The Development of a First Year Design Project: Focusing on Creativity, Independence, and Design Understanding

Dr. Breigh Nonte Roszelle, University of Denver

Dr. Breigh Roszelle completed her undergraduate degree in Mechanical Engineering at Colorado State University in 2006. She then continued in academia, completing her Masters and PhD in Bioengineering at The Pennsylvania State University. At Penn State Breigh worked in the Artificial Heart Lab, her research focused on studying the biofluid mechanics associated with the development of a pediatric ventricular assist device. After completing her PhD in 2010, Breigh came to Arizona State University to work as a post doc in the Image Processing Applications Lab. In 2013 she started teaching in the Mechanical and Materials Department at the University of Denver. She is currently the Associate Dean for Undergraduate Studies as well as a Teaching Associate Professor. Here Breigh teaches courses in the fields of thermodynamics, fluid mechanics, heat transfer, biofluids, and introduction to engineering. Her educational research interests include first-year engineering experiences, engineering assessment, and active learning pedagogy.
Introduction:

Over the past several years the engineering departments at the University of Denver (DU) have redeveloped the first-year curriculum to focus on engineering design, mostly using project-based learning. The importance of introducing students to engineering design has been well documented\cite{1,2}, however it was noticed by faculty that more and more students had knowledge of basic engineering design previous to entering college. This gave an opportunity for the introductory courses to expand beyond the “basics” of engineering design, allowing for more creativity and independence of the students. Green and Kennedy stated it well when they claimed that an engineering program should be one that “…balances technical, manufacturing and creative aspects so as to achieve imaginative solutions to human needs for products in world markets.” \cite{3} The goal of the project redevelopment described is to hit all three of these aspects in a wholsitic and fun experience for first-year students. Over the past several years the design project has expanded and changed with the changing student body, and a comparison of the project from 2012 and what it looks like today is outlined, along with student feedback and possible future directions.

Course Description:

During their first year at DU all engineering students take a three-course series to introduce them to the three different engineering disciplines offered: mechanical, electrical, and computer engineering. The first of these three courses is Introduction to Mechanical Systems with CAD, which is run by the Mechanical and Materials Engineering Department. The broad goals of the course are to introduce the students to basic mechanical concepts, CAD software, engineering drawing basics, engineering design, and to develop their skills within teamwork and technical writing. DU operates on a quarter system, so this is done during a ten-week period.

In order to aid in the teaching of engineering design a 3D-printing design project was developed about seven years ago and implemented in the course\cite{4}. While it was received well by the students overall, there were some limitations due to time and equipment available.

Project Description:

The goal of the original project was for students to work in groups to design, build, test, and present a child’s toy that was tasked at launching an object the maximum possible distance. This project has been described previously in full detail by Roszelle\cite{4}. Students were provided with a 10 cm square wood base, 6 smooth nails, 4 rubber bands, and a launching object, which varied each year, but included marbles, poker chips, and ping-pong balls. Along with these provided materials the students were tasked with designing three to seven parts in SolidWorks that were to be 3D printed. The design and all associated 3D parts were required to meet the following:

- All designs will be created in SolidWorks then printed on the rapid prototyping machine.
- Device must be loaded like a toy and have some sort of actuation mechanism.
- Entire device will be a planar device attached to the wood base provided
• Each rapid prototyped part can be no less than 3 mm thickness.
• The largest dimension of any part cannot be larger than 20 cm.
• Device must contain a minimum of 3 rapid prototyped parts and no more than 7
• Teams will be limited to 20 cc of material total for the rapid prototyped parts.

Groups then went through a process of brainstorming and selections of conceptual designs. After the design was approved by the customer (aka instructor and TAs), the students built their parts in SolidWorks and sent these designs to their TA. The 3D printing was completing by the TAs due to time and equipment limitations.

After receiving their 3D printed parts each group was given access to the engineering machine shop, where they could build their devices using basic hand tools. The groups were then required to develop and implement a testing plan to validate and adjust their designs. For their final presentations the students had to launch their object in front of the. Each group also completed a design report that documented their entire design process, including: conceptual designs, design matrix, final CAD drawings, testing and validation results, and a discussion of their design’s performance and the changes they would make if given the chance.

Post-project evaluation surveys showed that overall the students enjoyed the project, especially being able to design and build something themselves. However, there were also some areas where students felt the project could improve. The quotes below all speak to areas where there were some limitations felt by the students:
• “I would allow for less restrictions, so teams could build more complex designs.”
• “It would be nice to be able to make different parts to try out; this would allow for the best design to ultimately be chosen.”
• “Give groups more time for each section so it’s not so crammed in the end.”
• “I would allow for a larger volume constraint for the SolidWorks designs to facilitate more creative designs.”

In fall 2018 a redeveloped project was launched with the following goals:
• A more open design prompt that allowed for development of constraints and criteria
• A chance for students to participate in prototyping and testing
• 3D printing and other manufacturing done solely by the students

The new problem statement asked the students to design, test, and build a high-fidelity prototype of a child’s toy. Beyond this objective there were three requirements given: must be appropriate for 3-5 year old children, must include some concept of simple machines, and must contain at minimum, one 3D printed part that is designed by the team in SolidWorks.

Groups were then required to develop their own constraints and criteria. This was done by having each group first research toy safety and design requirements. The students were also provided with survey data from parents of preschool aged children about toys. Each group presented what they found using a “gallery walk” during a lab session where they made a poster with their initial constraints and criteria. All the groups read through and discussed the posters in order to help provide peer review feedback and brainstorming. This also gave each group some time self-assess their constraints and criteria and develop an official document.
The conceptual design phase was run similarly to the original project. Students brainstormed several ideas based on their constraints and criteria and selected a handful to be put through a design matrix. Final designs were selected and presented to the instructor, TAs and fellow classmates, during which groups received feedback. Previously the presentations took place without other students in the room. This change allowed not only for feedback from their peers on their projects, but also gave an opportunity for idea sharing between all groups within a lab.

After selecting a design to move forward with, the students began a prototyping and testing activity. Students were required to build at least one low-fidelity prototype that could be tested to provide design feedback. These prototypes varied from cardboard cutouts to 3D printed parts depending on the designs and choices of the students. Results were presented during lab to get feedback once again before students confirmed their design for the final high-fidelity prototype.

The biggest change of the final design process was having the students use the IF to build their own devices, instead of having TAs do the 3D printing for them. The IF is located within the Engineering and Computer Science Building and has equipment available for anyone on campus. There is also staff available during operating hours to help answer questions or solve any equipment problems. While the groups were required to design and print a minimum of one 3D printed piece for their toy, there was no limit in size, shape, or number except the limitations of the 3D printers themselves, and of course time. Students also used other equipment provided by the IF including the laser engraver, hand tools, and the wood shop, which is in a separate location.

As was the case for the original project, students were required to submit a report that compiled all of the design work they did over the seven-week period. This included sections on constraints and criteria, conceptual design, detailed design including SolidWorks drawings, prototyping, testing, and final design. Each group was also required to make a video demonstration of their device to share with the rest of the class. Figure 1 shows examples of final projects.

![Figure 1: Examples of final designs from the course. From the left: Monkey’s Playhouse complete with pulley elevator, gear crank door, and slide. Musical gear box with moveable gear train. Pull back car with interchangeable wheel sizes. Crane with pulley system.](image)

Table 1 gives a summary of the differences between the course in 2014 and 2018. In order to allow for a longer design project, some original elements of the course were removed. For example, there used to be a few lectures and a lab on DC and IC engines. While these are usually fun and interesting for the students, these are also areas that covered again in later courses once the students have more fundamentals and can truly appreciate the full scope of the designs. Therefore, the decision to leave these topics out was approved by the instructor.
Table 1: A comparison between the original and redeveloped project.

<table>
<thead>
<tr>
<th></th>
<th>Original Project - 2014</th>
<th>Redeveloped Project - 2018</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Timeline</strong></td>
<td>3 Weeks</td>
<td>7 Weeks</td>
</tr>
<tr>
<td><strong>Maker Resources</strong></td>
<td>Hand tools Parts printed by TAs</td>
<td>12+ 3D printers Hand tools Laser engraver Wood shop</td>
</tr>
<tr>
<td><strong>Other Course Topics</strong></td>
<td>Engineering Drawings Microsoft Office Tools SolidWorks Simple Machines Memo Lab Reports DC Motors IC Engines</td>
<td>Engineering Drawings SolidWorks Simple Machines Memo Lab Reports</td>
</tr>
<tr>
<td><strong>Other Course Assignments</strong></td>
<td>5 Labs 6 Individual Homework Assignments Final Exam</td>
<td>2 Labs 2 Individual Homework Assignments 1 Group Homework Assignment 1 Individual Quiz Final Exam</td>
</tr>
</tbody>
</table>

Results and Discussion:

A survey was given to the students upon completion of the course. This survey was given anonymously every year with the same questions starting in 2014, except for 2017 when the instructor was on family leave during the end of the quarter. The goal of the evaluation was to assess the students’ feelings about the project and engineering design in general. A scale of 1-5 was used where numbers corresponded to the following responses: 5 – Strongly Agree, 4 – Somewhat Agree, 3 – Neutral, 2 – Somewhat Disagree, 1 – Strongly Disagree, 0 – No Opinion. If a student gave an answer of “No Opinion” their response was taken out of the average calculation. Table 2 provides a list of the questions, plus the mean response for 2014 and 2018.

Table 2: Comparison of evaluation results from project surveys in 2014 and 2018.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Mean Response Score - 2014</th>
<th>Mean Response Score - 2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before the final project I knew a lot about engineering design</td>
<td>3.46</td>
<td>4.05</td>
</tr>
<tr>
<td>Before the final project I knew nothing about engineering design</td>
<td>2.24</td>
<td>1.65</td>
</tr>
<tr>
<td>After the final project my understanding of engineering design improved</td>
<td>4.53</td>
<td>4.71</td>
</tr>
<tr>
<td>The final project was a good way to teach engineering design</td>
<td>4.54</td>
<td>4.68</td>
</tr>
<tr>
<td>I think it is important that students be introduced to the design process early in their time as engineering students</td>
<td>4.61</td>
<td>4.83</td>
</tr>
</tbody>
</table>
The results of the evaluation gave some insight into a few areas that have changed over the past few years, both from the side of student knowledge and the project itself. First, since 2014 students have agreed more that they are more knowledgeable about engineering design before they enter the course. As shown in Figure 2, agreement with the statement “Before the final project I knew a lot about engineering design” has increased, along with disagreement with the statement “Before the final project I knew nothing about engineering design.”

The data in Figure 2 aligns with the subjective observation that many students coming into their first quarter at DU have an experience with some sort of engineering or technology course from high school. While the experiences and content in these classes varies, more students do appear have some introduction to these topics. However, there are still students who have no experience with engineering design. In both 2014 and 2018, about 10% of respondents strongly agreed that they did not know anything about engineering design before the course. This means that there is still a knowledge gap that must be bridged in order to develop a successful project for all students registered for the course.

Other data from the evaluations also revealed that agreement with the statements that they found the project fun, interesting, not boring, and overall liked the final project increased in 2018 from 2014. However, agreement with the statement that they found the project to be frustrating also increased. This is interesting as it implies that even though they were frustrated with the project, they still found it rewarding. This could be because they felt more personally invested in the device since it was a unique design, so even though they were frustrated they still enjoyed the process overall. This is similar to what was found in Savage et al. where they stated, “Even though students expressed frustration with what they perceived to be vague assignments, in the end their struggles seemed to yield a deeper level of understanding.”[5] One student summed it up as they stated in their evaluation “It was really fun, really stressful, and a lot of experience.”

The comments from the students also indicated how they felt about the creativity and freedom the design prompt allowed them to have:

- “I loved the amount of freedom and creativity that the final project allowed. I also thought it was a great way for students to apply their knowledge of engineering concepts.”
- “I would say that it was a great experience that relied on me to use my time effectively and

<table>
<thead>
<tr>
<th>Perception</th>
<th>2014 Score</th>
<th>2018 Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>I found the final project to be interesting</td>
<td>4.56</td>
<td>4.62</td>
</tr>
<tr>
<td>I found the final project to be fun</td>
<td>4.42</td>
<td>4.57</td>
</tr>
<tr>
<td>I found the final project to be boring</td>
<td>1.60</td>
<td>1.68</td>
</tr>
<tr>
<td>I found the final project to be frustrating</td>
<td>3.01</td>
<td>3.15</td>
</tr>
<tr>
<td>Overall I liked the final project</td>
<td>4.26</td>
<td>4.46</td>
</tr>
</tbody>
</table>
was one of the first times that it was really all up to my own mind to find a solution for problems, and I enjoyed being pushed in that direction.”

Of course, some students felt that the project had either too much freedom or not enough. One stated, “Give the constraints instead of having the students search for it.” And another commented they would have preferred “More of a creative choice on the project, I felt it was a very specific thing we had to build.” While no project can satisfy all student wants, the overall indication from the students was a preference for having design freedom.

Another area that came up when students were asked what they would change about the project in the future was the availability of 3D printers. Even with over a dozen 3D printers available, there was still a time crunch on making sure everyone was able to print their necessary parts. Because it is a much faster manufacturing process, allowing the students to use the laser engraver to make one of their custom parts would be a good solution. Students were required to present their 3D printing plan before making any parts, however it would also be beneficial to continue to train the students on best practices of 3D printing so they could be as efficient as possible when using the printers.

Conclusions and Future Plans:

Overall the new project hit the redevelopment goals of increased opportunity for creativity, student involvement in the printing and building process, and an expanded exploration of the engineering design process. This being said, there is still room for improvement and expansion of the project. One area is making sure that access to the IF and 3D printers is equitable. This is being worked on with the IF Director and staff so that a process for helping the students effectively print can be developed. There is also an opportunity for the project to have even more freedom. Perhaps allowing for a wider age range, or not including the requirement that a simple machine must be used. Moving forward, it will be of interest to track whether or not these students were better prepared for their next design course, which is in the 3rd year, and track retention of these first-year students to the second year and beyond and see if their initial experience may have impacted their desire to continue on an engineering path.

References:


