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GIFTS: First-Year Drone Design Competition

Dr. Charles E. Baukal Jr. P.E., Oklahoma Baptist University

Charles E. Baukal, Jr. has a Ph.D. in Mechanical Engineering, an Ed.D., and Professional Engineering License. He is the Director of Engineering. He has over 40 years of industrial experience.

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Abstract

This Great Ideas for Teaching Students (GIFTS) paper describes a Design Methodology project. First-year engineering projects play an important role in retention by exposing students early in the curriculum to the type of work done by engineers. In the project described here, electrical and mechanical engineering students were divided into teams to design drones to deliver Ready-to-Use Therapeutic Food (RUTF) packets intended to feed severely malnourished children. The main performance objective was to deliver as many RUTF packets as possible across a football field in 30 minutes as part of a drone competition.

The project exposed freshmen to all the major elements of design including cost, schedule, testing, reporting, communication, project management, and working in teams. While some technical specifications had to be modified during the course of the project, it ultimately achieved the primary learning objective of having students solve a real, ill-structured engineering problem of reasonable complexity with a humanitarian aspect that required innovation and creativity.

Introduction

Training students to become effective engineers is a very complex problem that continues to evolve and improve. One of the most important aspects of that training is teaching students how to design processes and equipment to meet client specifications. These projects incorporate many aspects of actual engineering practice such as design, teamwork, verbal and written communication, and project management. Gutiérrez-Berraondo et al. (2024) [1] wrote, "STEM higher education faces the challenge of educating its students in top level skills such as abstraction, generalization and transfer required to solve society's scientific technological problems." They argued strongly for the importance of including STEM projects in an engineering degree program.

The project described here is a major modification of a previously-described first-year drone design collaboration [2]. However, the only real similarity between the previous project and that described here is the humanitarian element. This design project was an important component of a three-credit course entitled "Engineering Innovation and Design Problem Solving." This first-semester freshmen course consists of two hours of lecture and two hours of lab each week. The drone project was part of the lab portion of the course. The other major element of the lab was disassembling and re-assembling some common engineered equipment such as a small compressor and a single-cylinder engine [3]. The class consisted of 26 students: 6 electrical engineering majors and 20 mechanical engineering majors. Two of the students were female and 24 were male. Most of the students were freshmen, although there were a few transfer students.

The engineering program has a full-time engineering lab manager and a 3D printing lab staffed by student workers which were both available to the students for the drone project. However, the students were encouraged to work things out as much as possible on their own which they largely did. Relevant lectures on subjects such as drones, creativity, and innovation were part of the lecture portion of the course.

Project-Based Learning

Considerable research has shown the importance of applied project-based learning (PBL) for undergraduate student development [4]. This is particularly important for engineering students as projects are an important part of what engineers do. Helle et al. (2006) [5] listed four primary motives for employing project-based learning: (1) preparing students for professional practice/work; (2) contributing to a desirable societal outcome; (3) fostering critical thinking; and (4) fostering understanding of the subject matter.

While the students received some training on teamwork and project management during the course, they learned largely by doing. Since this was for first semester freshmen, most students had not had much exposure to projects of any significant complexity. The intent was to give them a project with some challenge without being overwhelming.

First-Year Projects

While capstone projects have been a staple of engineering education for many years, freshmen design projects have more recently also become ubiquitous [6]. Research has shown that design projects for first-year engineering students have many benefits, such as improved self-efficacy and increased confidence in professional skills such as teamwork, communication, and leadership [7]. One important benefit is improved retention by exposing students to real engineering early in their college experience, particularly for students who have not yet decided on their major [8]. Earlier exposure to engineering helps motivate students to select engineering and to continue in that major. In the past, many students dropped out of engineering before they ever had any actual engineering courses which sometimes did not occur until the junior year. Most engineering programs today incorporate some type of design as early as the freshman year.

Another benefit of first-year design projects is exposure to creativity and innovation [9], depending on the nature of the project. A Royal Academy of Engineering study (2007) found that creativity and innovation are very important characteristics for working engineers [10]. Ideally, students would have some flexibility in a project to come up with designs that are innovative [11]. This motivates them to continue in engineering. Creativity is also an important characteristic desired by industry to help companies develop new and profitable products and services. In the project here, students had some ability to be creative.

The teams were selected by the instructor based on student survey responses to their prior knowledge of drones and 3D printing. The instructor attempted to distribute this knowledge as evenly as possible over the teams. Note that all students were required to complete the FAA drone certification exam (https://trust.modelaircraft.org/) by about the midpoint of the semester, so they would be all have at least a minimum knowledge about drones and FAA regulations.

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 concerned design related to the welfare of others. There is growing interest in engineering education projects that benefit people in need (e.g., [12]). Incorporating humanitarian values into a first-year engineering course [13] is congruous with the jobs of many engineers who design products that benefit the daily lives of others. Mitcham and Muñoz (2010) [14] defined 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." A survey of engineers found that some of the reasons for doing humanitarian engineering include helping people, improving society, and making a difference [15]. Singer et al. (2024) [16] showed that an Engineers Without Borders Challenge improved students' perceptions of important technical skills such as problem solving, communication, design process, and teamwork.

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 specific needs of malnourished children in a particular country.

Ill-Structured Projects

Ill-structured projects are those that can have multiple satisfactory solutions and multiple potential paths to get to those solutions [17]. These are in stark contrast to the vast majority of problems that engineering students solve which are usually focused on a relatively narrow range of technology (e.g., statics or thermodynamics), have only one correct answer, and typically only one method to get that answer. However, ill-structured problems are some of the most important that students will solve because they are much more similar to the types of problems they will face after graduation. Those problems typically do not have an answer in the back of the book which is one of the reasons why engineers are well-compensated because they must apply what they have learned to new and more complex problems than they studied in school. These ill-structured problems can be unnerving to many students, especially freshmen, who have often had very little prior exposure to them. It is argued here that early exposure to this type of problem better prepares students for what they will experience after graduation. This type of project also helps prepare students for their future capstone project.

From the very beginning, ill-structured projects can be challenging as they are not always well specified. Sometimes, a considerable amount of time must be spent deciding what problem is actually being solved. Again, that is something that may happen after graduation where a client may not know exactly what they want so engineers must help them decide by framing the problem. Significant ill-structured projects nearly always require a team to solve which may include not only other engineers, including those from other engineering disciplines, but also those from other functional areas such as marketing, sales, manufacturing, and procurement. While it is not usually feasible to simulate this in a freshman design class, students can be introduced to the complexity of real engineering problems.

Another aspect of ill-structured projects is that the design process is usually both creative and iterative. Designers make their best efforts on the first concept, but if the problem is sufficiently challenging, they will often find that improvements can and should be made. The number of iterations is impacted by the time and money available, how fast modifications can be made, and how close the initial design was to meeting the project specifications. These constraints are critical for students learning the design process. While a first-semester freshman design course cannot include all possible types of constraints, it should include at a minimum some important constraints such as schedule, budget, and performance. Other constraints such as sustainability, manufacturability, and aesthetics are less important at this early stage of students' education.

Drone Competition

Molina et al. (2014) [18] described an interdisciplinary quadcopter drone project to engage several autonomous vehicles to work together. Besides being of interest to university students, the project also attracted high school students to consider attending the university. Walker (2016) [19] discussed a competition sponsored by the Association for Unmanned Vehicle System International (AUVSI, https://www.auvsi.org/) where students designed, built, and tested airplane drones. This was an extracurricular activity where the competition objective varied over the years 2004 to 2015. Casado and Bermúdez (2021) [20] described a drone competition for undergraduate engineering students where the objective was to develop autonomous navigation systems. Félix-Herrán et al. (2022) [21] described a drone competition for undergraduate students. Rather than calling this PBL, they referred to it as challenge-based-learning (CBL). They argued this is an effective method for teaching undergraduate engineering students how to solve difficult problems in a collaborative environment, similar to what they might encounter working as engineers in industry. Abichandani et al. (2024) [22] discussed a CBL drone competition to prepare students specifically for careers in the drone industry. This concerned piloting drones rather than designing them.

Project Description

The primary student learning objective was to have students solve an ill-structured engineering problem of reasonable complexity with a humanitarian aspect that required innovation and creativity. The primary performance objective of this project was to deliver as many Ready-to-Use Therapeutic Food (RUTF) packets as possible across a football field in 30 minutes using airborne drones. A practice football field was chosen primarily for convenience as it was readily available throughout the semester. It also provided a safe environment for testing as no buildings were nearby and normally no other people were around except for a narrow window of time in the evening for band practice. The various elements of the project are described next.

Ready-to-Use Therapeutic Food

RUTF, sometimes referred to as "Plumpy Nut" (see Figure 1), is intended primarily to feed severely malnourished children older than six months who do not have any medical complications and who do have an appetite. It has the consistency of a paste and is made using peanuts, sugar, milk powder, oil, vitamins, and minerals. It can be used to feed malnourished adults as well. This food was designed for the United Nations approximately 40 years ago and is manufactured by a French company called Nutriset (https://nutriset.fr/en/) which makes a wide range of products for malnourished people.

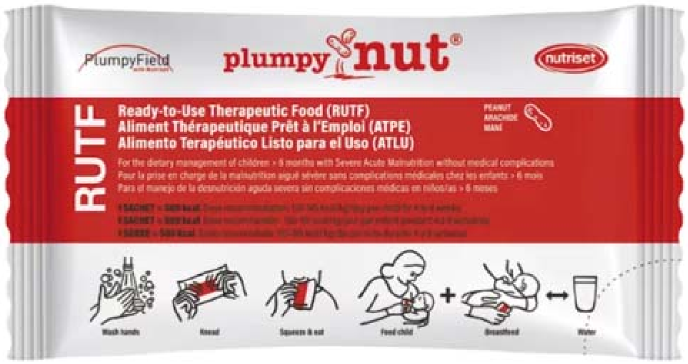

Figure 1 Ready-to-use therapeutic food or RUTF (https://nutriset.fr/en/products/plumpynut-en/).

Some important properties of the packets include: ready-to-use (does not need to be mixed with water), easy to store (does not require refrigeration even after opening and stays fresh for up to 2 years before opening) and distribute, and children like the taste. It may be consumed for up to 24 hours after the packet is opened. The recommended dosage is 150 – 185 kcal / kg body mass / day, where each packet contains 500 kcal. Plumpy'Nut must be prescribed by a healthcare professional and is not designed to replace, but to supplement, breastfeeding.

The standard packet weighs 92 g, is 16 cm long, 7 cm wide, and 1.5 cm thick although these can vary slightly depending on the manufacturer. The actual packets could not be obtained so a facsimile was created using 16 cm long and 9 cm wide resealable zip lock food storage bags filled with Nutella which is a spreadable food made from hazelnut that has the consistency of peanut butter. Actual peanut butter was not used because a student in the class was allergic to it but not to Nutella. Electronic food scales were purchased and students filled the food bags to approximately 92 g. A priori, it was unknown how many packets could be carried by each drone. It was initially assumed that teams might want to have two sets of packets so they could drop one set and have a spare set in case the first set was damaged or individual packets broke during a drop. A total of about 30 packets per team were made. It turned out that no packets were damaged during the competition and that less than 10 could be carried at a time by any of the drones.

Constraints

Two important constraints in virtually every project are time and money. For this project, the students had the entire semester to design, fabricate, test, and re-design if necessary their drones. As is often the case, particularly with first semester freshmen, they ran out of time and had to work some late nights near the end to have their drones ready in time. The budget for the drones was based primarily on the lab fees for the course which were $100/student. Although four of the teams had four students and two teams had five students, the budget was set at $500/team where the engineering department would supplement the lab fees if necessary. As will be shown later, the actual costs per team ranged from $149 to $462. There was an incentive in the competition to minimize costs. The teams could 3D print as much as they wanted at no additional cost.

The only constraints on the drones were that they had to be aerial, fly a minimum of 10 feet above the ground, and drop the payload from at least 10 feet above the ground. The previous year's drone project included ground-based and water-based drones which were not permitted here. Students could use leftover drones and/or parts from the previous year's project, could build their own from scratch, or could purchase a new or used drone they would modify. One team used a drone donated by the marketing department and another team modified an existing drone from the previous year's project. One team built an airplane out of poster board, two teams bought used drones from eBay, and one team bought a new drone from Best Buy.

Assessment

The drone project was a major component of the lab portion of the course and was worth 30% of the overall course grade. It was designed to help meet two of the student learning objectives:

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

The following assignments were required for this project:

	Task	Points	
1.	Design specifications	100	
2.	Drone concepts	100	
3.	Drone selection spreadsheet	100	
4.	Drone performance metrics	100	
5.	Drone test protocol	100	
6.	Drone competition	1200	*
7.	(5) drone photos	10	each
8.	(1) drone video (3 minutes maximum)	50	
9.	Drone final presentation	100	
	Total	1900	

* Scores above 1200 points were possible as will be discussed later.

All of these were team grades.

Drone Competition Scoring

The original scoring rubric is shown in Table 1, where the highest score would win the competition. However, scoring was modified based on unexpected results as discussed later in Results.

No points would be given for dropping a load less than 10 feet above the target. The plan was for three teams to go at a time with the other three teams collecting the data (number of packets delivered, drop height, and drop radius from the target).

Table 1 Drone competition original scoring rubric.

Parameter	Weight (1 = minimum, 5 = maximum)	Scoring
Payload delivered in 30 minutes	5	Maximum gets 100 points, rest proportional
Average drop accuracy	4	w/in 1 ft of bullseye = 100 points, 1 - 2 ft = 75 points, 2 - 3 ft = 50 points, 3 - 4 ft = 25 points, > 4 ft = 0 pts.
Total Cost	3	$0 = 100 points, $500 = 0 points, rest proportional

Results

Figure 2 shows a photo of students working on their drones. In the foreground, students are building an airplane from scratch out of poster board. In the background, two teams are working on modifying commercial drones.

Figure 2 Students working on their drones.

Figure 3 shows a student preparing for the competition where the drone was controlled by a phone app.

Figure 3 Student preparing drone (left) for the competition with a phone-app controller (right).

Figure 4 shows photos of drones during the competition just after taking off. The first day of competition was the last day of class on a Thursday afternoon on a clear but cold day.

Figure 4 Drones just after takeoff.

Figure 5a shows an example of a drone in flight and Figure 5b shows an example of a drone getting ready to drop its payload. Figure 6 is a photo of students attaching a new payload on the bottom of their drone, just after dropping a payload.

(a) (b)

Figure 5 Drone (a) in flight, (b) about to drop its payload on a target.

Figure 6 Student attaching a food packet after a payload has been dropped.

One of the unexpected results of the competition was that three of the six teams were initially unable to deliver any packets from a minimum height of at least 10 feet. The airplane drone crashed in a practice run right before the start of the competition and was unusable. A second team's used drone failed to operate properly, crashed, was damaged, and became unusable, even though it successfully ran the day before. A third team's dropping mechanism failed to operate properly so their drone had to land to deliver packets. The third team also had a delayed start when their phone-app-controlled drone decided to do a software update right when the competition started. It was originally planned that no points would be given for payloads dropped below 10 feet. This would have meant that three of the teams would not have gotten 900 of the 1200 available points for the competition. Because the drone project was worth 30% of the overall course grade, this would have meant over a letter grade reduction in their overall grade.

As a result of the unexpected failed initial performances, the three teams were given the opportunity to take an incomplete if they so desired and finish the course at the beginning of the next semester. All three decided to try again after the weekend. The airplane team built a new plane using parts salvaged from their damaged plane along with some new posterboard. The team that crashed a used drone substituted a drone owned by one of the team members as there was not enough time or money to buy another drone. The third team with the failed dropping mechanism used a different dropping mechanism. All three successfully competed at the beginning of the following week during finals.

The scores for the competition are shown in Table 2. For the three teams that competed on two different days, both scores are shown along with the average which was what was used to determine the winning team. Final scores for the drone project ranged from 80.6 to 99.4%.

Table 2 Drone Competition Scoring

Team	Trial	# Packets	# Packets	Packet Score[a]	Weighted Packet Factor[b]	Average Radius (in.)	Average Radius (in.)	Radius Score[c]	Weighted Radius[d]	Cost	Cost Score[e]	Weighted Cost Score[f]	Overall Score	%
1	1	27.0	27.0	97.0	485	19.8	19.8	100	400	$380	74	222	1107	92%
2	1	0.0				120.0								
2	2	56.0				43.9								
2	ave.	28.0	28.0	104.0	520	81.9	81.9	98	391	$149	100	300	1211	101%
3	1	16.5	16.5	86.5	433	142.9	142.9	96	383	$372	80	241	1056	88%
4	1	0.0				120.0								
4	2	6.0				1620.0								
4	ave.	3.0	3.0	73.0	365	870.0	870.0	70	280	$416	75	226	871	73%
5	1	20.5	20.5	90.5	453	79.0	79.0	98	392	$336	84	253	1097	91%
6	1	22.3				120.0								
6	2	68.0				45.2								
6	ave.	45.1	45.1	109.1	546	82.6	82.6	98	391	$462	70	210	1147	96%

[a] calculated by proportioning as follows: 0 – 10 packets = 70 – 80, 10 – 20 packets = 80 – 90, 20 – 30 packets = 90 – 100, above 30 = 100+.
[b] calculated by multiplying the packet score by 5 which is the weighting factor for this element.
[c] calculated by proportioning the farthest average distance to 70 and the shortest average distance to 100.
[d] calculated by multiplying the radius score by 4 which is the weighting factor for this element.
[e] calculated by proportioning the highest cost to 70 and the lowest cost to 100.
[f] calculated by multiplying the cost score by 3 which is the weighting factor for this element.

Student Feedback

Students were surveyed after the course was completed using Survey Monkey. Seven students voluntarily responded to the survey with the results summarized here:

1. What did you like best about the drone project?
   - Working with students they did not previously know to achieve an end goal
   - Getting to know new people with different working styles
   - Chance to work on something new and come up with their own ideas to solve
   - Learning to consider many ideas instead of just the easiest ones
2. What did you like least about the drone project?
   - Not all students contributed as expected
   - Some felt grading was unfair as some teams went a second time to improve their grade
   - Team did not work well together
   - Settled for easiest option
3. What was your greatest success on the drone project?
   - For some, their first run failed so having a successful second run after only a few short days was a great success.
   - Number of deliveries far exceeded expectations
   - Meeting the project requirements
4. What was your greatest challenge on the drone project?
   - Time constraints and some minimally-performing team members
   - Dropping accuracy
   - Initial run failed
   - Solving last minute technical problems
5. What suggestion(s) do you have to improve the drone project?
   - Making the competition even more challenging by adding an obstacle to the course
   - More time
   - Incorporating design originality into the scoring system
6. Did your view of engineering change as a result of the drone project and if so how?
   - The importance of time and project management
   - Some were encouraged to continue learning
   - Finding the most simple solution is sometimes the best
   - Showed how difficult engineering can be, but can still have fun
   - More encouraged to pursue best option, not necessarily the easiest

The university anonymously surveys students at the conclusion of every course. Some relevant comments from that survey were as follows:

- "I literally got to work on drones . . . Literally loved that."
- "I really enjoyed how this course developed my ability to have a sense of great teamwork. Also, I enjoyed the hands-on portion of this class to balance the theory that we have been taught."
- "In the lab we had a lot of free reign for ourselves. He let us do things for ourselves. Allowing us to work like actual engineers and come to our own conclusions. So, letting us have independence and guiding us along the way."

Conclusions

This project exposed freshmen to all the major elements of design including cost, schedule, testing, communication, presenting, project management, and working in teams. It also had a humanitarian element. It was neither too easy nor too hard for first-semester freshmen. It stretched students without discouraging them. It involved a technology, drones, that most freshmen engineering students are familiar with and excited about, but have not used to carry a significant payload.

This project is ill-structured as demonstrated by the various different solutions developed by each team. The project is well-suited for teams so students get experience working with others they do not previously know, which often occurs in industry. While there is some cost involved, it is not excessive and can normally be covered by typical lab fees. The competition aspect gives the students added incentive and urgency. Based on student feedback and the competition results, it appears the project successfully fulfilled the primary learning objective of having students solve an ill-structured problem that required creativity, innovation, and effective project management.

Recommendations

Assigning students to a team, rather than having them select their own, is recommended for a first-semester course where very few of the students know each other at the start of the course. Assigning members to a team is also more representative of how projects are typically handled in industry.

In hindsight, there are some improvements that will be made the next time the course is taught. Half of the teams had very significant problems on their first attempt at the competition and had to make changes and make an originally unplanned second attempt. In the future, at least two attempts will be planned for each team, where the results would be averaged together so there is sufficient incentive to get it right the first time. For the project described here, many intermediate assignments were given, but no final written report was required. In the future, a final written report incorporating the many intermediate assignments will be required as that is typically what would be done in industry.

Other recommended changes regard assessment. Some type of team member assessment is recommended using a tool such as CATME (https://catme.org/login/index). This would provide a mechanism to give different grades to students on the same team. A common complaint on team projects is that some members do not contribute as much as others, yet they get the same grade. While it is not expected that all members will contribute exactly equally, it is expected each member will give a full faith effort. Another related option is to have each team member discuss their own contributions to the project. This would likely expose any freeloaders on a team. Future projects will have more specific requirements for the photos which were basically randomly selected by the students. Photos should include at least some during fabrication and testing. Photos provided here were nearly all from the competition.

Some other possible assessment changes relate to the drone competition scoring. One is to have an element related to creativity, sustainability, maintainability, and aesthetics. These are not important factors in this particular type of project, so this element should not be weighted very highly. Involving engineering advisory board members as judges could be an effective method of evaluating such an element.

Another modification that is planned for the next time the course is offered is to have the students do some research on the humanitarian aspect of the project. This could include finding out what countries use RUTF and how the packets are delivered. Drone delivery would be reserved for emergencies as large-scale delivery of RUTF would be much more effective using conventional delivery methods such as trucks.

There are also other variations of the project that are possible. One is to have the drones make a single round trip over a longer distance, which is more representative of the intended scenario. A related change is not to have any team members on the receiving end of the delivery to help the drone driver who would then have to rely solely on the drone camera which is also likely closer to the actual scenario.

This project could be adapted for large class sizes. One suggestion might be to have separate competitions for each section of the course or to divide the students into multiple sections. If there is only a single competition, a potential challenge of having teams compete on different days and relying solely on the team scores is the possible differences in weather conditions that could impact the results. For example, a rainy and windy day could hamper the small aerial drones compared to a dry day with little wind. In that case, another variation might be to have an elimination process where winning teams continue to advance until a final winner is determined.

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