Human-Centered Pilot Stakeholder Design Project Development for Second-Year Aerospace Students

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Introduction

In modern engineering education, there is a growing need to support students in developing empathic design skills so that they are better prepared to navigate the complexities of collaborative design projects in industry. One way to support students in developing their design competency is through the practice of human-centered engineering design (HCED) [1]. This paper describes, from an instructor's perspective, efforts to develop and implement a collaborative, in-class project for aerospace engineering students for which HCED is a central practice. We discuss motivations regarding the design and implementation of the project and how it fits into the bigger picture of our team's efforts.

Research Background

Investigating Human-Centered Design in Engineering Education

Brown defines human-centered design (HCD) as a problem-solving approach that uses design thinking processes and practices to identify the unmet needs of a population in order to collaboratively and iteratively develop collaborative solutions [2]. Lawrence et al. [3] expand on this definition by constructing a literature-based taxonomy in which HCD is characterized as five spaces, each of which consist of four processes. In ongoing work, our interdisciplinary team of researchers and instructors has relied on the five-space HCD taxonomy to create course development tools that support the integration of human-centered design within engineering design courses, culminating in a framework that we refer to as human-centered engineering design [1].

Over the last few years, our team has focused on designing and implementing HCED content within select, required aerospace courses at the University of Illinois Urbana-Champaign. We aim to support students in building and reinforcing their content knowledge by providing them consistent opportunities to recall and apply lecture topics in collaborative projects and lab assignments. Through active learning in class with worksheets and with structured class design and interaction from the instructor, gaps in student prior knowledge can be addressed [4]. Due to the repeated exposure to topics, students construct their own understanding by testing the concepts and applying them in familiar and unfamiliar situations, and integrating prior knowledge into new understanding [5]. In previous work, we described the overarching goal of our research study to develop learning progressions across these courses and implement content in a way that strengthens cohesive connections among the courses [6, 7]. Currently, we are actively collecting and analyzing data to understand the impact of HCED materials in our courses. In this paper, we discuss our efforts from a course development perspective.

Study Summary

Our team developed and implemented the project described in this paper as part of our ongoing study. To investigate the potential impact of the project on students' design competency development, we used a pre-/post-test survey format that employed a Likert-scale measure of students' self-reported confidence levels. We validated our survey using Cronach's alpha; the survey development and initial data is described in a previous conference paper [7]. We also qualitatively analyzed course artifacts including students' written reflections from the project. Survey results and reflection content were used in conjunction with feedback from the teaching team to discuss the results of early versions of the project and iterate its design. We are currently analyzing data from a cohort of students who participated in the project and then took other courses for which we had implemented similar material; these results will be discussed in a future publication. In this paper, we focus on the development and implementation of the project in a way that can be replicated by other instructors.

Course Background

Aerospace Engineering & Design

One of the objectives of the Aerospace Engineering curriculum is to build the skills and knowledge for students to be capable of working on many aspects of aerospace vehicle design, fabrication, operations, and maintenance [8]. The content topics that fall under the aerospace engineering umbrella are therefore very broad and include aerodynamics and fluid mechanics, structural mechanics, material properties, stability and control, performance analysis, orbital mechanics, and aircraft flight mechanics. Most third- and fourth-year classes dive deep into just one of these topics. At the first- and second-year level, however, these topics are taught in an integrated manner and through vehicle projects so that students can also experience systems engineering and design work. In aerospace engineering, not every professional works on design, but every engineer does have their work dictated by the design process at some point. Additionally, vehicle designs and catastrophic design failures are particularly visible to the public, and faith in commercial flight and space exploration are important for the industry to maintain the status quo.

Aerospace HCED Sequence

Within the curriculum for the Department of Aerospace, students are exposed to design projects at the first-year level with a rocket project and a glider project. The human-centered design aspects are emphasized by the performance requirements of these projects. The rocket will carry an eggstronaut to a specified altitude to simulate the opportunity for a rendezvous or collecting particular data at a known position. The students are responsible for ensuring their rocket is sized properly for the mission and the eggstronaut has appropriate padding. The glider project requires the students to maximize range and endurance to simulate real needs of flight vehicles. This semester we experimented with having a team of Catpilots (one per each student) on the gliders so that we could emphasize safety. The gliders are deemed "safe" if the catpilots don't fall off and if the glider doesn't land on them, and "unsafe" if there are issues with pitching, rolling, or yawing, or if there is some incident that affects the Catpilots.

At the second-year level the glider-catapult project of this paper is utilized, with additional projects in conceptual design: one is a term project that is on a vehicle type of the students choice, from a selection of prompts provided by the instructor. The second conceptual design project is a lunar lander project, with ethical considerations for astronaut safety. These second-year projects have been iterated and improved upon over four years based on student feedback and the tailoring of the course to meet curricular needs. At the third-year level students design control algorithms for computational projects that involve moving vehicles, working to create a controller that will meet the needs of the project which includes a digital Catpilot. The fourth-year students take their senior design sequence. That sequence is an entire year and requires student groups to walk through the steps required to produce a conceptual design for AIAA design competitions. The project includes assumed business stakeholders and presentations to the rest of the class and invited guests attend throughout the second semester to provide students with feedback on how to improve their design to meet stakeholder needs.

Glider-Catapult Project Overview

Motivation

The motivation for the glider-catapult project was to develop a hands-on project at the second-year level that built off the first-year experience and integrated aerospace engineering theory in a more applied way. There was a need to develop a hands-on project to accompany existing conceptual design projects to allow students to experience the consequences of fatigue, benefits of thoughtful experiment design, and the iterative design process. To motivate students to engage in the iterative process and increase glider and catapult performance and safety, competition and stakeholder elements were introduced into the glider-catapult project. The initial version of the project was to create a catapult, and since then the project has been adapted to include a glider-launch to allow for more applied HCED elements. The goals of the project are to teach the students about cost, fabrication, fatigue, aerodynamics, flight mechanics, performance, stakeholder needs, safety, and design.

The goal of the second-year class is to teach students how to apply pre-requisite skills and knowledge and new skills and knowledge to aerospace engineering vehicle systems, systems design, and vehicle performance. The beginning of the class is a mix of kinematics and kinetics review and new systems engineering concepts, with an accompanying project on identifying requirements of real vehicles in history to create a group video. The class then switches to new concepts in fluid mechanics and aircraft flight mechanics. The glider-catapult project follows as a practical application. The content following the glider-catapult project is on orbital mechanics and spacecraft systems, and the students engage in a conceptual lunar lander design activity as a practical application for those concepts. The final section of the course goes more in depth on aircraft performance and operations, and the students work in and outside of class on their final project: a conceptual design of a novel aerospace vehicle. The combination of lecture content and applied projects allows students the opportunity to see how their physics-based instruction and homework works in tandem with design and systems engineering skills such as identifying requirements and sizing components [4, 5].

Implementation with Second-Year Students

The second year students have approximately four weeks of lecture content before the project begins, and once the project begins they have one additional lecture and five days of build time to construct and experiment with their gliders and catapults. Three of the build days are dedicated to glider design and manufacturing and testing, two of the build days are dedicated to catapult design, manufacturing and testing. The final, sixth, day of the project is for the class competition.

The students are prepared in advance for the work due to their experience as a first-year, but many students forget the foundational topics taught in the first-year course and therefore need refreshers and guidance before and during this project. Additionally, transfer students are exempt from the first year course and need the instruction in order to be on equal footing. The students receive lectures in advance on kinematics and kinetics, fluid statics and dynamics, aircraft forces and trajectory, and systems engineering. They also have daily worksheets throughout the project to guide them in creating a design, practicing mathematics for estimating performance, recording materials and costs, and conducting and recording experimental flight testing. Students first design and create an individual glider, they then create a group, then they finish gliders and begin creating a catapult as a group together for the competition.

Aerodynamics and Flight Mechanics

The flight mechanics lesson content of the gliders is derived from works like McCormick and Anderson and integrated into class lectures before the project unit and into worksheets throughout [9, 10]. The gliders need to produce enough lift to maintain airborne over a long distance. This is achieved by creating large wings, having the wing cross section designed in an airfoil shape, and reducing weight. Additionally, the gliders need to have reduced drag so that the launch force used by the catapult or when launched by hand is adequate to achieve long-range flight. Drag reduction can be achieved by creating streamlined shapes and reducing overall surface area. Moments need to be balanced such that a stable flight is achievable. The most likely problem is an unstable pitch-up moment which results in glider stall. This can be fixed by adjusting the horizontal tail area and the radius from the center of gravity to the tail. These design requirements can be in tension, and it is up to the students to create designs that perform well using the experimental and iterative process.

The gliders can fly in one of three patterns: either they glide straight down from the launch position, they fly in a parabolic arc and have a maximum height at some point after launch, or they can fly in an oscillating pattern operating between stall and glide. All three patterns can offer long range or short range, the result depends on the glider and catapult design.

Group Formation

Student groups are formed from a networking activity where the students draw the Catpilot they have selected and give it a name and personal details. The only requirement for group creation is that they are in a group of three (3) and don't work with people they have on their term project group. This typically results in mixed groups, where some students work with their friends and other students work with strangers. The group selection process anecdotally seems to reduce issues with group cohesion, which can be an issue when groups are assigned randomly.

While working with a group, the students are able to learn from each other and craft their own best practices for experimental techniques, glider design, and recording data. By first independently creating a glider, and then joining a group for testing and catapult development, students benefit from refining their understanding through collaboration with peers who may be more capable in different aspects of the project [11]. By having easy access to peers to reach out when at the limit of their current problem-solving capabilities, students are able to advance the project and learn the material.

Catpilot Stakeholder

The Catpilot stakeholder is a small plastic cat charm purchased online that has a small keychain loop on the head. This can be attached to gliders through the loop with string, glued down, attached with duct tape or rubber bands, or affixed with clay. Figure 1 shows an example of a Catpilot affixed to a glider.

Figure 1. Glider prototype with Catpilot

The Catpilot is fictionally positioned as the students' boss in their worksheet assignments, and they are asked during experimental proceedings how the Catpilot feels about the flights and whether the Catpilot has suffered an incident (ejection from the vehicle is the most common, hitting a wall or the ceiling is a close second). The Catpilot is required to fly every time the glider is thrown or launched, and students are frequently reminded, "Cats Always Fly," so that they do not forget their stakeholder. This practice is intended to build sociotechnical connection, where the engineering students develop their technical design with understanding of the stakeholder needs and requirements, analogous to problems they would solve in their future careers in industry, research, or government work [12]. On the first two days of class a check is done to ensure every student brought their Catpilot to class, as they were requested. If they do not, they are given a new Catpilot and told “You Have Eight Lives Left” to emphasize the importance of bringing the stakeholder to class. Cat charms were chosen as the stakeholder because of their lightweight, durable material properties, existence of small hoops for attachments, for having a happy and cute face, and because there are five different color options so students can select one that they prefer.

Crafting Materials

Students are allowed to choose from the inventory provided. Each item in inventory has an associated cost, and students are not allowed to put inventory back that has been modified in any way. There are 1/8th inch thick 12x12 inch balsa wood planks, as well as thinner 1/16th inch thick 12x12 balsa wood planks. There are also popsicle sticks of different sizes, string, different weights of paper, rubber bands, binder clips, and duct tape. Students are allowed scissors, craft knives, super glue, and hot glue guns for crafting materials. Inventory is listed in Appendix B. Materials are purchased before the project begins, and refreshed as needed when stock runs low.

Low-Cost Requirement

The cost of the knives, glue, and scissors are bundled together in a “fixed lab fee” that students must calculate and include in their total expenses. On top of that they are required to count and determine costs for all the pieces of material they used for their project, including materials that were ruined or destroyed during the process that didn’t make it onto the final design. The total project cost is part of their competition score, and the groups will be able to see and compare their total project cost with other students in the class. The motivation behind this process is sustainability and reusing resources between phases of the project to reduce waste. Sustainable Aviation is taught as a fourth-year elective, and exposing students to the idea in the second-year curriculum helps address preconceptions and misconceptions that students may not otherwise address in their understanding. For our definition of sustainable aviation we adapt the framework developed by Waddington & Ansell, as “the process of creating the air transportation system that maintains the connectivity of communities and mobility of people, goods, and services while minimizing negative impacts to human health, fostering a productive quality of life, and conserving natural resources” [13].

Safety Requirement

The objective of the project is to keep the catpilot safe, although due to the nature of the artificial stakeholder, the safety and happiness of the Catpilots are subjective. Students are told on the first build day that suffering of the catpilot would include the following: unstable flight patterns, Catpilot ejection, glider hitting walls and ceilings, the glider flipping upside-down, components on the glider fatiguing, or the vehicle undergoing complete failure. From the perspective of the student the goal is to make sure the Catpilot stays on board the glider during operations, that the glider doesn’t hit anything during operation, and lands upright without rolling, pitching, yawing, or stalling. This mirrors real glider and aircraft safety in that these performance characteristics are not desirable, and stalling in particular, can lead to uncontrolled descent and crashes.

Performance Requirements

Real gliders are built for maximized and predictable range and endurance, and the student projects mirror those desired effects. The performance requirements are chosen to aid the students in developing their design thinking skills. With design thinking, students must make choices to build their glider based on the desired performance outcomes dictated by the requirements and deal with uncertainty in how to best accomplish that. In addition they must adapt to experimentation and iterative procedures within the design process, and the social nature of thinking as part of a team with a larger goal (winning the competition) and communication and documentation needs for their graded laboratory report [14]. The competition score includes the range of the glider upon launch, with a subtraction component for any deviation from centerline. If a glider doesn't fly according to the flightpath, it would not be a very useful way to travel, as such the performance goal is to fly as far as possible in a straight path. The competition score also includes a precision element, where tests taken during the competition are compared to the expected flight range given before the competition. The standard deviation is found and 100 minus the standard deviation is taken as the precision score. In addition to not rolling, pitching, yawing, or stalling, a final performance requirement is to hold up during experimental testing and competition testing without fatigue. There is no scoring element for this, however fatigued gliders and catapults are less predictable, and the precision score suffers as a result.

Table 1. Process Timeline for Glider-Catapult Project

Week	Day	Activity
1	1	Meet Catpilot & Enjoy Lecture
1	2	Receive Detailed Prompt & Draw Glider Design
2	3	Construct Glider Design & Begin Testing
2	4	Iteratively Test Glider Design with Catpilot
3	5	Begin Catapult Design Construction
3	6	Finalize Glider-Catapult System with Iterative Testing
4	7	Compete With Gliders and Catapults and/or Finish Testing
4	8	Finish Competition & Begin Laboratory Report & Catpilot Reflection

Experimentation Process

Students follow along with a lecture on the first day of the project as they are introduced to their catpilot. This lecture outlines the key vocabulary and goals of the project. For the three weeks of build and experiment time the students are tasked with forming a group and following along on worksheets to complete a certain amount of work each day. This work includes building the glider, hand tossing it, and collecting performance data and safety information. Then the catapult is built and one of the gliders from the team must be tested with the catapult. The same performance data and safety information is collected. Most groups need to come in outside of class-time to work on the project before the competition day, however this time commitment is typically small.

Iterative Process

The worksheets are created to prompt students to document Catpilot incidents, consider why performance and safety issues occur, and create a problem-solving strategy to address them. In addition, the classroom is set up so that there is a clear flight testing area, and the instructor and course staff stand near that area to observe flights and suggest glider and launch changes that would improve the flight. Students make changes, come back, we have more observations, and then they return to make more changes. Once the glider is safe for their Catpilot, structurally robust to handle repeated testing, and has consistent long range, student iteration is to fine-tune their glider to avoid small disturbances due to throwing or launching inconsistencies or damage upon landing.

Implementation Details

On each class day students pick up their daily worksheet from the pile. Students received a folder earlier in the semester to help keep track of their paper worksheets. On the first build day of the project the students are given safety glasses to use throughout the semester. The class day before the project begins they chose their Catpilot, and on the first and second days "Catpilot Checks" are conducted to make sure they form the habit of bringing the Catpilot to class. Most students keep their catpilot on their keys or in their pen cases. At the beginning of the first build day, all students are walked through the context of the project and are shown example gliders from the previous semester as well as the supplies. Then students are then given the remainder of the 80 minute class to design a glider, record dimensions, and begin building. Announcements are typically made at the beginning of class verbally and with whiteboards. Course staff is available to help answer questions and observe flights, and the professor checks that students are designing before they build, have a Catpilot, and are iterating between each flight by observing any performance or safety issues. Students often need help assessing how to fix their glider upon observation of issues, so suggestions are offered. Course staff typically learns from the professor how to offer guidance and becomes more proficient as the project continues. Students also become more proficient with diagnosing the issues with their gliders, and are assessed on this skill with an essay problem on the final exam for the course.

Students are able to come in to work on their project outside of class time. The building is open 7AM–12AM daily, and the students are given the code to the supply locker with instructions to "leave it better than you found it" or "campsite rules" so that the supplies don't become disheveled and unusable. Students store their projects in the open spaces in the building, and they are typically left alone by other users of the facility due to the nature of the design center.

Project Assessment and Evaluation

Individual Worksheets

As stated previously, each student completes a worksheet each day of the project. The worksheets include problem sets, instructions, as well as their experimental log. This continues a practice from the class before and after the project where daily worksheets are used to promote attendance and provide active learning opportunities during class time.

Competition

The competition occurs on the last day of the project, and students are expected to come to class prepared on that day to compete.

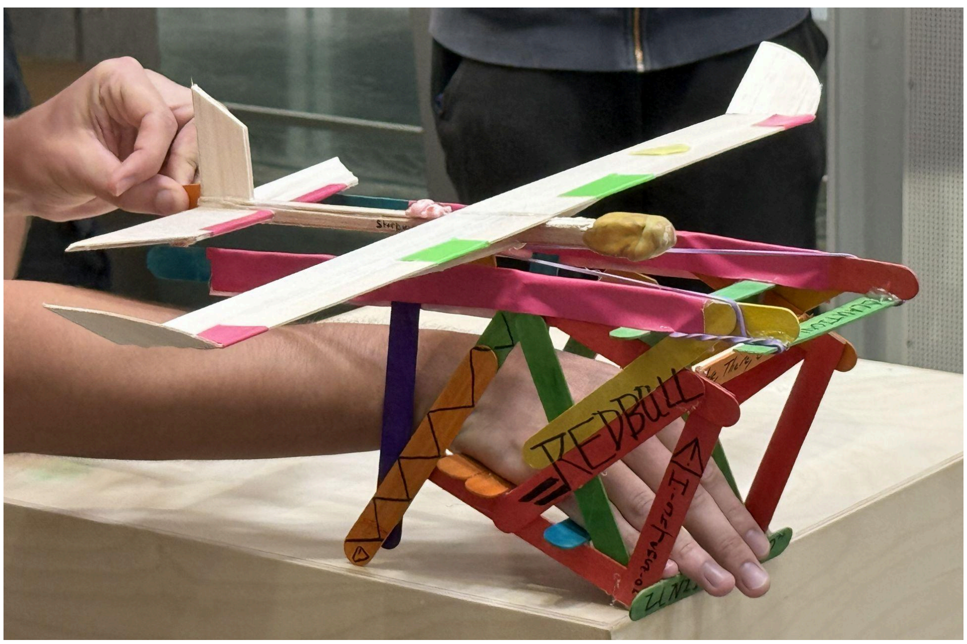

Figure 2. Competition flight with glider, Catpilot, and catapult

Each team is expected to create value by developing a system for a class-wide final design competition, as scored during their end-of-project competition by Equation 1.

$$Competition\ Score = \frac{Range\ [ft] - Deviaton\ from\ Center\ [ft]}{Cost\ (\$)}(Precision) \quad \text{Eq. 1}$$

The competition goes in order of whoever is ready to compete. Usually there are few people ready at the beginning of class, but the testing and scoring goes smoothly after the first two-three groups have gone. Scoring is done on a shared Google Sheet, and students pre-fill their Google Sheet page with the name of their team, team members names, Catpilot names, Glider and Catapult product names, and the expected range of their glider-catapult system. The expected range is determined by each group in advance of the competition. The competition score and precision score are calculated automatically within the document. Figure 2 shows a glider-and-catapult system used in the competition.

The students are graded with only their precision score, as this is easily taken out of 100. The grading based only on precision also allows teams that are struggling to aim for only one goal as opposed to four goals, reducing the complexity and allowing them to finish the project by the competition day. However, the entire class has access to the scoring sheet used that day and can compare the more elaborate competition score between teams. This increases competition within the project which allows for more competitive students to benefit from external motivation. Some comparison is required for their group report, so all groups do need to be aware of how they compare to the rest of the class.

Written Group Report

Student groups are expected to collaborate to create a "Laboratory Note" based on their work on this project. This element is intended as a tool for students to construct an understanding for themselves of the importance of communicating design methods and experimentation procedures [11]. A template is provided to students with prompts and the students are expected to complete each prompt, format the document correctly, and edit their work for flow and consistency. The template is provided in Appendix A. This is a group grade, and it requires teams to be collaborative and share the responsibility of documentation and writing.

Expense Group Report

Student groups are also expected to collaborate to create an expense report based on the work for this project which is provided in Appendix B. A template was provided with line items to calculate and the students were expected to complete the arithmetic accurately for their expense report. This is a group grade, so there are sometimes issues within student groups as a consequence of poor communication and incorrect mathematics.

Catpilot Stakeholder Evaluation

The catpilot reflection requires students to discuss how they adapted their design to meet the needs of their catpilot, discuss the experience of the catpilot, and put themselves in the shoes of the catpilot to make suggestions and evaluate the work of the team. This reflection includes eight questions which each require responses of 2-3 sentences. The goal of this assignment is to provide an individual opportunity for students to receive grades for the project as well as to emphasize the importance of catpilot stakeholders and designing with their needs in mind.

Some example Catpilot Stakeholder Evaluations are below:

> "From my Catpilot's perspective, I balanced cost, schedule, and risk well by keeping spending low and structural integrity / feline safety high. I finished constructing my glider early enough to allow for multiple test flights to keep risks down for a potential final flight."

> "My Catpilot saw how I was always building a new glider and constantly testing the crappy ones that didn't work. I'm sure Puck was confused about my approach, but considering I was able to quickly build a final glider that was decent, he trusted me. I definitely risked his life and the cost of our group a little too much, but my quick building made up for that, so we were right on schedule."

> "My glider incorporated several safety measures to protect Catpilot Garry during all test flights. Garry was secured to the upper surface of the left wing using a folded tape loop, and he remained firmly attached even during abrupt impacts. The glider's structure also emphasized smooth, stable flight through careful balancing and iterative trimming, reducing the likelihood of spins or stalls that could endanger the Catpilot."

Individual Reflection

In addition to the catpilot evaluation, students are asked to reflect on their teamwork skills and collaboration during this project and remark on what was challenging with the project. The students are asked how they modified their teamwork strategies and what they would like to do to improve their skill in the future. Furthermore, they are prompted to revisit their reflection from a previous project in the course and articulate whether they experienced challenges in implementing the intentions they had set.

Some example reflections are given below:

> "The most challenging part was creating a glider that was durable. Many gliders broke on impact with the ground during testing, so finding a way to reinforce the fuselage and wings to survive landing was more difficult than expected."

> "One aspect of the project that I benefitted from having a team was overall idea creation. I know that I wouldn't be able to come up with the ideas that we implemented for our catapult unless it was in a group setting."

> "One teamwork strategy I have learned this semester that I am going to continue to use is that of open and close communication. I have found that my groups are much more successful when we keep fairly close tabs on each other to hold each other accountable for our respective work. This also allows for group members who are behind to say so and let others pitch in and help close the gaps. Clear and frequent communication also ensures that the final product is up to every group member's standards, and no one is blindsided by a single rash decision from any individual."

Observations

The project is anecdotally one of the "most fun" that the students experience throughout the second-year course, and it tends to go well from the instructor perspective. One observation is that students always wish they could have more time with the project to iterate and improve their designs even more. Unfortunately there is not enough time in the course to dedicate to this.

Additionally, students who have no experience with experimentation tend to catch on due to observing their peers as to how to conduct experiments and iteration. They are often dependent on the instructor and course staff for initial insight on how to observe and fix performance issues, but through the shared learning experience with their group many become proficient by the end of the project and carry that knowledge to their final exam.

Students' written work across the board accurately documents the construction of glider designs and catapult designs with material selection and implementation of design discussed clearly. Students' discussion of experimental procedures and iteration is less clear in the laboratory report, but is fully documented in the daily worksheets. The ability of the students to reflect on teamwork and stakeholder requirements integration improves by the explicit use of the Catpilot Stakeholder report and the individual reflection, along with similar content in their daily worksheets. Finally, all students convey understanding of meeting or not meeting the performance requirements given their experience on competition day as well as from writing about their competition performance compared to other teams in the laboratory report. This understanding is brought into individual reflections as well, and in reflection and laboratory reports, most students attempt to identify an issue with either their teamwork, the time available for the project, or the project instructions.

Challenges With Assessment and Evaluation

There is a consistent challenge faced by students getting sick and needing to make up time for the project. However, having access to a facility where the students can come in from 7AM–12AM and work on their project when they need to alleviates some of this issue. The stakeholder evaluation is something that might better serve the students to consider at the mid-point of the project instead of at the end. The opportunity for individual points is something that the project needs, but the actual questions asked and the thinking that students do would help them during the project in addition to at the end. The expense report assignment was graded based on the students completing their calculations properly. Several groups lost significant points because of incorrect addition and multiplication. The emphasis on the correctness of the calculations should be established clearly, as the students who lost points didn't seem to understand the importance of the expense report. Providing clear rubrics with expected questions to answer for the writing assignment increased confidence and quality in the written report and reduced redundancy between report sections. It was also easier for the graders to go through and grade. As a consequence, we were able to be more thorough with our grammar and formatting requirements to better prepare students for the expectations of their third- and fourth-year classes.

Conclusion & Next Steps

We developed and implemented a collaborative, in-class project for aerospace engineering students for which HCED is a central practice. This work has relevance as something from which other instructors may take away a few aspects, or which they may replicate entirely in their own courses. The project is also adaptable for different class environments. The specific changes recommended would be to create an artificial stakeholder that is more suitable for the curriculum at different universities (e.g., ties into mascot identity or instructor preferences). Additionally, different vehicles or projects may be better suited for different engineering disciplines—for example, we tried artificial stakeholder implementation with boats on a smaller scale, and it works well as long as flowing water is available. Any structure that can be built during class with restricted materials, a human stakeholder stand-in, and an experimental process to test the structure would be suitable, such as a bridge project, scale building, hydrology studies, or urban environment wind tunnel testing.

In ongoing work, we are collecting data for this project from pre- and post-test surveys [7] for analysis for a future publication. In future iterations, we expect to provide more guidance regarding making connections between the project and classical mechanics and aerodynamics content with guided problem solving on the Laboratory Note. Connecting this project to the fundamentals of Aerospace Engineering on an even deeper level would better prepare students for their upper-level coursework. Finally, during experimentation we intend to increase the amount of observation time for the instructors and course staff to witness flights and provide helpful feedback, as this will allow for iteration to occur more rapidly and lessen the stress of the limited timeframe for the project's completion.

Appendix A

Glider-Catapult Project Laboratory Note
By: Team Name: Student Name, Student Name, Student Name

Be sure to answer each question in your final assignment, but do not leave all the question prompts as questions in your final submission. Change them to be appropriately formatted subheadings or remove the prompts entirely and just write in paragraph form under the main headings. Include figure number and captions below each figure. Include table number and title above each table.

I. **Introduction**
   a. **What are the requirements for the glider-catapult designs for this project?**
   b. **Who are your NASADA flight test Catpilots?**
   c. **Photographs of NASADA flight test Catpilots**
   d. **Who are your unpaid engineering interns?**
   e. **Photographs of unpaid engineering interns**
   f. **Provide a summary of project goals and strategies**
   g. **Provide a summary of approach to keep Catpilots safe**

II. **Theory (Gliders and Catapults)**
   a. **Use equations to demonstrate how Range and Height can be used to calculate Lift-to-Drag Ratio**
   b. **Use equations to discuss what forces are in play during glide**
   c. **Include FBD for glider in flight**
   d. **Use equations to demonstrate how spring physics can be used to model catapult designs**
   e. **Include FBD for catapult preparing for launch**
   f. **Discuss how theory can be used to improve safety of glider-catapult**

system for Catpilots

III. Design (Gliders and Catapults)

a. Discuss what design ideas were brought up to meet project requirements

b. Discuss what ideas you had to try to minimize project costs

c. Discuss what ideas you had to secure Catpilots safely

d. Show TOP, FRONT, AND SIDE view PHOTOGRAPHS of all gliders (even if broken)

e. Show TOP, FRONT, AND SIDE view DRAWINGS of all gliders with major dimensions labeled

f. Analyze Catpilot locations to note safety concerns for each glider

g. Analyze glider designs to note fatigue for each glider

h. Analyze glider designs to note material usage for each glider

i. Show TOP, FRONT, AND SIDE view PHOTOGRAPHS of catapult

j. Show TOP, FRONT, AND SIDE view DRAWINGS of catapult

k. Analyze catapult design to note fatigue

l. Analyze catapult design to note material usage

m. Analyze catapult-glider integration, how were they attached?

IV. Experimental Methods

a. Explain how gliders were tested

b. Explain what data was collected from glider tests

c. Explain how iteration on gliders occurred

d. Explain how catapults were tested

e. Explain what data was collected from catapult tests

f. Explain how iteration on catapults occurred

g. Discuss Project Management Throughout Project - how were you and your group members able to complete it

i. Did you have a schedule of internal deadlines?

ii. How much time did you meet outside of class (if at all?)

iii. Did you have a game plan coming into class or did you make a game plan during class?

V. Experiment Results, Analysis, & Discussion

a. Provide Experiment Range Results in graph form for all three gliders: bar-charts or scatter plots

b. Analyze each glider's performance individually and discuss how performance is related to design

c. Highlight the quantity of Catpilot incidents for each glider and discuss how this was related to design

d. Analyze the three gliders as a group and discuss which performance was best and why

e. Provide Experiment Range Results in graph form for the catapult-glider

system: bar-charts or scatter plots

f. Analyze catapult performance and discuss how it is related to design

g. Highlight the quantity of Catpilot incidents for catapult-launched glider flights and discuss how this was related to design

VI. Competition Results, Analysis, & Discussion

a. Provide total expense for project

b. Analysis of Costs / Tradeoffs - Were those team costs worth it? Why or why not?

c. Provide Competition Results in tabular form for your group

d. Highlight any Catpilot incidents during the competition (if any) and explain how the design of the system contributed to Catpilot safety

e. Provide scatter-plot or bar graph data comparing your group to the rest of the class. Choose to plot ONE of the following in this comparison:

i. Total Project Cost Comparison of All Groups

ii. Precision Score Comparison of All Groups

iii. Range Comparison of All Groups

iv. Competition Score Comparison of All Groups

f. Discuss why you chose to analyze the comparison you did

g. Analyze your comparison and hypothesize why your group is placed where it is compared to the rest of the class

VII. Conclusions

a. Summarize how the three glider builds and experiments went and why

b. Summarize how the catapult build and experiments went and why

c. Summarize how Catpilot safety was impacted by glider and catapult designs

d. Were there issues with team schedule management?

e. Were there issues with overall team costs?

f. Were there issues with mitigating risks to Catpilots by team members?

g. Summarize the schedule-risk-cost relationships that were in tension in this project.

VIII. Future Work

a. If you could redesign the gliders or catapult again, what suggestions do you have to improve your work?

b. If you are faced with a glider flight experiment essay question on your final exam, do you think you have a solid understanding of glider stability to recommend fixes to a broken glider based on data alone?

c. If you were to become a paid engineering intern to work with your catpilot again, what type of physical vehicle project would you want to build for NASADA?

Appendix B

Glider-Catapult Project 2025

Expense Report

By: Team Name: Student Name, Student Name, Student Name

Total Expense: ________________ (total material costs + fixed lab fee)

Table of Material Costs at NASADA Glider-Catapult Prototype Lab

Experiment Build Materials	Cost Each	# Used	Total Cost:
Sandpaper Sheet	$1.00		
Thin Balsa Sticks	$0.08		
Large Rubber Band	$0.09		
Piece of Paper	$0.08		
Small Popsicle Stick	$0.02		
Large Popsicle Stick	$0.06		
Thin Balsa Wood Sheet	$1.84		
Thick Balsa Wood Sheet	$1.74		
Small Binder Clip	$0.13		
Medium Binder Clip	$0.33		
Large Binder Clip	$0.43		
		Total Material Costs:	

Table of Fixed Fee Lab Expenditures at NASADA Glider-Catapult Prototype Lab

Lab Experiment Equipment	Fixed Fee
Scissors	$3.00
Exacto Knife	$0.66
Cutting Board	$1.99
Hot Glue Gun	$3.37
2 Extra Glue Sticks	$0.16
Kitchen Scale Fee	$0.42
Super Glue	$3.91
Protractor	$0.44
Ruler	$1.79
27 ft Tape Measure	$4.75
3 Pairs Safety Glasses	$3.00
1 Roll Duct Tape	$3.46
Clay Fee	$0.10
Total Fixed Fees per Team:	

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