fully 100% found the assignments challenging, but only 28.7% found them to be too challenging. As before, the students exhibited a marked dislike for the homework assignments that required MATLAB. Given that MATLAB is popular and much-loved tool of practicing engineers, these students will eventually become accustomed to it.

As to the design projects, 93.6% of the students felt that the compressor project was suitable for first-year students and the same number felt that the walker project was suitable for first-year students. The student comments reflect their enjoyment of hands-on design projects, and how much educational benefit they derive from them:

“It was a fun, but challenging project.”
“The project was challenging and time consuming but was not overly difficult.”
“Fun”
“It was a lot of fun and I learned a lot.”
“Good project to get freshmen working hands on early on so they can understand problems with designs you can’t learn in a classroom.”

“So much fun. The best possible way to learn how to use equipment is to just be thrown into a project with them. With the help of technicians and the professor, I learned so many ‘do’s and don’ts.’”

“The project was challenging but we were given enough time and information for everyone to complete it. The only problem was that some days it was impossible to use the machines because too many people were using them or they were off.”

The last comment above reflects a common concern. This particular group of first-year students was very large relative to the normal Rowan class size (56 students, instead of the usual 35). This resulted in long waiting times for the rapid-prototyping and machine shop equipment.

Finally, the author wanted to assess how students perceived the field of mechanical engineering, and their place in it. The survey asked the students if the Mech Design course had changed their perception of mechanical engineering in general, and more than half replied that it had. Of these, an appreciable fraction (38%) said that the course had changed their perception in a positive way, for example:

“I feel much more confident that I can be successful as a mechanical engineer.”

“Yes, I like it more.”

“Yes, in a good way.”

“Made me sure it’s what I want to do.”

“Yes. Much more creativity and less boring formulas and calcs.”

The last comment is particularly inspiring to the author; while the course abounds in formulas and calculations, a major goal was to give the students a sense of the creativity involved in successful engineering.

When asked if they would remain in the mechanical engineering program after this semester, two of the 48 respondents said that they would not, and one said he/she would, but reluctantly. Thus, 93.8% of the respondents intended to continue their mechanical engineering studies.

RetentionPolicy
At this time of this writing it is too early to make any definitive statements about retention. During the semester, two students withdrew from the course: one changed majors and the other took a leave of absence. A third student informed the author that he plans to switch out of mechanical engineering at the end of the semester.

Final Observations
In conclusion, there were some interesting lessons learned by the author over the past semester. First, students newly arrived from high school have different expectations of their instructors than do experienced college students. Course material tends to be “spoon fed” in high school, and some of the first-year students became frustrated when homework problems required outside
knowledge (i.e. reading the textbook) for completion. The author plans to inform next year’s students that not everything necessary for completing the homework will be covered in lecture, and some degree of independent study is required.

Second, the overall quantity of work that can be expected of first-year students is less than that for third-year students. While it is commonplace to assign two major design projects, seven homework assignments and two examinations for upper division students, many of the first-year students appeared to “burn out” by the end of the semester. The author plans to assign only one major design project next year, and to use it in more depth. In total, however, the course was a success, and will remain an important part of the Rowan Mechanical Engineering curriculum.

References