Balancing the Engineering Disciplines!: An Interdisciplinary First-Year Design Project

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Abstract

When engineering students graduate and begin work as an engineer, they are confronted with the reality of the interdisciplinary nature of the workplace. This reality frequently extends beyond engineering disciplines and includes colleagues from other backgrounds ranging from project managers, marketing and sales, to assemblers, machinists, and technicians. Often, they are also required to follow a documented or prescribed process that may resemble an engineering design process. To better prepare students for both engineering practice and internships along the way, we developed a semester-long design project that is bound by many of these constraints. This Work in Progress paper describes the project goals and constraints, periodic checkpoints that reinforce the engineering design process, assessment methods, and project motivations with the objective of enabling others to successfully implement the design project in their course.

Since its founding, Dunwoody College of Technology has prided itself on ensuring students learn in an environment that mirrors industry as closely as possible. With this history in mind, we guide interdisciplinary groups of students consisting of electrical, mechanical, and software engineering majors through the engineering design process. The project objective is to research, design, build, calibrate, and test a balance or scale with a digital readout made from simple components. Successful completion requires elements of each engineering discipline represented in the course. The course itself, Introduction to Engineering, is laid out in a manner that incrementally introduces each of the concepts required for the design. For example, the concept of forces and moments are introduced within the mechanical engineering module prior to requesting the students demonstrate their weight measurement scheme.

The project was carried out with three independent sections of students participating in team sizes ranging from 2 – 3 students, with the intent of having a mix of all three disciplines when possible. Preliminary lessons learned and feedback from administering the project are presented. Additionally, resulting designs are compiled and organized into categories, with some common themes and pitfalls identified. Recommendations for future iterations that incorporate lessons learned are discussed.

Introduction and project goals

The Introduction to Engineering course at Dunwoody College of Technology is required for first semester Electrical, Mechanical, and Software engineering students. The intent of the course is to expose students to real engineering work with the expectation that students will determine whether engineering is right for them and which discipline is the right fit for them to pursue. One of the ways the course explores these questions is through an interdisciplinary, semester long design project. Specifically, in fall 2020 (when we had 30 students across three course sections), we developed and administered a balance design project. The benefits of these types of projects have been well documented in the literature [1, 2, 3, 4, 5]. One of the authors' primary goals was to get student design teams collaborating on a project that crossed all represented disciplines in a reasonably well-balanced experience. It is also intended for students to rely on each other and the numerous subject matter experts on campus to successfully complete the design. One benefit of this approach, which we heard from students throughout, is the appreciation for other disciplines and fields that can come from needing to do that type of work. Course content on the engineering design process, teamwork, communication, and discipline specific concepts were scaffolded around the project leading to just-in-time teaching of relevant information. This scaffolding technique is discussed in the literature as well [6]. We have listed all the course objectives; those that the project is intended to assess are denoted by an asterisk.

<u>Course objectives (asterisks indicate objectives addressed in the project)</u>

1. Relate expectations required by engineering curriculum*
2. Differentiate engineering disciplines (electrical, industrial, mechanical, software, etc.)*
3. Apply the engineering design process to a group project*
4. Outline the history and development of engineering and the various disciplines
5. Utilize software tools to improve productivity by creating flowcharts and spreadsheets*
6. Collaborate on a project as a member of a team*
7. Determine reliable sources of information and new knowledge (scientific method)*
8. Evaluate engineering environments to develop paths of personal exploration (i.e. internships, elective courses, etc.)
9. Document and communicate project success through a written report and project presentation*
10. Create a professional portfolio to begin a collection of engineering artifacts

In addition to the indicated course objectives above, the authors set out to design a project that would emphasize additional skills that frequently arise in engineering practice.

1. Demonstrate how the engineering design process itself can be non-sequential and require iterations to incorporate feedback and learning from prototyping and research activities.
2. Acquire a better understanding of how physical quantities are measured in practice; in this project, the mass of an object. That is, how can you use known physical quantities and laws to measure those quantities that are not known?

Assignment details

The project was structured to stretch over the majority of the semester, which at the time of writing, is 18 weeks long. During week 3 of the semester, the authors introduced the project to their respective sections. Milestone deliverables that follow the engineering design process were assigned to build up to the final testing and documentation stages. An additional purpose of the deliverables was to keep the project progressing while enabling instructors to provide feedback on each team's design and build. Each of the milestone deliverables are worth 20 points total. The initial submission earns half the points and the final submission earns the remaining half. The final submission includes an opportunity to incorporate instructor feedback and other learning gained throughout the semester. The final presentation and report are considered a single assignment worth 80 points. The course as a whole has approximately 1,000 points; thus, the project is approximately 20% of the overall grade. **Table 1** displays the titles of each deliverable. Each deliverable is assigned a number with a PR code that indicates to students and faculty it is related to the PRoject. The students quickly adopted the shared language, e.g. "working on PR3". Each PR is described, along with its intent, in further detail in the following section.

Table 1: Overview of Project Deliverables

Week Due	Deliverable	Description
5	PR1	Project Concepts and Schedule
7	PR2	Conceptual Design Candidates
8	PR3	Force Measurement Scheme Demonstration
10	PR4	Project Status Update
13	PR5	Wiring Diagram and I/O Sheet
15	PR6	Pseudo Code
16	PR7	Testing Results
17	PR8	Project Presentation and Report

The specific design requirements for the balance were as follows:

- It must determine the mass of objects ranging from 50 g to 1500 g.
- It must have a digital display that reads the mass out to 0.1 g precision.
- It must have capacity to hold a 4" x 4" x 4" cube.
- The total budget is $100.
- Off-the-shelf load cells are not permitted (the use of strain gages was also discouraged, but not forbidden).

Performance incentives were also added to increase interest in the project. A 5% bonus on the project grade was offered for the most accurate (minimized error) balance. Further, if more than 50% of the project teams in each section were successful all project teams would earn a 5% bonus on the project grade. This second incentive was designed to facilitate collaboration among teams. In one of the sections, a team had difficulties getting a signal and displaying the information on their digital display during final testing. Seeing this issue, another team sprang into action to help with troubleshooting of both the hardware and the software, resulting in a successful series of tests and a 5% bonus for that section.

<u>Deliverable short summaries</u>

PR1: Project Concepts and Schedule – Due week 5

The first project deliverable required each team to submit a minimum of three concepts, which consisted of a hand sketch and a short paragraph describing the general principle. A few examples included measuring water rise height from squeezing a flexible membrane, measuring deflection of a thin beam, and measuring the stretch of an extension spring. Additionally, we requested a rough project schedule to encourage the students to start breaking the project into workable pieces and coordinate their individual schedules. Lastly, each team was asked to identify two areas of challenge/pitfalls for the project and their project team to develop a plan to mitigate the risk. Asking the teams for pitfalls in several deliverables was another way to give us visibility to challenges and offer feedback throughout the project. Note that asking for challenges was a theme throughout the deliverables, but we won't explicitly mention each time it was asked in the remaining short descriptions.

PR2: Conceptual Design Candidates – Due week 7

At this point in the project, we asked each team to identify which design or pair of designs they are continuing to pursue, along with rationale for both the continuation and abandonment of other options. In the lecture portion of the class, we discussed techniques for effective decision making and design narrowing. To reinforce the value of these techniques, we asked the teams to briefly explain what process they used as a group to narrow down their options.

PR3: Force Measurement Scheme Demonstration – Due week 8

This deliverable was designed to get the teams thinking of how the actual measurement will occur in practice. Each team was required to describe the physical principle behind their chosen design, along with the components and specifications they deem necessary to the measurement itself. For example, if using an extension spring, the displacement will need to be measured. Additionally, the appropriate spring constant and overall travel should be considered. Lastly, each team included a step-by-step sample calculation, including how the system is initially calibrated, showing how their design would measure a 750g mass.

PR4: Project Status Update – Due week 10

There were two objectives for this deliverable. The first objective was to compare the schedule provided in PR1 (the team's baseline schedule) to the current state along with developing a revised schedule. The second objective was to schedule a 30 min meeting with their respective instructor to have an informal design review as they may encounter in engineering practice. This meeting also served the additional purpose of a "spot" check to have the teams talk through their plan and see if we could help provide guidance. In several instances, talking through the design as a group helped fill in students' gaps in knowledge.

PR5: Wiring Diagram and I/O Sheet – Due week 13

This deliverable coincided with the electrical engineering module being taught in class. Much of the focus was on making sure the teams will be able to specify components and wire the circuits needed. In class, a couple of days were dedicated to students stepping through building and measuring basic circuits (DC series, parallel). The electrical engineering module ended with building a Wheatstone bridge to further emphasize how one measures a small change in resistance. The content of the deliverable was a simple diagram showing each of the electrical components, with part numbers labeled, and how they connect together. Further, the students were asked to show how the inputs/outputs were expected to function during operation.

PR6: Pseudo Code – Due week 15

This deliverable, as was done with the electrical engineering section, was synced with the software engineering module. A portion of the software module stressed the importance of thinking through and documenting the structure of a code in a pseudo code or flowchart format. For this deliverable, the teams were tasked with showing a flowchart for the project, along with a list of Arduino functions they anticipate needing (e.g. pinMode(), digitalWrite(), delay(), et cetera). For many of the students, this was their first introduction to programming and the lecture portion of the class helped to bridge that gap in knowledge. We used Arduino Unos as a teaching platform and most teams adopted the platform as their controller. We also requested that the students list out a minimum set of features to have a viable build on testing day as this was the last deliverable before testing.

PR7: Testing Results – Due week 16

This deliverable was unique in that students weren't explicitly asked to submit anything. The contents of this deliverable laid out how each of the design elements were going to be graded on testing day. Test results were compiled and sent out to the students for inclusion in their final report. The "performance" was based on having a functional design. Students earned points for complying with all design requirements, reading a signal into their program, and displaying some value on a digital display (it did not need to be correct to receive the points for functionality). Some bonus points were awarded for the most accurate results.

PR8: Project Presentation and Report – Due week 17

This final deliverable consists of a group presentation and report. We won't go into the details for each, but we provided general guidance on how to properly lay out a technical report and the rubric for the presentation made expectations clear. A unique aspect of the final deliverable was an opportunity to take the feedback received throughout the semester, revise the appropriate deliverable, and resubmit it to improve the grade.

Example student projects from testing day

Over the three sections a total of 12 unique balances were designed and built. The designs fit into a few major categories. Several designs used a spring, either extension or compression, and gathered a signal with either an ultrasonic distance sensor or a potentiometer (linear or rotary). Several groups attempted strain gage based designs (at least five designs used a strain gage of some variety). One group attempted to make their own strain gage by measuring the resistance of a stretched wire. Only one of the strain gage designs was successful. One group tried a method of measuring the current needed for an electric motor to lift the mass off of a limit switch and correlated the reading to a mass; the team's unique approach was met with some success. A traditional beam balance with a rotary encoder to determine the location of the counterbalance was the last design type. A number of example balances from the final day of testing are shown in **Figures 1 & 2**. Based on the lack of success with the strain gage (and the level of experience needed for the group that was successful) future iterations will not allow strain gage based designs.

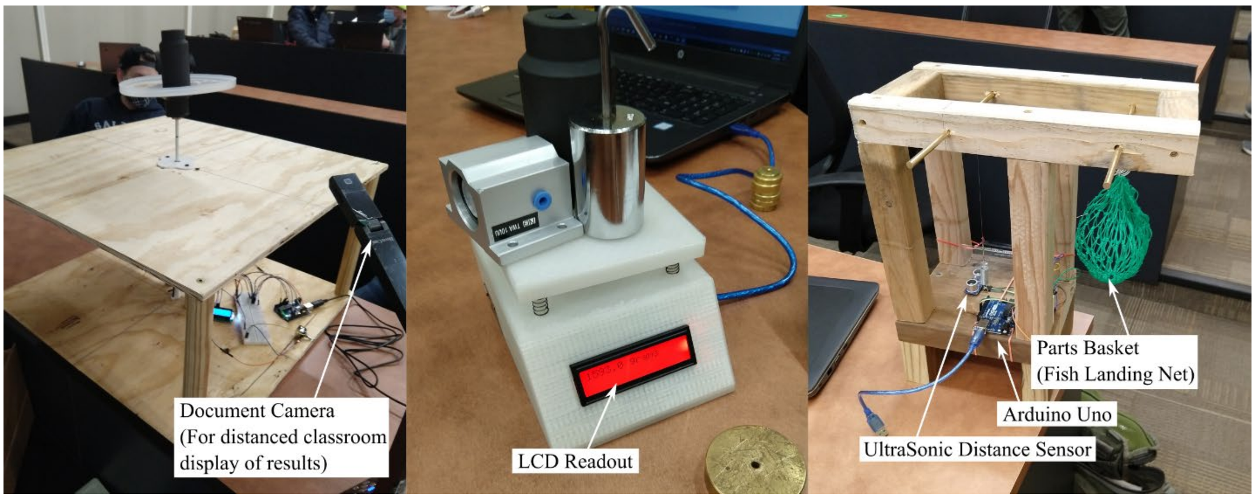

Figure 1 - Example student balances. The left balance utilized a rack and pinion connected to a rotary potentiometer to convert the linear motion of the plunger to a mass value. Due to Covid-19 distancing requirements, a document camera that projected the testing for all students to see in real-time was used. The team that made the middle balance leveraged 3D printing to package all of the electronic components. Lastly, the rightmost design measured the deflection of their spring with an ultrasonic distance sensor.

Figure 2: Students making last minute adjustments during testing day.

Assessing the project effectiveness with student feedback

The student's perception of the project's effectiveness in achieving the instructional goals was measured both quantitatively and qualitatively. The quantitative feedback was measured through an anonymous survey, while the qualitative feedback consisted of a series of non-anonymous reflection questions on the final exam. In order to keep the feedback balanced, we asked for two items to keep and two items to either remove or improve on the project. Below we have listed a sampling of feedback from the qualitative responses with a summary of the quantitative results following afterward.

<u>Student feedback on aspects to keep:</u>

1. "I would recommend keeping multiple disciplines of engineering involved as it makes you work outside of your comfort zone, which I feel is a good way to learn."
2. "I really enjoyed the fact that there was a lot of freedom with the project. It allowed us to generate our own ideas about things and learn (or get better at) a lot of things like coding, wiring, building, etc."
3. "I really liked that we didn't have to use specific parts. Being able to order our own parts was really cool and it made us responsible for ourselves and the project even more than we already knew we were."
4. "I would also keep the milestone deliverables because it ensures that the project is worked on early in the semester and prevents students from waiting until the last minute to work on the project."
5. "Two aspects of our semester-long project that I would recommend keeping are the PR style check-ins and the team/group aspect. The PR style check-ins worked extremely well to ensure our group developed our project in a logical and practical way, as well as helped ensure that we stayed on track over the semester. This check-in format was easy to follow, yet was critical in breaking down a large project into smaller, more manageable pieces. I also recommend keeping the team/group aspect when it comes to this project, as

it was very beneficial to have other people to bounce ideas off of, help in weaker areas, and collaborate with."

Student feedback on aspects to change:

1. "Deliverables (wait what?) - Yes the deliverables were a good way to stay on track and I do understand the point is to go through the whole process, but some deliverables felt repetitive or redundant. Maybe they weren't, but that is how some of the earlier PR's felt. They could potentially be reduced in number, but increase the work for each PR. This would also help groups split the work up. My group definitely have difficulties finding work for everyone for each deliverable."
2. "Project updates to be presented in class. Everyone can use extra experience with public speaking. This could also benefit a group that is having trouble generating ideas."
3. "Some of the lectures regarding key areas, such as circuits, provided a general overview rather than the direct relation to the project. I think lecturing and working on how these concepts related to the project would have been more helpful than trying to understand the concept as a whole."

Anonymous quantitative student feedback

The quantitative portion of the student survey asked students to anonymously rank the prompts in **Table 2** on a 5-point Likert scale from 1 being strongly disagree to 5 being strongly agree [7]. Over three sections a total of 26 responses were received. The total final enrollment across the sections was 30 students with a resulting response rate of 86.7%. Course sections were reduced in size to comply with Covid-19 social distancing requirements. The aggregated responses are included in **Table 2**.

Table 2: Student responses to anonymous survey

Prompt	Average	Std Dev.
1 - The project helped me understand how different engineering disciplines work together.	4.58	0.50
2 - I learned more about my discipline from the project.	4.04	0.77
3 - I learned more about other disciplines through the project.	4.42	0.64
4 - I learned how to learn new skills through the project.	4.37	0.82
5 - If given the choice, I would do this (or a similar) project again.	3.77	1.34
6 - The project helped me work on a team more effectively.	4.04	0.87
7 - I grew in communication through the project.	4.12	0.71
8 - I developed an understanding of how the engineering process is applied.	4.35	0.80
9 - On a scale of 1-5 (5 being the best) I rate the project as a ____ overall.	4.00	0.91

Based on these results, we consider the project a success. Overall, the anonymous feedback does agree well with the more long-form feedback elicited on their final exam. The fifth prompt may have been taken literally by some students, i.e. repeating the exact project again, resulting in the lower average and higher standard deviation in the responses. We plan to revise this prompt in future surveys.

Lessons learned and future improvements

While we consider the initial iteration of the project a success, there are several items the authors plan to incorporate next time the course is offered. These improvements are based on lessons learned by the authors during the course of the semester and student feedback (both officially captured and given anecdotally throughout the semester).

Project specific

Revising of deliverables
After reviewing the final reports, it became clear that only a few project teams substantively revised initial milestone deliverables. Based on anecdotal exchanges with students it seems there was initially confusion on how feedback is provided through the Learning Management System on campus. Another factor that appeared to be at play is the time between the initial submission and when it is being reconsidered; a significant amount of design iteration occurs between. In future iterations of design projects, we plan to address this by having a rolling set of submissions and resubmissions. For example, when the milestone deliverable PR3 "Force Measurement Scheme Demonstration" is submitted the prior milestone deliverable PR2 "Conceptual Design Candidates" is resubmitted in its final form incorporating instructor feedback for the second half of the point value.

Size of PR deliverables
Some student feedback indicated that there were instances where there were not enough individual tasks to truly split or collaborate on a deliverable. The original intent was to have standalone deliverables that were discipline specific, but it may be better overall to reduce the total number of deliverables and increase the work required for each.

Timing of the prototypes and physical builds
A common theme among individual student interactions and in the qualitative feedback was the desire to have started earlier on the building of the physical model. There were several teams that waited until late in the semester to physically build an apparatus, leaving little to no time for troubleshooting when issues inevitably arose. Moving the physical build earlier in the semester may improve this sentiment and leave more time for troubleshooting and code development later in the semester rather than a mad dash to present *something* on the final testing day. Another issue that would be helped is some teams waiting too long to order parts only to realize they need to place an additional order due to needed design changes or delays in processing.

Further, the build could progress more closely with the course content. For example, if class time is spent discussing how to read an analog sensor value with an Arduino, the project deliverable a week or two later could be demonstrating that the measurement scheme works and an analog value is being read by the microcontroller. This adjustment could be made without significant reshuffling of course material and flow. In fact, it would likely help to reinforce the teaching of that topic with immediate hands-on application.

Strain gages

The last change related specifically to the project would be to remove the option of strain gages. In the original project requirements, off-the-shelf load cells were not allowed as using a pre-built device removes much of the learning opportunity from the design and build. Strain gages are similar in this disadvantage with the added downside of being finicky, particularly when students have little experience with sensitive electro-mechanical components. Lastly, a strain gage done well is unlikely to be beaten in the bonus points competition, so removing that option would level the playing field and result in more diverse designs.

Course homework

Throughout the semester, homework assignments relating to the various topics covered in the course are assigned. While there are a couple of assignments related to the project, in future course offerings, we will be intentionally using the assignments to build on the skills needed to be successful with the design project. For example, very early on, we plan to have an assignment to research different methods of determining the mass of something. This could then be pulled upon by each team member when concepts are being developed a few weeks into the course. Depending on available time, an activity could be to take apart and describe the inner workings of an existing digital scale or balance.

Communication Skills

Introducing and reinforcing proper technical writing habits

Because Introduction to Engineering is one of the student's first technical courses, it provides an excellent opportunity to introduce and start reinforcing good technical writing habits and concepts. A dedicated course on technical writing is taken later in the curriculum. In future iterations of the project, we plan to provide more guidance on the formatting of each PR, likely sharing how the final report will be expected to look to help the students see how everything comes together. This effort will become easier as more examples from previous years can be pulled upon, but providing the example report formats up front can go a long way in setting expectations.

Presenting and providing constructive feedback

Another form of communication, in addition to writing, that is important to the success of the project is presenting. Depending on the size of the class, having each group present several times throughout the semester can be challenging as it directly reduces time for other material. However, in future iterations, we plan to leverage the design reviews to have teams practice their public speaking and critical thinking skills by having the review take place with another team. The vision is to have Team A present their design to the instructor and Team B. Team B would get exposure to another design and be challenged to point out areas that need further thought and refinement. After the first half, the roles would swap and Team B would present to Team A.

Summary and conclusions

Throughout this paper, we highlight the successes and areas for future improvements based on the development of a semester-long design project. The project, working on a small team to design and build a digital balance from simple components, provided students with a better appreciation of engineering disciplines beyond their chosen major. Further, a number of students begin college having little to no hands-on experience. This project, being in the first semester, helps to bridge that experience gap and ensure that all students end with the ability to build a simple, physical prototype or model, setting them up for better success on future engineering projects.

We look forward to extending the work by making incremental changes to the project. We also plan on investigating the impact of this project on retention and persistence of underrepresented populations in engineering by monitoring this cohort of students as well as future groups. As this was the first course offering incorporating this project, we will collect data on retention and persistence of this first cohort in a longitudinal study. The baseline groups will be the cohorts from fall 2018 and fall 2019 when a different project focused on robotics was used.

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