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Integrated and Multi-Disciplinary First-Year Engineering Drone Design Project

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Abstract

This paper is in the Design Methodology category. First-year engineering projects play an important role in retention by exposing students early in the curriculum to the type of work done by real engineers. In the project described here, electrical and mechanical engineering students were divided into six teams to design a drone system for a developing country to deliver supplies such as food and medicine. Each team looked at a different aspect of the project. The six teams included: land-based delivery drone, water-based delivery drone, quadcopter delivery drone, airplane delivery drone, retrieval drone, and power generation. All of these would be based at the same location in a country selected by the students. The first four are common types of drones that can be used to deliver supplies. The retrieval drone was intended to recover a delivery drone that failed to make it back to the home base. The power generation team designed a method to produce power to charge the drones using some type of renewable energy such as wind, solar, or hydroelectric. This interdisciplinary project exposes first-year students to design, teamwork, communications, and humanitarian engineering.

Introduction

Design Projects

Wankat and Oreovicz wrote, “Many engineers contend that design is the heart of engineering” [1]. ABET defines engineering design as “a process of devising a system, component, or process to meet desired needs and specifications within constraints” [2]. The ability to design is a key attribute of an effective engineer. Design projects help engineering students, [3]:

- enhance their understanding and enjoyment of engineering,
- increase their technological repertoire,
- appreciate the integration of design and analysis,
- learn how to work in multi-disciplinary teams,
- develop leadership, management, and communication skills,
- appreciate the importance of professional responsibility, and
- become motivated towards their engineering studies.

While capstone projects have been a staple of engineering education for many years, freshmen design projects have more recently also become ubiquitous [4]. That is a dramatic change from the past where it was not uncommon for engineering students to first encounter engineering courses as late as their junior year [5]. A key recommendation from the iconic National Academy of Engineering Report *Educating the Engineer of 2020* is “Whatever other creative approaches are taken in the four-year engineering curriculum, the essence of engineering – the iterative process of designing, predicting performance, building, and testing – should be taught from the earliest stages of the curriculum, including the first year” [6].

A complaint from industry is that too many undergraduate engineering projects are not representative of real-world problems. Jonassen et al. wrote [7],

> Workplace engineering problems are substantively different from the kinds of problems that engineering students most often solve in the classroom; therefore, learning to solve classroom problems does not necessarily prepare engineering students to solve workplace problems.

Therefore, it is recommended that projects contain as many elements (e.g., design, fabrication, testing, etc.) of real-world projects as possible. This project contains most of those elements.

More and more, today's challenging and complex engineering projects are interdisciplinary. Where appropriate, undergraduate engineering education should include interdisciplinary projects [8]. This is a change in approach compared to the past where most undergraduate engineering projects were completed by students from a single engineering discipline. In the project discussed here, electrical and mechanical engineering students worked together as the project required both electrical and mechanical skills. However, since these are first-semester freshmen, they have not had any engineering courses yet, so it is not truly interdisciplinary in the same way that it would be in industry where degreed engineers possess the appropriate skills in their disciplines.

An argument can be made to let students select their project from a limited list of possible choices, with the thinking that students will be more motivated to work on a project they selected [9]. Another approach might be to let them come up with their own project, which is sometimes the case for capstone projects. While there is something to be said for giving choices, the approach taken here is that all students work on the same project, although on different aspects of it. This is more straightforward for instructors, particularly if there is only one instructor for a course. It also better simulates projects in industry where engineers rarely get to select what projects they work on.

First-Year Projects

Research has shown that design projects for first-year engineering students have many benefits. One of the most important is improved retention by exposing students to real engineering early in their college experience, particularly for those students who have not yet decided on their major [10]. Earlier exposure to engineering helps motivate students to select engineering as a major and to continue in that major. In the past, many students dropped out of engineering before they ever had any actual engineering courses.

Another benefit of first-year design projects is exposure to creativity and innovation [11], depending on the nature of the project. A Royal Academy of Engineering study found that creativity and innovation are very important characteristics of working engineers [12]. Ideally, students would have some flexibility in a project to come up with designs that are innovative [13]. This motivates them to continue in engineering. Creativity is also an important characteristic desired by industry to help them develop new and profitable products and services. In the project here, students had some ability to be creative.

Humanitarian Engineering

ABET Student Outcome 2 is "an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors." This project specifically concerns design related to the welfare of others and the social conditions in a developing country. There is growing interest in engineering education projects that benefit people in need (e.g., [14]). Incorporating humanitarian values into a first-year engineering course [15] is congruous with the jobs of many engineers who design products that benefit the daily lives of others. Mitcham and Muñoz define humanitarian engineering as "the artful drawing on science to direct the resources of nature with active compassion to meet the basic needs of all – especially the powerless, poor, or otherwise marginalized" [16]. A survey of engineers found that some of the reasons for doing humanitarian engineering include helping people, improving society, and making a difference [17].

For this particular project, the focus was not specifically on humanitarian engineering, but rather on the design process for a drone delivery system. No attempt was made to determine the needs of the chosen country. The drones were designed to deliver supplies that were assumed to be chosen by appropriate people in the selected country. Future implementation of this project may include some type of engagement with the selected country.

Hands-on Experience

Sometime after WW2, the emphasis in engineering education shifted from the practice of, to the science of, engineering [18]. Kerr and Pipes identified this as a crisis in engineering education and called for a more hands-on curriculum [19]. Dym et al. wrote, "The resulting engineering graduates were perceived by industry and academia as being unable to practice in industry because of the change of focus from the practical (including drawing and shop) to the theoretical" [18]. In the past couple of decades, there has been increased attention to the practice of engineering, particularly on design. Project-based learning (PBL) has increased significantly in popularity in engineering education, including for first-year students (e.g., [20]). Projects more closely simulate what real engineers do [21]. To be as realistic as possible, these projects should be ill-structured, have potentially multiple answers, and have constraints (e.g., budget, schedule, performance). The objective of these projects is to "immerse students in authentic engineering practice" [22]. The project described here attempts to do that.

A fundamental aspect of PBL is students working together in teams and solving problems collectively [23]. Springer et al. conducted a meta-analysis of research studies considering the impact of group learning on undergraduate science, mathematics, engineering, and technology (SMET) students [24]. They wrote, "Students who learn in small groups generally demonstrate greater academic achievement, express more favorable attitudes toward learning, and persist through SMET courses or programs to a greater extent than their more traditionally taught counterparts." One study found that forming first-year engineering teams increased retention going into the second year [25]. Another study also found that retention was increased for students taking a first-year project course, particularly for underrepresented students [26].

Teamwork is extremely important in virtually all aspects of engineering. Goldberg and Somerville describe engineering as a "team sport" [27] that requires interaction and collaboration to be effective. ABET defines a team as consisting of "more than one person working toward a common goal and should include individuals of diverse backgrounds, skills, or perspectives" [2]. The project here required teams because the scope would have been too big for individual students to reasonably handle on their own.

Project Description

The project discussed here is one element of a first-semester introductory engineering course named Engineering Innovation and Design Problem Solving that is required for all engineering degrees. The three-credit course consists of two hours of lecture and two hours of lab each week. Specifically, the project here is part of the lab portion of the class, but is not the only assignment for the lab. This project was designed to help meet two of the course learning objectives:

- Students will determine constraints for an engineering design problem
- Students will develop a drone system for a specific application

Drones, also known as unmanned aerial vehicles (UAV), are widely used in a range of consumer, commercial, and military applications. Drones are of general interest to many engineering students, probably because they combine technology in a type of live video game. Other universities have included drone projects for their engineering students, which have generally focused either on drone design or the application of drones [28]. Here, an attempt has been made to incorporate both design and application.

In this project, students were divided into six teams to design a drone system for a developing country to deliver supplies such as food and medicine. Students were assigned to each team and each team was assigned to a specific aspect of the project. The six teams included: land-based drone, water-based drone, quadcopter drone, airplane drone, retrieval drone, and power generation. Four of the drone teams had 5 students, one drone team had 6 students, and the power generation team had 9 students for a total of 35 students. Six students in the class were female students. All were freshmen engineering students including 27 mechanical engineering majors and 8 electrical engineering majors.

Because this is a first-year design project, the students were asked to select a commercially-available drone, rather than design a drone from scratch, that they then modified as appropriate. Regarding first-year design projects, Hicks wrote, "the lack of assumed knowledge limits the range of design challenges that can be assigned" [29]. Example modifications included: the delivery drones needed to include some method to be easily retrieved by the retrieval drone and the delivery drones needed to be able to carry a payload. An important constraint was their final design had to be easily maintained in the selected developing country. Another constraint was that each team had a budget of approximately $500 which came from their lab fees ($100/student) for the course.

The teams were selected based on each student's self-assessment of their knowledge of drones, 3D plastic printing, and renewable power generation. The instructor then divided the students so that each drone team had at least one student with significant knowledge and experience with drones. However, all students had to pass the FAA's drone certification exam (https://trust.modelaircraft.org/) by about the midpoint of the semester, so they would be more knowledgeable about drones. The power generation team had a student with significant knowledge and experience with renewable energy generation. All six teams had at least one student with significant 3D printing experience. In this scenario, it was preferred to assign students to a team, rather than have them self-select, for a variety of reasons:

- students were first-semester freshmen who did not know each other yet,
- being placed on a team is more consistent with how it is in industry where the supervisors, not the individual contributors, normally decide who will be on which teams,
- there is often less diversity on self-selected teams where students typically select other students similar to themselves (e.g., same major, gender, ethnicity, etc.), and
- students sometimes select other students of comparable abilities which could produce some teams with mostly higher achievers and some with mostly lower achievers.

Since this was a first-year, first semester project, most of the students did not know each other so teamwork and collaboration were important outcomes of the project. The teams needed to work together for the entire system to work properly. For example, the drone retrieval team developed a common method for retrieving the delivery drones, which included incorporating a type of hook that could be easily attached to the delivery drones. The power generation team had to work with the other five teams to develop suitable methods for charging the drones, where the latter did not all have the same types of batteries.

Teams determined the specifications for their part of the project. For example, the delivery drone teams decided what their payload would be, how far from the home base they could deliver their payload, and how the payload would be delivered. Then, they developed a preliminary design including what type of equipment needed to be purchased. The purchased equipment was then modified to meet the objectives. Then, the equipment was tested to determine its capability and the original design was modified to improve the performance which was measured and documented. As might be expected, students' approaches to design projects can vary widely depending on the context and their prior knowledge [30]. Some of the teams made significant modifications to their purchased equipment while others did not.

Communication is another important objective of this project. Students must learn how to communicate within their own team, since most of the students do not know each other yet as the course is for first semester freshmen. They must also learn to communicate with the other teams to ensure the entire system works as intended. Teams delivered oral presentations at various times during the project. They also prepared a final poster which was displayed for the entire campus to see.

There was some limited systems engineering in this project as the retrieval drone had to be capable of retrieving the delivery drones and the delivery drones had to have the capability of being retrieved. Additionally, the power generation team had to provide sufficient power to charge all of the drones at least once daily, assuming renewable energy such as wind or solar was available in sufficient quantity on a given day.

The purpose here was not to design a ready-to-use drone delivery system, but rather to expose students to a real-world problem with constraints and no single solution. With a limited budget, students were only able to deliver a small payload over a short distance. However, as part of the project, they also recommended other equipment that could deliver a more significant payload over a longer distance if they had a larger budget.

Results

Students had numerous graded assignments as part of this project which included:

- Select the location they recommended where the drone system would be located
- Discuss the impact of the selected location on their aspect of the project
- Determine rules for their teams
- Develop design specifications for their part of the project
- Produce at least three different concepts
- Select their preferred concept with sufficient justification
- Conduct a preliminary literature search
- Present the initial design concept to the class
- Complete the FAA drone training certificate training
- Select which drone or power generation equipment to purchase
- List any special tools that might be needed
- Developing a testing plan with metrics and an associated protocol
- Design an 8.5" x 11" campus-wide advertisement for the drone poster session
- Present preliminary test results to the class
- Present their poster on the campus-wide poster session

Some of these were relatively short written assignments that could be typed directly into the learning management system (LMS) while others were more substantial and required papers and presentations to be uploaded to the LMS. All of these assignments were done by groups with the same grade assigned to all members in the group.

Each of the six teams recommended a different location for the drone system. The location had to accessible by both land and by water. Teams made a brief presentation to the class advocating for their location and then the class voted on which location they preferred. Chad was selected because it is one of the poorest nations in Africa, has experienced many humanitarian crises, is relatively flat, and has access by land and water. A particular challenge is a rainy season that can produce flooding.

Figures 1 – 5 show the unmodified drones selected by the teams.

Figure 1. Land-based drone (Traxxas Rustler 4x4 BL 2S).

Figure 2. Water-based drone (Pro Boat Aerotrooper)

Figure 3. Quadcopter drone (DJI Mini 2 SE)

Figure 4. Airplane drone (HobbyZone Carbon Cub S 2).

Figure 5. Retrieval drone (Holy Stone HS600).

Figures 6 and 7 show two of the drones after modifications which had the most significant changes. Note that the nose of the airplane drone in Figure 7 was damaged during testing. The airplane is made out of predominantly Styrofoam and when it encountered a gust of wind it crashed into a light pole. The students learned first-hand about unplanned testing conditions but were able to successfully glue the nose back on. Challenges and setbacks are a reality in many actual engineering projects so student projects should ideally have the potential for failure [31].

Figure 6. Final land-based drone.

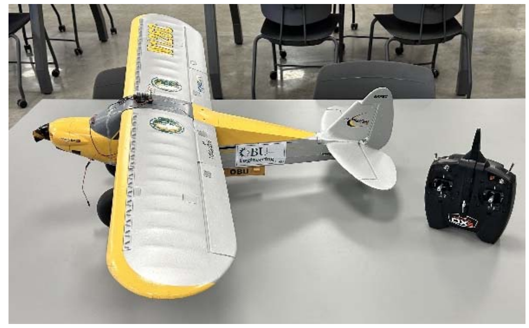

Figure 7. Final airplane drone.

A poster session was held at the end of the course for all students and faculty to see as shown in Figure 8.

Figure 8. Poster session at the end of the drone project.

There were some important limitations to this project. As is typically the case, the budget was limited so students were not able to purchase drones large enough to carry much weight. As is commonly the case, students often run out of time (regardless of how much time is allowed!). For this project, there was not enough time to fully test the drones to determine their travel range carrying a load. There was also not enough time to fully test the solar-powered charging system and determine the turnaround time for each drone.

Student Feedback

Twenty-one of the 35 students completed a voluntary and anonymous survey at the end of the course about their opinion of the drone project, among other questions related to various aspects of the course. The results are shown in Figure 9. The vast majority rated it good or excellent.

Figure 9. Student survey results for drone project.

Some selected student comments included:

- "I enjoyed the drone project as a whole. I liked that I was in the drone group. I think there were enough groups. I think there was enough time to do the work. I disliked the constant presentations & checkups we had to make."
- "I really enjoyed the drone project. I think that it is up to a group to challenge themselves and make the project interesting and fun. If we started working on it sooner, it would have been better. My group, as well as most groups, waited too long."
- "Really liked getting hands on experience. Not a lot of freshmen get the chance to do labs like this."
- "I liked how it stretched my perspective on engineering."
- "Higher budget for better drones with more design capabilities."

Several students recommended larger budgets and more time. Note the project lasted the entire semester.

Recommendations

Although one specific embodiment of this project is described here, there are a variety of ways this type of project could be implemented. For example, teams could be assigned to deliver a specific payload and have the flexibility to select whatever drone they choose given their budget. Rather than a drone system, student teams could each select the country they want to deliver supplies in, as well as what they want to deliver. Here, no attempt was made to connect with anyone in the country of interest, but that could be made a requirement for the students as part of the project.

It is recommended that students select their drones to be purchased as early in the semester as possible to give them more time to modify and test them. Multiple smaller milestones and rigorous deadlines are suggested to keep teams on time and on task, particularly because with freshmen who often have not learned effective time management skills yet. Next time this course is taught, it is planned to bring in a guest speaker who is an expert on drones. It is also planned to have some of the students from the first class who completed the project discussed here to offer advice to the next class who will be working on this project.

It is recommended that more questions be added to the end-of-the-course survey about this project. A question could ask the students about their impressions of designing with their peers and how this impacted decision-making. One observation was that there was a dominant student in some of the groups. Two students in one of the groups asked to be moved to another group because they felt their ideas were not seriously considered in their original group. Other questions could ask students about various aspects of the project such as hands-on, motivation, and teamwork. Other potential survey modifications include questions about teamwork and communication.

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