APPLYING PROJECT-BASED LEARNING WITH AN EMPHASIS ON ENGINEERING COMMUNICATION: A REPORT ON AE 100 COURSE RENOVATIONS

BY

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THESIS

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ABSTRACT

This work summarizes an effort performed to modify and improve AE 100, an introductory course in the Department of Aerospace Engineering at the University of Illinois Urbana-Champaign. This project was motivated by the desire to design the class around project-based learning, which research shows can improve learning outcomes for students. Additional changes were implemented to improve education in engineering presentation and technical communication skills. This freshmen-level course has been offered for more than a decade, although it has traditionally been used to introduce only a few specific concepts in aerospace engineering. Previously, freshmen were made to choose between two versions of this course, one focused on aeronautical engineering and the other on astronautical engineering. This project aimed to unite the two subjects and introduce a goal-oriented design project for each subject: a model rocket and a hand-thrown glider. Both projects featured a final report designed to emphasize different communication skills.

Additional changes were made to improve engineering communication skills in students taking the course. Evidence has been collected to compare final reports from before and after these changes were implemented, and evaluation of this evidence shows a drastic improvement in the quality of the final reports following these changes. Surveys taken at the beginning and end of the class to assess student perceptions of their skills in several areas have been collected and analyzed for this report. The results of these surveys show success in learning outcomes across a variety of subjects, although on most measures a direct comparison of outcomes from before and after the changes were implemented cannot be made. The introduction of project-based learning with an emphasis on engineering communication skills in AE 100 has improved the experience of the students in the Department of Aerospace Engineering.

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Table of Contents

Chapter 1: Introduction

First-year students in the aerospace engineering program at the University of Illinois are strongly encouraged to take AE 100, a two-hour introductory course during their first semester. This class introduces students to aspects of aeronautical and astronautical engineering through team-based projects. The goal of this effort was to improve the outcomes of these projects by aligning them with the principles of Project-Based Learning (PBL). Research in engineering education has shown that PBL enhances student interest and retention in engineering [1] [2] [3]. The modified course features two projects: a model rocket and a large hand-thrown glider. Each project has a set of requirements that the student teams must satisfy. The primary assessment for the rocket project is a narrated video presentation, and the primary assessment for the glider project is a technical written report. Traditional lectures are given for one hour a week and a build/lab session is held two hours a week. These projects and the improvements made over the prior class are described in detail in this paper, and an analysis of improvements in student technical communication abilities over the period of the class is provided. The changes made to the course are detailed in Chapter 3, and an analysis of survey data taken in the class is provided in Chapter 4. Chapter 5 discusses the results of the analysis, and Chapter 6 discusses potential future improvements.[1]

The impetus for changes to the course emerged from comments and critiques on the quality of students graduating from the program made by the department's Aerospace Alumni Board. Anecdotally, they identified weaknesses in communication skills among recent graduates. Similarly, the department's senior design instructors suggested that their students often lacked presentation skills and demonstrated poor technical writing. This experience is reflected in research, as surveys have shown that engineering graduates are often dissatisfied with their instruction in technical writing [4]. The instructors believed that they could start to address these issues in the aerospace engineering program's first-year class, as first-year engineering education has proven critical to student performance and retention [5] [6] [7]. Changes to this course were implemented starting in 2015.

[1] This report is based on the ASEE Conference paper "Applying Project-based Learning with an Emphasis on Engineering Communication for First-Year Students" [47], by David Degenhardt, the author of this report, and Dr. Brian Woodard. © 2019 American Society for Engineering Education holds the copyright and provided permission for reuse of material from the paper. Chapters 1-5 and 7 include material from this paper.

This project to improve AE 100 was supported by a grant from SIIP, the Strategic Instructional Innovations Program. SIIP awards education-innovation grants to faculty teams, motivated by the vision to *teach like we do research*, or put plainly that teaching should involve collaboration, creativity, excitement, measurement, perseverance, and continual improvement. SIIP funding support comes from AE3, the Academy for Excellence in Engineering Education at the University of Illinois. The grant provided for this project funded the team of aerospace engineering faculty that implemented these changes, allowing them to purchase the hardware and tools needed to implement the renovated projects.

Chapter 2: Literature Review

Project-Based Learning (PBL) is an experiential approach to education, in which students learn through facilitated problem solving [8]. PBL uses ill-structured problems, i.e. problems without a single solution, to guide students in developing self-directed learning strategies. Projects based on PBL are often more reflective of industry work and take place over extended timescales, which can enable better acquisition of problem-solving skills than traditional lecture methods [9] [10]. PBL entails turning time management over to the students; they must learn new topics and also learn to apply previously studied topics to their projects at their own direction [11] [12]. This frees instructors to participate in class not as classroom managers, but as peers assisting students in learning. PBL also assists learning in the non-technical skills required by engineers, including teamwork, project management, and presentation skills. While not a replacement for traditional lecture courses, PBL assists in teaching design as the core of "what engineering is about" [13] [14] [15].

PBL is well received by students, earning praise for the inclusion of real-world applications of engineering course work [9]. An additional benefit of PBL is that it can help students make better connections between different engineering disciplines when design projects are multidisciplinary [16]. Finally, PBL in a first-year design course can enhance intellectual development as measured by the Perry model [17].

While the body of research on PBL is extensive, a concise description of exactly what constitutes PBL is hard to come by, and when provided the description varies from researcher to researcher. PBL is often associated with other experiential learning systems such as *problem*-based learning, a method that shares many traits with PBL but places greater emphasis on student-directed learning. Similarly, the model used in AE 100 can be described more specifically as project-*assisted* learning, which mixes PBL and traditional lecture methods [9]. This leads to the conclusion that PBL is not understood as a single, uniform concept, but as a collection of commonly-described practices. For this reason, a set of key PBL principles was drawn from multiple sources for use in this report:

Table 1. Principles of Project-Based Learning

#	Principle:	Expected Benefit:
1	Open-Ended Design Problems: Problems without a definite answer force students to engage in design. Students must learn to manage their projects to see them to conclusion	Improved project management and design skills [18], Improved motivation [15] [19] [20]
2	Self-Directed Learning: Places the emphasis for acquiring and applying knowledge on the students.	Improved understanding of course material [8], Improved research skills and learning strategies [13] [15] [18] [21]
3	Collaboration: Students must learn to work together in teams to complete their projects.	Improved ability to work in teams [8] [15] [18]

The use of projects in aerospace engineering programs is widespread. At the Massachusetts Institute of Technology, problem-based design projects are incorporated in each year of the Aeronautics and Astronautics undergraduate curriculum [22]. This curriculum includes a sequence of design-build challenges, starting with a radio-controlled lighter-than-air vehicle, followed by a more complicated radio-controlled aircraft. Upper-level courses draw scenarios from industry or government sources and are topped with an extensive, multidisciplinary capstone laboratory. These projects also progress from structured, well-formulated problems to multi-faceted, unconstrained design projects. Feedback collected by instructors at MIT shows that students find the project-oriented curriculum to be rewarding and stimulating.

Regarding first-year experiences, many universities have implemented projects similar to those introduced in AE 100. In particular, model rockets have proven to be a cost-effective way of implementing PBL in first-year classes. The University of Massachusetts Lowell has many years of experience with model rocket projects [23]. In this curriculum, second-semester students are presented with the challenge of launching a rocket as high as possible with as short a flight time as possible. This project is intended to provide an early opportunity for design work, building on math and science courses offered prior to this class. Students submit a technical report, which accounts for the majority of each student’s grade. At Old Dominion University, instructors developed a rocket project with a focus on predictive methods for calculating a rocket's apogee [24]. In this course, students built and launched model rockets in randomly assigned teams and were then asked to calculate their apogee using analytical-hand methods, computer-based numerical solvers, and a purpose-built rocketry simulator. Finally, instructors at Universitat Politècnica de Catalunya in Spain use a PBL-oriented model rocket workshop to teach students project management skills, oral and written communication, and teamwork [25].

Similarly, model glider projects have also proven popular. The United States Military Academy at West Point has introduced a short engineering class in which an inexpensive hands-on glider project is used to teach fundamentals of aircraft design [26]. Designs are built for two competitions, one in which the Lift-to-Drag ratio of the glider is the primary criteria, and another in which the glider is designed for minimal lateral drift. Surveys taken in this course yielded wide agreement about the utility of this project among the students.

An intriguing implementation of a combined rocket-glider project was undertaken at the United States Air Force Academy [27]. First-year students are assigned to design and build a boost-glider, which is launched like a rocket and then glides back to earth under radio control. This project was multidisciplinary, and require students to learn topics in aeronautical, civil, and electrical engineering.

Chapter 3: Course Changes

3.1 Summary of Course Changes

Prior to 2015, AE 100 was offered in two sections, an aeronautics course featuring an RC-plane design project, and an astronautics course featuring a model rocket design project. While these classes were notionally project-based, the instructors believed that the projects did not meet the principles of PBL laid out in Table 1, for reasons discussed in section 3.2. Another deficiency observed in this model was the fact that freshmen students were forced to choose between these two sections, and therefore the two subjects. While students in the aerospace engineering program eventual need to choose between aeronautics and astronautics for their senior design class, the instructors believed that imposing this choice on first-year students was unnecessary. By combining the courses and exposing students to both subjects freshman year, it was hoped that they would be able to make a more informed choice later in their education. This motivated combining the two separate courses into a unified format.

In the new combined course, the two projects that accompanied each of these prior classes were modified to align better with the principles of PBL and fit into a single semester. This reform had the additional benefit of extending the use of projects throughout the entire semester, as opposed to just three or four weeks spent on projects in the previous model. This strategy aligns with the PBL concept of an overarching project experience. Table 2 includes a summary of the changes made to the projects.

Table 2. List of Course Changes

Course Aspect	Changes Made
Rocket project	• Reduced team size from four to two • Reduced scale of rocket allowing each team to build their own • Added goal of launching the rocket to a specific altitude • Provided students freedom in implementing a design • Moved build sessions from the middle of the semester to the start of the semester • Moved rocket launches from end of 2nd month to end of 1st month • Introduced a video report as the conclusion to the project

Table 2 (cont.)

Course Aspect	**Changes Made**
Aircraft Project	• Changed project from RC aircraft to glider • Added design goals for glide distance and glide time • Provided students freedom in implementing a design • Introduced prototyping build sessions to allow students to test different designs
Technical Writing	• Added two writing assignments to prep students for their final technical report • Introduced peer review grading
Other	• Combined astronautics and aeronautics AE 100 sections into a single course • Extended total time spent by students on design projects • Introduced the use of course assistants

The renovated model rocket project is discussed in section 3.3, and the glider project in sections 3.4 and 3.5. To accommodate the lecture material on both aeronautics and astronautics, lectures that had been devoted to programming prior to 2015 were removed, as the 2015 course change was accompanied by the addition of a first-year programming course to the aerospace curriculum. However, a set of lectures delivered on programming and modeling were introduced in a single section of the course in 2018. This lecture set is described in detail in section 3.7, and the assessed impact in section 4.7.

Additional changes were made to the course to improve learning outcomes in technical communication. This includes a battery of writing assignments designed to address specific communication skills prior to a final technical report assigned for the glider project. A video presentation was implemented as the conclusion of the rocket project. The video presentation is detailed at the end of section 3.3, and the writing assignments are explored in detail in section 3.6.

Course assistants were used to help with class activities starting in 2016. In 2016 and 2017 these course assistants participated unofficially and were drawn from upperclassmen volunteers to help students build and launch their rockets. In 2018 four sophomore course assistants were hired. These students were selected by the instructors due to their enthusiasm, leadership, and competency displayed in AE 100 the year before. This had the benefit of reducing the age gap between the students and their mentors, which can make first-year students more likely to ask for help [28]. These course assistants attended all of the build sessions, helping students with their projects and taking some of the workload off the shoulders of the instructors. In addition, they participated in grading student reports and assisted with flight days for both the gliders and the rockets. This model of hired course assistants will be continued in 2019.

3.2 Prior Course Projects and Their Deficiencies

The prior model for the astronautic project was the construction and launch of a large model rocket in groups of four students. Due to cost and time constraints, most of the rocket was provided to students pre-built, with these sections being reused year-to-year. For their part in the project, students followed an instruction manual to assemble an altimeter and camera payload for the prebuilt rocket, which would then be launched with a local rocketry organization near the end of the semester.

The prior model for the aeronautic project was a remote-controlled aircraft built in groups of four. A foam wing section was provided to students, who would then design control surfaces as specified in an instruction manual, in addition to attaching motors and radio-control equipment. The instructors believed that this project had many of the same deficiencies as prior rocket project, namely that this project only amounted to students following a set of instructions with very little actual design. In addition, these RC aircraft proved so difficult to control that they could only be flown by experienced RC hobbyists. However, this project was initially used in the modified course in 2015 and 2016, and was finally replaced in 2017.

The instructors felt that these projects failed to adhere to the principles of project-based learning in large part due to the projects revolving around following specific instructions. In an open-ended design project following the first principle of PBL, students would be afforded great freedom in their design process. This forces students to seek out and apply knowledge, the second principle of PBL. The prior projects featured almost no analysis, and the little work that was present was guided by set processes in the instructional manuals. It is evident that the old model of design projects fell far short of PBL and therefore could not expect to see the benefits

PBL has shown to provide. Efforts to bring these projects in line with the above PBL principles are detailed in the next two sections, and conclusions draw for survey results are discussed in section 4.3. Recalling the list of PBL principles outlined in Table 1, more specifics for how each project included or failed to include these principles are presented in Table 3.

Table 3. PBL Principles Related to Pre-2015 Projects

PBL Principles	Rocket Project	Aircraft Project
Open-Ended Design Problems	The rocket project had a clear design outcome that was specified in the instructions, which is clearly not open-ended. Students complete activities in the instructions in time blocks set by the instructor, removing project-management responsibilities from the students.	The aircraft project included some design on the aerodynamic surfaces of the aircraft, although the instructions specified size ranges that the control surfaces had to meet. This resulted in little design work taking place, so the project was not open-ended.
Self-Directed Learning	Knowledge gained in lecture was not applied in the rocket project, as no design or analysis during construction took place. Some analysis of the rocket trajectory was included in the final report, which required application of lecture material.	The design work present in the project was constrained by the instructions, allowing students to build workable aircraft without applying knowledge learned in class.
Collaboration	Students worked in teams of 4-5. Written reports assigned at the end of the projects were completed in teams. While this nominally fulfills the PBL principle, the projects did not require much collaboration in the way of technical design. Since very little design work took place, the students did not need to communicate their reasoning for design decisions to their teammates, which is a critical skill in engineering.	

Another core weakness of these design projects is that they both started after several months of the semester had elapsed, concluding near or after Thanksgiving break. This left the start of the semester as a long set of uninterrupted lectures. The instructors believed that completing a design project within the first month of school could boost enthusiasm and retention, as PBL and design courses have been shown to boost these in the past [4].

The old projects had severe logistics problems. The rocket for the old project was very large, 4 inches in diameter and nearly 6 feet tall. The cost of parts to build one of these rockets, as well as the time necessary to put them together, precluded students from building new ones each year. Instead, a set of these rockets was built and used for several years, with the students only constructing an avionic bay holding a camera and an altimeter. An additional problem with these rockets was that they were so large that they could only be launched at specific sites with the assistance of a local rocketry group, Central Illinois Aerospace. The preferred launch site for these rockets was a farm field in the town of Monticello that could only be used once it had been harvested, which normally did not occur until late October. In addition, the site was a 30-minute drive from campus, which required the course instructors to reserve a bus. This required all students to stay at the launch site for the entire day, a huge time commitment for students, with many unable to attend due to sport-related conflicts. Weather was often another significant issue, as all the difficulties mentioned above made attempts to reschedule launches for weather purposes almost impossible. These weaknesses were additional driving factors behind the modification of this project.

The RC-plane project did not suffer from the same site-constraints as the rocket project, however the RC-components proved to be expensive and difficult to reuse multiple times. In addition, these planes required experienced RC pilots to fly, resulting in a large bottleneck during the flight day, as only one or two planes could be flown at a time. Given that this event often occurred in late October or November, weather could also be a hindrance. These issues were addressed by removing the RC component of the project and moving the flights to an indoor facility.

3.3 Rocket Project

The improved astronautics project is a small model rocket built in teams of two, which reduces cost and allows new rockets to be built by each team every year. The body tubes of these rockets are less than two inches in diameter, and all the parts for a rocket can be purchased for under $20. These rockets are designed to fly to altitudes under 1000 feet and can be launched with minimal equipment from a local park. This allows instructors great flexibility to plan the launch date around sporting events and weather. Furthermore, Colbert Park, the location used to launch these rockets in 2015-2018, is easily accessible by public transport, allowing students to attend for much shorter blocks of time and removing the cost of a bus reservation from the department.

When the project is introduced, the students are given two goals: (1) launch the rocket as close as possible to a goal altitude and (2) return an onboard egg safely to the ground. To design a rocket to meet these goals, students must understand rocket trajectories and how they are affected by aerodynamic stability. A minimal instruction manual is provided to walk students through the more critical sections of construction such as the motor assembly and the parachute attachments. However, most variables in the design of the rocket are left open to the students and are described below.

Each team has the freedom to adjust the length of the rocket, the weight of the rocket, and the size, shape, and number of fins. These variables are provided with a set of minimum values, at which the rocket would achieve a maximum altitude far above goal altitude. As an upper limit, the teams are constrained to a certain quantity of building materials. Students must apply lecture material, as well as computer simulations, to design a rocket that will meet the altitude goal.

These modifications to the project align it with the first principle of PBL: the use of open-ended design problems. While some instruction is provided, there is no single path to designing a rocket that will meet the design goals. Students must take an active role in the design process, working through that process with their partner. Given four lab sessions to complete their rockets, the students must learn to manage their time, their materials, and the division of labor. They must also learn to communicate their design ideas with their teammates and come to common ground for a final design. Figure 1 shows one of the rockets that survived both launch and recovery.

Figure 1. Model rocket from the modified course section (Approximately 18 inches long)

Students receive lectures in rocket trajectories, rocket propulsion, and aerodynamics over the course of the project. A tutorial for the open-source simulation software OpenRocket is also provided in lecture, during which students were asked to follow along on their own computers [29]. This class was followed by an OpenRocket homework assignment, where students modeled a basic rocket and analyzed the effects of aerodynamic stability on a rocket's trajectory. The OpenRocket editor and trajectory simulator are shown in Figure 2 and Figure 3, similar to what is submitted in the homework assignment. Students were then encouraged to use this experience to model their group's rocket before construction, which would allow them to adjust the design parameters of the rocket appropriately to achieve the goal altitude. The rockets are constructed over several dedicated work sessions, in which the instructor, teaching assistant, and additional undergraduate course assistants are present to answer questions. However, students are encouraged to use technical reasoning and lecture material when making design decisions, rather than on relying directly on instructor feedback.

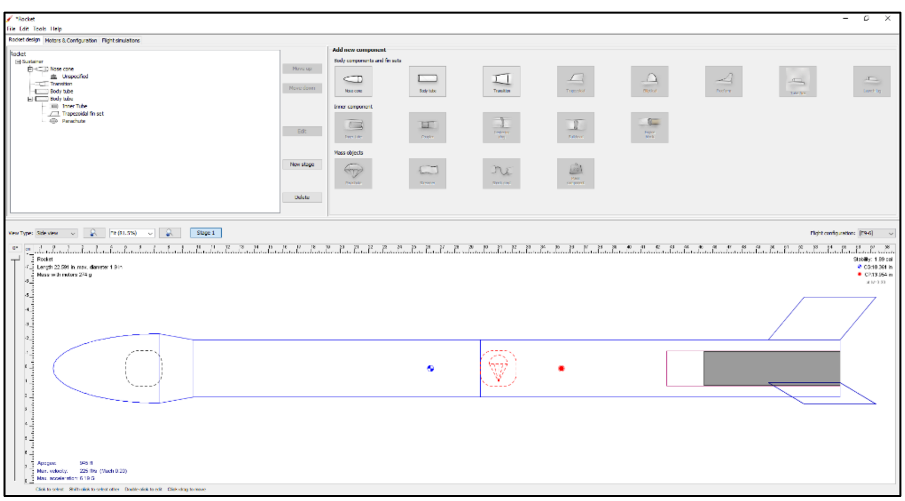

Figure 2. OpenRocket Vehicle Editor

The application of lecture material and the use of simulation software aligns with the second principle of PBL: self-directed learning. While the concepts behind rocket trajectories and rocket design are taught in class, the students are left to their own devices to learn how to apply these lessons to their rockets. By applying these lessons in design, it is hoped that the students will internalize them better than by traditional lecture and homework methods. The use of OpenRocket software is also critical to this principle, as it allows the students to assess the impact of different designs in simulation, which provides immediate feedback for their design ideas.

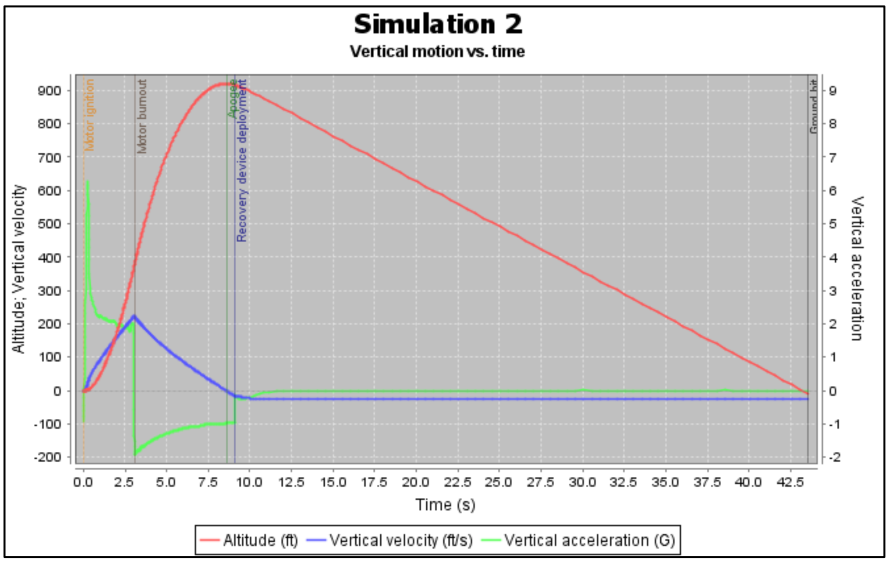

Figure 3. OpenRocket Trajectory Simulation

Each group is responsible for preparing their rocket for launch, with assistance from the instructors. Each rocket is fitted with an altimeter to determine the final altitude, and a camera to provide video of the launch. A scale is also provided so that students can fine-tune the mass of their rocket to achieve the goal altitude. Altitudes are reported as rockets are launched and recovered, so that the students know which team is closest to the goal altitude. Finally, trajectory data from the altimeters and videos are distributed to the students after the launch day for use in their video report.

The video presentation report is assigned before the construction of the rockets. The purpose of this report is for each group to present their rocket design and to analyze their rocket's performance in meeting the goals. The videos are restricted to between 2.5 and 3.5 minutes and are made in lieu of an in-class presentation. This assignment was intended to be an unintimidating introduction to giving a technical report as students would not have to give the report to a live audience. Following the submission of these videos, one or two were played at the beginning of each lecture for the rest of the semester, so that the students could watch their peers' presentations. The guidelines and grading for the video presentation focus on detailing the design decisions the students made and the analysis of their flight, which are a critical part of normal engineering presentations. The timed format of the videos requires that the students concisely summarize their results and report them cogently. The instructors believed that the video presentation format would force students to put serious thought into what they were saying. Students watching their videos in editing would have the chance to pick up on parts of their report that were lacking or that were poorly communicated, a benefit not available to them in a live presentation. The instructors believe that these factors could contribute to improvements in technical communication skills.

3.4 Glider Project

A renovated aeronautics project was designed so that students would prototype, design, build, and test a glider that would maximize flight time and distance when thrown. The gliders also must be reconfigurable through control surfaces to fly at a constant turn, which adds complexity to the design. This allows students to apply engineering principles learned in lecture to a real-world design challenge. Unlike the prior project, no instructions are given on the design of the gliders. Instead, students must rely on a trial-and-error approach informed by lecture material. Working in groups of four, the students are tasked with prototyping small gliders made from foam sheets and balsa wood, using the best configuration as a basis for their full-sized glider. They then use a computer-aided design tool to create a template for glider components that are laser cut out of thicker sheets of foam board. Once assembled, these gliders are test flown and optimized by the students. A prototype glider and full-sized glider are shown in Figure 4 and Figure 5.

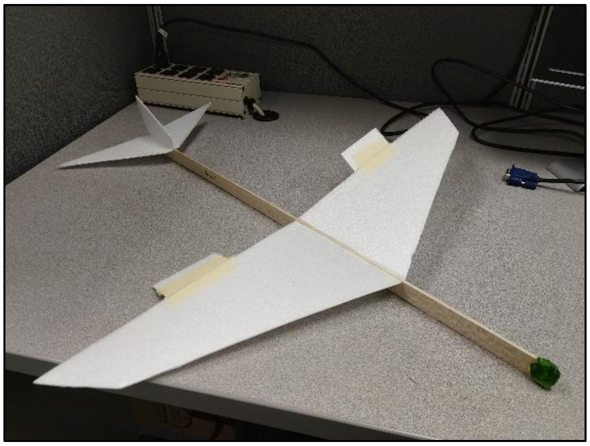

Figure 4. Prototype glider from the modified course section (2 ft wingspan)

Figure 5. Completed glider from the modified course section (7 ft wingspan)

The complete removal of any instructions related to the design on the gliders aligns this project with the PBL principle of open-ended design problems. While before a concise plan for the RC plane was provided to the students that removed any real need for design, this project ensured that students would engage in design to meet the provided goals. As with the rocket project, the glider project required the students to manage a limited set of materials and to keep track of the time, as only four to five lab sessions were provided for prototyping and final glider construction. Due to the large size of these gliders, the students need to learn to multitask in teams, dividing the project up into separate jobs that can be completed individually or in groups of two.

Lectures for this project cover basic aerodynamic principles such as lift and drag, as well as aircraft stability. These lectures are given in between prototyping build sessions, allowing students to apply these newfound principles to their glider prototypes. The instructors provide few guidelines for the glider, which results in a wide variety of prototype designs. For their final design, the students need to apply the lessons they have learned in prototyping, as well as the material covered in lecture. As with the rocket project, this aligns with the PBL principle of self-directed learning. When prototypes have failed to fly stably, the instructors reminded the students of the lecture material on that subject but did not provide design guidance. Instead, the students would have to understand the lecture material and apply it. Many students took this a step further, using their lab time to research glider designs on the internet. The students also practiced their teamwork and communication skills by debating with their teammates over the final design. In most cases, each student built multiple prototypes on their own while learning from their teammates. To come to a final design, these teams need to discuss the merits of each design and learn to follow along with the group if their own design is not chosen. These teamwork skills are not practiced if the project lacks design and are one of the secondary benefits of the course modifications.

Following the prototyping lab sessions, the full-sized gliders are constructed over another three build sessions, which allows the students plenty of time to optimize their designs. Upon completion, these gliders are flown at a large indoor facility. After the glider competition, the students are assigned to write a technical report on the design and performance of their glider in their groups of four. This report will be described in detail in the next section.

It should be noted that this project did not settle into a steady configuration until 2018. The initial plan in 2017 was to test the gliders by dropping them from a great height. The students were given the goal of designing a glider capable of pulling out of this dive and flying in a spiral to the ground, landing as close to the drop coordinates as possible while remaining in the air for the as long as possible. The implementation of this included a method of dropping the gliders from a balloon-hosted platform that was tethered to the ground. On the first competition flight day, the platform was unable to achieve a height of more than twenty feet due to slight winds and was deemed a failure. Following this, the goal of the project shifted to what was described above, a glide distance and flight time test. This change was implemented from the start of the 2018 class, and it was decided that this would be the permanent project implementation moving forward.

3.5 Aircraft Project Simulation Software

The successful implementation of OpenRocket in the rocket project drove an effort to include a similar simulation software for the glider project. In 2017 several options for aircraft simulation software were evaluated. The video game Simple Planes, in which the user selects from components such as wings and engines to construct an aircraft, was a possible option for teaching some of the basics of flight mechanics. However, the selection of components was too limited to create aircraft like those being constructed by the students for the glider project, so Simple Planes was not selected.

Another game, Kerbal Space Program, was also evaluated. Prior to this effort, Kerbal Space Program was used in the sophomore-level AE 202 course for homework assignments on orbital mechanics. The game includes a large array of parts for aircraft as well as spacecraft, which can then be flown in the game. Additionally, a number of 3rd-party modifications to the game are available that greatly enhance its ability to simulate gliders, such as a package that calculates stability derivatives and plots lift-to-drag ratio vs velocity and angle-of-attack. Despite these advantages, the requirement of installing 3rd party modifications, especially on the university machines that Kerbal Space Program was provided on, would make implementing this software too cumbersome. There were additional concerns about a steep learning curve for creating flyable gliders in the game, so Kerbal Space Program was not selected.

Another option, OpenVSP (Open Vehicle Sketch Pad), was evaluated [30]. OpenVSP is an open-source software developed by researchers at NASA Langley that had previously used in AE 460, the department's aerodynamics laboratory. The software allows the user to create a model of an aircraft and perform some basic aerodynamic analysis such as creating a coefficient of lift vs angle of attack plot and plotting pressure distributions along the aircraft. An example of the editor is provided in Figure 6, and a capture from the pressure distribution simulation can be seen in Figure 7.

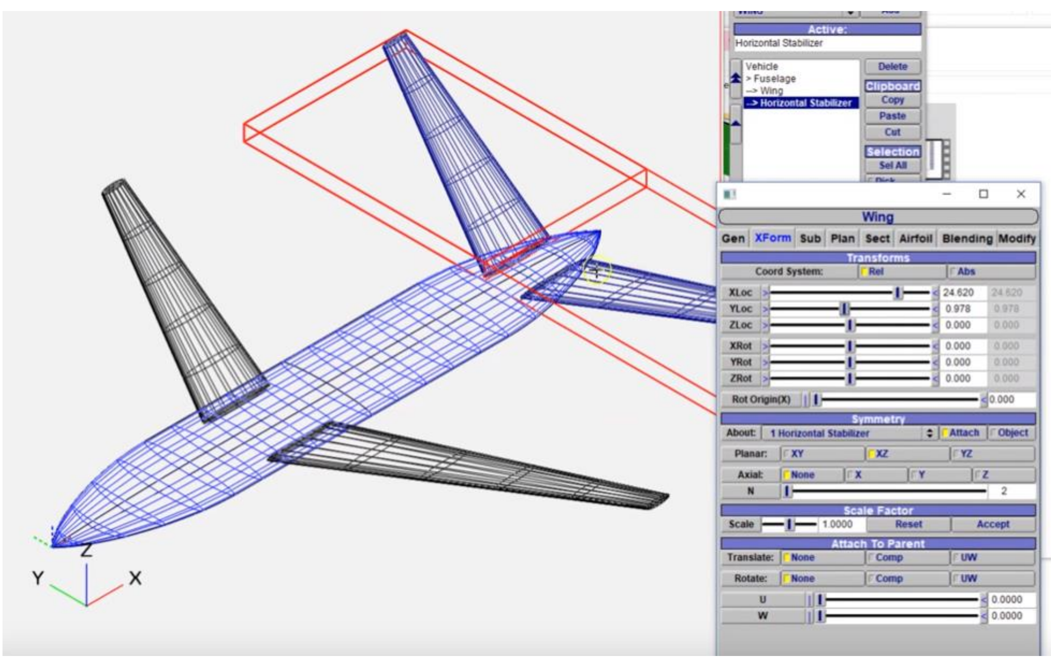

Figure 6. OpenVSP Modeling Window

While OpenVSP had a steep learning curve, the software provided analysis tools that the students could use to simulate their gliders, which was the driving goal of this project. To account for the learning curve, a lecture on the use of the software was given, and a series of four YouTube tutorials designed to walk students through the modeling and analysis of an aircraft very similar to common glider designs were produced and provided to the students.

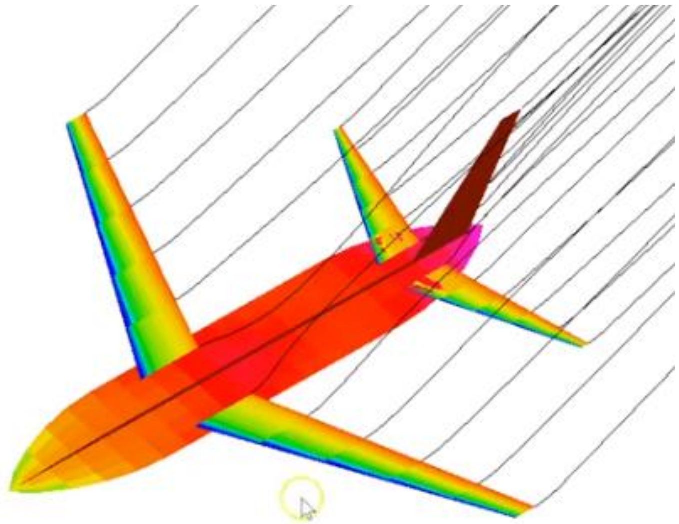

Figure 7. OpenVSP Pressure Distribution Simulation

Following the lecture, the class was assigned homework asked students to modify an OpenVSP model created by the instructors similar to the gliders they were producing for the project. They were asked to run a simulation and provide the following plots:

- A convergence plot of lift-to-drag ratios
- A load distribution plot
- A plot of coefficient-of-lift vs angle of attack
- A plot of lift-to-drag ratio vs angle of attack
- A plot of coefficient of the moment about the pitch angle vs angle of attack

The YouTube videos created to assist the students each covered a separate topic of the homework, and the homework was completed without significant difficulty by the students. Unfortunately, the instructors found that not a single team used OpenVSP to assist in designing their gliders or to help with their analysis in their final reports. Due to this factor, OpenVSP was not used the following year. Instead, the number of prototyping lab sessions was increased from two in 2017 to three in 2018, as the 2017 prototyping sessions proved to be very successful in providing students with an understanding of aircraft stability and dynamics. However, simulation software for this project is still desired, and may be the focus of future course improvements.

3.6 Written Communication Assignments

Technical communication skills are critical for early-career engineers, often proving to be key to promotion and advancement [31] [32]. Industry representatives often consider the communication skills of recent graduates to be weak, in part due to the disparity between the writing situations students are exposed to versus those they encounter as graduates in industry [33]. By incorporating technical writing into a design and prototyping course, students can gain a better understanding of workplace audiences and expectations [34].

The modified course instituted a sequence of three written assignments. The objective of this model was to gradually increase the scope and difficulty of writing. In contrast, the old model of a single, final technical report was found to produce reports of widely varying quality with poor grammar and structure. In the new format, high expectations for grammar, structure and technical content can be reinforced prior to the final report through strict grading, instructor feedback, and peer review. The sequence of writing assignments is described below.

Writing assignment #1 asks the students to describe the reason why they chose aerospace engineering as their major. The assignment is limited to 400 words, with the use of proper grammar and structure emphasized by the instructor. The instructor can use this report to gauge the priorities of the students and look for topics of interest to focus on in later lectures. Due to the significant emphasis on grammar and structure in grading, students often find their grades come back much lower than they expected on an assignment they perceive as simple, assigned a week into their college careers. This outcome serves the purpose of introducing high expectations for writing, which can actually provide intrinsic motivation to students to improve their writing skills [35]. However, the instructors do not seek to penalize students and offer an opportunity for students to revise and resubmit their papers. This incentivizes the students to correct and learn from their mistakes, instead of just glancing over the instructor’s feedback. By providing feedback on grammar and structure early, students are incentivized to recognize these errors and correct them in a way that promotes long-term improvement [36].

Writing assignment #2 is used to introduce several aspects of technical writing. Students are asked to research a topic that they believe will one day be influential in the field of aerospace. They must then cite an article or paper published within the last year and briefly summarize it before explaining their reasoning for why this particular topic is important. Grading for this report is split between quality of technical content and grammar, structure, and references.

An additional improvement made to the course was the inclusion of peer review. Past research has shown that peer assessment can lead to improved outcomes in college writing. Through peer review, students gain insight into the grading process and develop skills in document review [37, 38]. For writing assignment #2, the students each grade two of their classmates' reports with the same rubric used by the instructor. This peer review is double-blind, as anonymous reviewers tend to feel that they can be more honest with their feedback [39]. While peer review can motivate students to improve the quality of their work, students may feel that their peers are not fairly assessing their skills [40] [41]. When peer review is instituted, instructors must closely manage the peer review process to maintain anonymity and to ensure that grades are fairly assigned.

Students submit their papers with only an identifying number provided at the top of their first page. These numbers are provided by the instructors anonymously through email. The reports are then uploaded to Compass, where students are assigned two other numbers at random to grade. They submit the graded copies with their identifying number so that the instructor can record who completed the peer review assignment. The scores of the peer review are tabulated and the reports are returned to the students. Grades for this assignment are calculated as an average of the peer review scores and the instructor's score. The instructors analyze the scores provided by the students and in select circumstances remove scores that are obviously outliers, such as when the instructor and one student give a paper a score in the 90% range while the second peer review score is 70%. This peer assessment engages students by the process of *learning-by-teaching*, which helps place the student in the mindset of the reviewer. After reading and grading other papers as reviewers, it is expected that the students can then return to view their own work from the same perspective, leading to improvements in writing. For the AE 100 implementation, data collected on writing scores from before and after this change was implemented will be discussed later in this report, as it seems to indicate that this approach was successful. While there were concerns that students would not take this assignment seriously and give their peers artificially high grades, this has proven not to be the case as the instructors of this course found that students have taken to the peer review with enthusiasm, providing detailed, critical analysis of their peers' writing.

The final written report follows the completion of the glider project. In their groups of four, the students are assigned to provide a detailed description of their glider design and analyze the results of their flight. Properly formatted figures and tables are also required, building on the technical writing skills introduced in earlier assignments. While no minimum length is given, the instructors have found that most papers are between eight and twelve pages in length. A draft submission of the report is required, and the instructor returns the paper with general feedback. This draft submission was instituted to provide a last-minute instructional opportunity for the students to receive feedback on their writing skills. The final version of the report is usually due about one week after the reviewed drafts were returned to the students.

3.7 Programming Lecture Series

Prior to the changes implemented in 2015, AE 100 featured a lengthy introduction to MATLAB, taught in lecture with several accompanying homework assignments. Concurrent with the changes in AE 100 was a change in the aerospace engineering curriculum, in which students were required to take an introductory level course in computer science. This change allowed the AE 100 focus on MATLAB to be reduced and to allow more time for the lecture material of both the aeronautic and astronautic sections of the course to be taught. One or two lectures on programming were retained, although these focused on plotting and creating charts in Microsoft Excel, which were immediately useful skills for the freshman students. However, the author of this report, having recently graduated from the undergraduate aerospace curriculum, decided to implement a new series of lectures in the 2018 version of AE 100 to address personally observed deficiencies in the curriculum's instruction of computer programming.

The weaknesses identified by the author stemmed from personal experience and were not the focus of a larger review. The primary weakness identified was that during the instruction of programming, the concepts and methods presented were often not immediately traced to applicability in the field of aerospace engineering. While higher-level aerospace courses often required computation to complete homework assignments, the author felt after internship experiences that these assignments did not often accurately represent the types of problems engineers solve in industry. Because of this, there was not a direct link between the computational problems presented in the undergraduate curriculum and the types of computational problems presented to engineers in industry. The new set of lectures created by the author was designed to directly bridge this gap early, in the hopes that, by being exposed to the types of problems they might face in industry, the students would better understand how topics in programming and numerical computation presented in later classes would be useful to them in their careers. In addition, the author hoped to inspire students to use programming to assist them in their homework earlier in their education.

Research in engineering education has pointed to deficiencies in approaches to teaching modeling in traditional engineering coursework [42] [43]. Intentional instruction on strategies for modeling development has been shown to result in improvements in students' coded solutions to complex problems [44].

The author devised a set of three programming examples to be taught over two lectures. These examples were designed to introduce a problem, show how to model it, and present the path to solving it using computation. The first example used a monte carlo method to calculate the value of pi. Also known as the shooting method, this example used the following problem statement:

"In a future apocalypse, no one remembers the value of pi. However, you have a circular target and a shotgun, and with enough ammo you can approximate pi."

In the lecture, the author prompted the students for a solution to this problem, and then explained the proof behind the problem. That is, pi can be calculated if the area of a circle and the area of the square that perfectly encompasses that circle are known. If these areas are not known, they can be approximated by counting the number of randomly plotted points falling within each shape, for which the shotgun in analogous. The author then broke the problem into a set of codable steps. The first step was to randomly generate a set of coordinates within a square box. The second step was to determine one-by-one if an individual point lies within the circle using the formula for calculating the distance between two points. The third step used the number of points falling within the circle and square respectively to calculate the value of pi. Pseudocode for each step was written on the board, and finally the algorithm was demonstrated in MATLAB, with the output displayed in Figure 8.

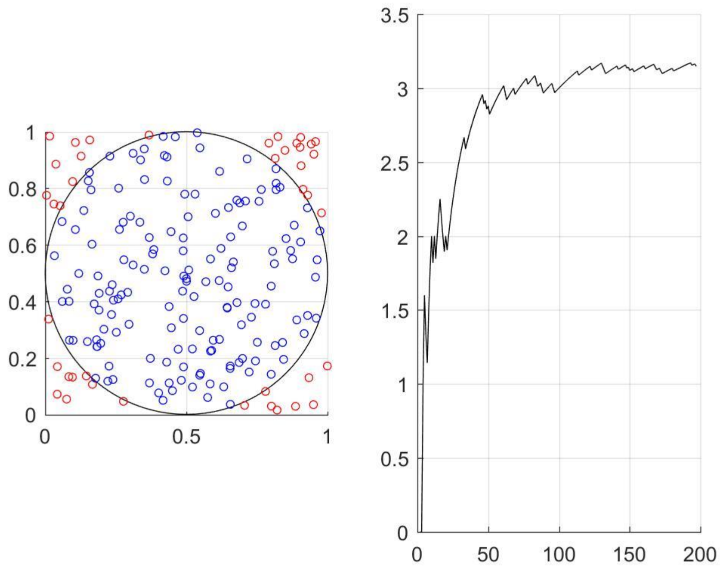

Figure 8. Shooting Method Approximation of Pi

This example served to demonstrate how a problem can be broken down into a series of computational steps. The lecture was then finished with a quick example of how writing MATLAB scripts could directly assist the students. The author brought up a homework assignment that had been turned in by the class several months prior, in which the students had calculated transfer velocities between different orbits. This homework required several extensive calculations, which resulted in most students making small mistakes that lost them points. The author demonstrated how one of the problems, calculating a Hohmann transfer between two Earth orbits, could be solved in MATLAB. The author then explained that, simply by changing variables, the script could be applied to several of the other problems on that homework, drastically reducing the amount of work required by the students. As the author had hoped, many students quickly commented that they wished this lecture had been held earlier. At the end of the lecture, the class was encouraged to think about how to apply these new skills to homework in later courses.

The second lecture began with a quick review of the first two examples before exploring several scripts the author had produced for different classes in the aerospace curriculum. As with the first lecture, the author presented the problem each script was written to answer, showed how the problem could be modeled, and briefly explained the steps taken in the code. The examples proceeded from sophomore level to the senior level, with scripts increasing from the 20-line example previously discussed to several scripts for senior-level classes that exceeded 1000 lines. The author explained that, while these may seem daunting, these scripts were written after the author had gained significant experience in coding through years of assignments. The author advised the class that, by actively applying MATLAB to their homework in the coming years, they would find themselves well equipped to handle their upper-level courses.

The author then presented the final example, taken from a graduate-level course that the author felt adequately represented a problem that could be faced by an engineer in industry. The problem presented was to calculate the trajectory of the space shuttle during reentry and to solve for cumulative heating along the length of the shuttle. This example stemmed from a homework problem the author had recently encountered in a graduate-level course. While this problem seemed daunting, the author explained that, with MATLAB, the solution to the problem could be obtained within five minutes. First, the author wrote down the governing equations of motion for a reentering spacecraft, a set of five short differential equations. The author then briefly explained how the Euler method could be used to solve a differential equation. This was then applied to solve the equations of motion and produce the spacecraft's trajectory over time. The author then wrote the algebraic expression for entry heating as a function of velocity and calculated the final result. While many of the finer details of the example were not explained, the steps taken to solve this problem were explained at a freshman level.

Should these lectures be offered in the future, the author recommends that they are given early in the semester, and that the students be encouraged to use MATLAB or other programming tools to solve problems on their homework. The immediate positive feedback from students in class lends credence to this lecture model, however, survey results analyzed in Section 4.7 do not conclusively point to immediate benefits.

Chapter 4: Data Analysis

4.1 Methods

Two primary sources of data are presented in this section. The first is a set of surveys collected in 2016, 2017, and 2018. These surveys, taken anonymously at the start and end of the semester, allowed students to provide feedback on the course. These surveys were designed to gauge growth in several areas over the period of the class, so that instructors could identify and correct course deficiencies after each year. However, it should be noted that the surveys were not intended to be used for this research, and thus do not directly address some of the expected benefits associated with the course change as described in this report. Changes to the surveys to better address these questions are suggested in Chapter 6. While the questions compared for this analysis were consistent across the years evaluated, other questions on the survey not evaluated here saw some modification. The order in which the questions were asked, however, did not stay consistent from year to year. The number of surveys collected each year is provided in Table 4. While the course renovations were started in 2015, surveys were not collected until 2016, nor were surveys taken prior to 2015 before the changes were implemented. An analysis of the survey results is provided in section 4.2.

Table 4. Surveys Collected

Academic Year	Initial Surveys (n)	End Surveys (n)
2016	73	56
2017	57	54
2018	127	111

The second set of data is a collection of final technical reports written by students in 2014 and 2015. While significant changes were implemented starting in 2015, particularly those relating to technical communication skills, both the 2014 and 2015 classes featured the same final project and were taught by the same instructor. These reports enable a direct comparison of learning outcomes for technical communication before and after the relevant course changes were made. 11 reports were collected in 2014 and 10 reports were collected in 2015. A comparison of the reports from both years is presented in section 4.5. After 2015 the final project was changed, preventing further analysis along this line.

Data collection and analysis was completed under approval from the University of Illinois Institutional Review Board (IRB), under IRB protocol #19433. The data used in this report was not initially collected for the purpose of this research and was exempt from normal IRB review processes. Because of this, the use of consent forms was not required to access the surveys and report data.

4.2 Survey Results

In the surveys collected at the start and end of the classes, the students were asked to provide a value from a 5-level Likert scale to the following questions, with 1 representing strong disagreement and 5 representing strong agreement. The questions used for this analysis are:

1. I understand the fundamental concepts that govern the trajectories of rockets and airplanes
2. I can effectively write a proposal detailing a plan to solve an engineering challenge
3. I am confident in my ability to give a presentation to my peers on a technical subject
4. I am effective at describing non-technical topics in a written format
5. I can create videos (in contrast to traditional written homework or presentations) to answer homework questions or present ideas to others
6. I am able to effectively edit and evaluate other students' work
7. I prefer to be the team leader in team-project situations
8. I can work with others to accomplish a team goal regardless of my personal preferences regarding a particular course of action once the team has made a decision
9. I can successfully delegate tasks to others in a team-project environment
10. I prefer to work on individual homework assignments on my own rather than with classmates
11. I can confidently utilize computer programming to solve engineering problems

The results for these questions are provided in Table 5. An independent t-test was used to determine the statistical significance of improvements in the survey responses across the semester [45]. In addition, the end surveys also asked students whether they preferred the video presentation over the final written report, which is reported in Figure 9.

Table 5. Survey Responses from 2016, 2017, and 2018

	2016			2017			2018		
Survey Question	**Start/End Mean**	**Change**	**p**	**Start/End Mean**	**Change**	**p**	**Start/End Mean**	**Change**	**p**
Q1	3.01/4.02	+1.01	**0.000**	3.52/4.28	+0.76	**0.000**	3.44/4.22	+0.78	**0.000**
Q2	3.00/3.49	+0.49	**0.002**	3.17/3.82	+0.65	**0.003**	3.17/3.88	+0.71	**0.000**
Q3	3.70/4.09	+0.39	**0.010**	3.76/4.02	+0.26	0.191	3.86/4.19	+0.33	**0.004**
Q4	3.59/4.00	+0.41	**0.009**	3.83/3.94	+0.11	0.559	3.81/4.09	+0.28	**0.016**
Q5	3.21/4.11	+0.90	**0.000**	3.19/4.04	+0.85	**0.000**	3.44/4.08	+0.64	**0.000**
Q6	3.86/4.10	+0.24	0.091	4.00/4.09	+0.093	0.590	3.88/4.33	+0.447	**0.000**
Q7	3.45/3.49	+0.04	0.810	3.83/3.93	+0.098	0.565	3.69/3.79	+0.098	0.395
Q8	4.30/4.42	+0.11	0.394	4.31/4.21	-0.103	0.472	4.45/4.54	+0.086	0.314
Q9	3.99/4.14	+0.154	0.269	4.27/4.18	-0.091	0.564	4.18/4.49	+0.303	**0.001**
Q10	2.90/2.91	+0.01	0.957	2.88/3.57	+0.695	**0.001**	2.99/3.34	+0.34	**0.017**
Q11	2.32/3.49	+1.17	**0.000**	3.00/3.39	+0.39	0.106	3.03/3.22	+0.19	0.255

4.3 Survey Results for PBL Benefits

Analysis of the survey results shows statistically significant improvement ($p < 0.05$, shown in bold) across the semester for many of the questions. The responses to question #1 indicate that course succeeds in teaching the fundamentals of rocket and aircraft trajectories, a key goal for the instructors and one of the benefits reported in the literature on PBL. This benefit has been tied to self-directed learning, where the students seek out new knowledge or apply knowledge learned in lecture to their design projects. Unfortunately, survey data is not available to compare these results to the previous version of the class, so it cannot be determined whether the efforts made to introduce this PBL principle provided benefit over the previous course model.

Question 2, “I can effectively write a proposal detailing a plan to solve an engineering challenge”, may provide some insight as to whether the use of open-ended design problems improved skills in design and project management. While at first glance the increase in score for this question may appear to be explained by benefits related to technical writing skills, this question may instead indicate benefits to project management and design skills. Question 4 relates to general writing scores, and in 2017 and 2018 did not see nearly as much increase in score as question 2 did, noting that the implementation of PBL was not completed until 2017 with regards to the aircraft project. This may indicate that the improvement relates to increased confidence in ability to formulate a plan to solve an engineering plan, not just the ability to write one. This points toward success, although due to the vague nature of the question it cannot be regarded as a strong result.

Other expected benefits of PBL relate to teamwork skills. Questions 8 and 9 reflect these skills, and with the exception of question 9 in 2018, statistically significant increases in these scores were not observed. In fact, some slight decreases in score are seen in 2017. This may indicate that the expected benefit to teamwork skills associated with PBL did not occur in this implementation. However, the scores for these questions were already at the high end of the Likert scale at the beginning of the semester, leaving little room for improvement. Interestingly, students in 2017 and 2018 were far more likely to report that they preferred to work in groups on homework assignments following the class, which may indicate students grew to like working in teams more after taking AE 100. Ultimately, these results do not conclusively answer whether or not PBL in this course improved teamwork skills.

4.4 Survey Results for Technical Communication Skills

Confidence in technical reporting and presentation skills generally saw significant improvement in the survey. However, the results from 2017 for questions 3 and 4 did not show statistical significance. The instructors were not able to identify specific differences in 2017 that would account for this discrepancy, however, the smaller sample size for 2017 may be a contributing factor. Confidence in presentation skills saw similar gains to technical writing, likely due to the use of a video presentation. Question 6, which rated ability to peer review work, only saw statistically significant improvement in 2018, although this was very clear result. A reason for why 2016 and 2017 did not see similar improvements has not been forthcoming.

As shown in Figure 9, the class of 2016 favored the video presentation by 73%, while the 2017 and 2018 classes preferred the final written report by 55% and 57%, respectively. Changes to the aircraft project, made in 2017, might be responsible for this change. Writing about the prior aircraft project may have been uninteresting to the students, as they performed little design work. In contrast, the reports written after the change in project were heavily focused on the design process and rationalizing the glider design.

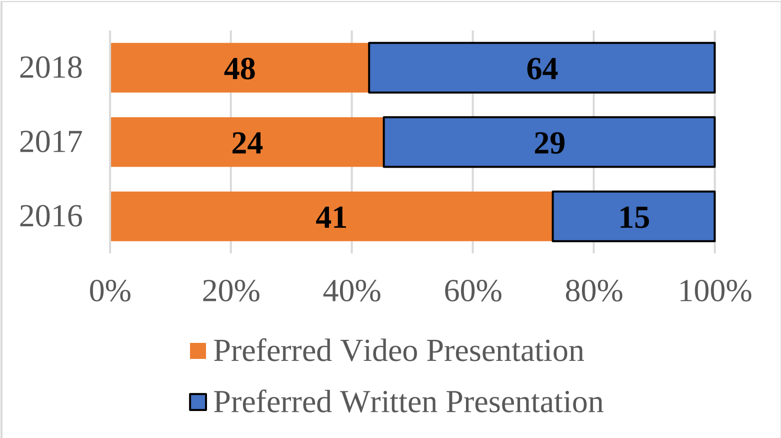

Figure 9. Student Preferences for Presentation Format

Interestingly, the technical writing skills assessed in Question 2 indicates larger improvements in 2017 and 2018 than in 2016. Given that the improvements to the glider project were not implemented until 2017, this finding may indicate that a project designed under PBL principles can produce secondary benefits to technical writing skills. However, section 4.3 discusses why this question may not be an indicator of writing abilities, and there are many possible sources of error in these surveys. Section 4.6 details significant differences in survey scores depending on the environment in which the surveys are taken, and records do not exist of when and how the surveys were taken in 2016. The large discrepancy between the number of surveys obtained between the start and end of the 2016 course (Table 5) may also introduce error that cannot be accounted for. Therefore, this result should not be viewed as strong evidence for the benefits of PBL to technical writing skills. Instead, this may indicate an area of future study.

4.5 Final Report Grades

To assess the impact of the course changes on technical writing skills for first-year students, final written reports from one of the instructors' 2014 unmodified course section and 2015 modified course section were compared. 11 reports from 2014 and 10 reports from 2015 were graded by a library sciences graduate student who was a teaching assistant for the 2015 class.

Identifying information was removed from all 21 reports before they were handed off to minimize any possible bias. The teaching assistant used a rubric grading for structure, grammar, tables and references, and thesis statement. The reports were scored according to the first column in Table 6. The mean scores for each class are shown along with the p-value score resulting from an independent t-test comparing the two populations.

Table 6. Comparison of Final Report Grades

	2014 Mean Score	2015 Mean Score	Change in Score	p-value
Structure (/30)	17.2	23.2	+6.0	**0.002**
Grammar (/30)	18.1	22.6	+4.5	**0.026**
Tables and References (/30)	18.9	23.1	+4.2	0.090
Thesis (/10)	6.5	6.7	+0.2	0.903
Total (/100)	60.7	75.6	+14.9	**0.017**

The 2015 reports showed a statistically significant improvement ($p > 0.05$) in structure, grammar, and total score. The improvements made to tables and references were not statistically significant, but they do indicate a possible trend of improvement. This result may also indicate that further exposure to these topics is advisable in future course changes.

Little-to-no improvement was seen in thesis statements between 2014 and 2015. However, this score was interpreted and assigned by the grader following a narrow definition of a single, clear and concise thesis statement, and does not have significant bearing on the overall quality of technical content. Nevertheless, this result indicates that writing a clear and concise thesis statement is an area for future improvement.

It should be acknowledged that there are a number of factors in this analysis that were not controlled. Information on the makeup of the student populations compared was not collected, and this analysis was not able to account for differences in writing ability at the start of the course. However, the instructors judged that many important factors remained consistent. For example, the two course sections that provided data for this analysis were both taught by a single instructor. The setup for the final report, including the final project, was identical between the courses. The reports were given to the grader such that they could not be identified as belonging to one class or another and were graded on the same rubric. The only significant difference in instruction between the two classes with regard to the final report was the opportunity for students to practice their technical writing skills and receive critical feedback in preceding assignments for the 2015 class. This, along with the strong improvement in the structure and grammar fields for the 2015 class, appears to validate the model of using writing assignments throughout this first-year course to improve technical writing on final reports.

4.6 Impact of Survey Collection Methods

Survey results from the three separate sections of AE 100 in 2018 reveal a curious discrepancy in average survey scores that may be the result of a difference in survey distribution method. The three sections, A, B, and C were taught by separate instructors, although the lecture material remained the same. The scores for a selection of the questions evaluated in section 4.2 broken down by section from 2018 are shown in Table 7.

Table 7. 2018 Section Comparison

	Q1	Q2	Q3	Q4	Q5	Q11	Average
Section A Start/End Mean	3.56/4.40	3.10/4.15	3.78/4.38	3.82/4.23	3.60/4.30	2.90/3.20	3.46/4.11
Section B Start/End Mean	3.35/4.04	3.21/3.67	3.90/4.02	3.76/3.94	3.15/3.92	3.05/3.06	3.40/3.77
Section C Start/End Mean	3.40/4.27	3.25/3.86	3.95/4.23	3.90/4.18	3.90/4.05	3.30/3.59	3.62/4.03
Section A Score Improvement	0.84	1.05	0.60	0.41	0.70	0.30	0.65
Section B Score Improvement	0.69	0.45	0.12	0.18	0.77	0.01	0.37
Section C Score Improvement	0.87	0.61	0.28	0.28	0.15	0.29	0.41

The significantly larger improvements made by section A from the start surveys to the end surveys struck the instructors of the course as odd. While it is possible that section A saw significantly more improvement, the method that section A used to take the end-of-semester survey may contribute significantly to this difference. The three sections each issued paper copies in class for the initial survey, but section A had students submit the end of semester surveys online, while sections B and C conducted those surveys in class. There are many possible reasons why changing the environment the survey could produce a bias in the data, and the instructors believed that this change was the cause of the improvement discrepancy. Future sections of AE 100 should take care to collect these surveys at the same lecture and in the same environment.

4.7 Impact of Programming Lecture Improvements.

The programming lectures discussed in section 3.7 were given to section C of the 2018 course. The relevant survey question, Q11, asked students to rate their confidence in their ability to utilize computers to solve problems. Breakdowns for the scores of the three 2018 sections are provided above in Table 7. Disregarding the scores from section A due to the discrepancies discussed above, it appears that section C saw significant improvement for question 11, while section B did not improve at all. Furthermore, the end survey for section C has the highest total score for question 11. At first glance, this appears to support the new programming lecture model.

Unfortunately, when the initial and end survey results for section C are compared with a two-sided t-test, the improvement in question 6 is not statistically significant ($p = 0.40$). However, obtaining statistical significance with the small sample size of section C ($n = 20$) is difficult for any result, and should not be taken as evidence that the lectures had no effect. Rather, this indicates an area of potential future study, as there is much interest in the department in improving education regarding computational methods and programming.

Chapter 5: Discussion

5.1 Impact of PBL Improvements

From the results of the surveys in section 4.3, while it is clear that the implementation of PBL in AE 100 has produced beneficial learning outcomes for students, the question of whether or not these benefits exceeded those of the prior AE 100 course cannot be answered. This is due to two primary factors, the first of which is the lack of survey data from the course prior to 2016. This precludes any direct comparison of the expected benefits of PBL outlined in Table 1, which is an unsatisfying result. The second factor limiting this analysis is that the questions asked in the survey were not specifically designed to assess all of the expected PBL benefits, specifically project management skills, time management skills, research skills, and overall motivation. It is recommended that changes to the surveys be made to address these issues, especially now that the AE 100 projects have fallen into a stable configuration, per the discussion at the end of section 3.4.

From the experience of the instructors, students broadly enjoyed the new projects, displaying far more enthusiasm and motivation in the lab session of the course than in the traditional lecture session. Some students that had already made up their minds about wanting to focus on either aeronautics or astronautics showed less enthusiasm for the other topic's project, but these cases were a clear minority. The enthusiasm and motivation for these projects were so great that many students willingly attended several extra work sessions held in the evening. While some students had to attend these sessions because of poor time management, many others came because they wanted to continue to test their designs or to decorate them.

Another anecdotal benefit, partially backed up by survey data, is an improvement in understanding of course material. While survey data was only able to demonstrate that these subjects were learned during the semester and not that the PBL model provides benefit over traditional lecture models, instructors observed students coming to a better understanding of stability derivates for gliders during the construction of their gliders. As mentioned previously, the instructor would prompt students to review the lecture material on stability when their prototype gliders flew poorly. With subtle hints from the instructor, students were able to apply this complicated topic to improve their designs dramatically in just a few minutes. From there they were able to design for stability on their own, demonstrating much better understanding than they had following the lecture. Future surveys or quizzes could be designed to address this topic following the lecture and following the completion of the glider project, allowing for the collection of definitive data on this topic.

5.2 Impact of Technical Communication Improvements

Unlike the application of PBL, some learning outcomes regarding technical communication can be assessed directly against the prior course model, albeit with a small sample size. The results outlined in section 4.5 show a 25% improvement in final report grades, from a mean of 60.7 points in 2014 to a mean of 75.6 points in 2015. This is a drastic improvement. On closer inspection, significant improvements were seen in structure and the use of grammar in these reports, validating the use of written communication assignments through this first-semester course to improve writing skills. Survey results show increasing confidence in writing and presentation skills over the course of the semester in 2016 and 2018, although some results in 2017 did not show a statistically significant benefit.

The changes made to AE 100 to improve technical communication outcomes centered on writing skills. While the use of a video presentation midway through the course has improved student confidence in their presentation skills, no other course work addressed oral communication. Future efforts should be devoted to improving oral communication skills, as research into first-year engineering communication reveals that incoming students tend to believe that their oral communication skills need more practice than their writing skills [46]. Possible methods to address this are discussed in Chapter 6.

Chapter 6: Future Work

Improvements made to AE 100 have addressed technical writing and aligned the design projects with the principles of PBL. These changes have produced solid results and the instructors are satisfied with these sections of the course. However, there remains room for improvement in several areas, specifically related to presentation skills and the use of surveys to assess learning outcomes. Further, this report is derived from a paper presented at the 2019 American Society for Engineering Education (ASEE) Annual Conference & Exposition [47], and useful feedback from this event is presented.

6.1 Recommended Survey Modifications

It is evident in the discussion of the survey results that the questions on the surveys used from 2016 to 2018 were not able to sufficiently evaluate learning outcomes for the expected benefits of PBL. Specifically, questions to address motivation, application of knowledge, time management skills, communication skills, and research skills are recommended for use in future surveys. A full list of recommended survey questions is provided in Table 8. To be clear, these questions are not intended to completely replace the prior survey, and questions may be added or replaced at the discretion of future instructors.

Table 8. Recommended Survey Questions

	Question	**Rationale**
1	I am excited about becoming an engineer.	This question is used to address motivation. The use of design projects to give students a taste of the engineering design process is expected to increase motivation over a semester.
2	I am able to apply lecture material to projects both inside and outside of class.	Directly addresses whether students believe they know how to take lessons learned in lecture and apply them in design projects. Expected to increase over a semester

Table 8 (cont.)

	Question	**Rationale**
3	I am able to create and follow a plan to complete a project.	Addresses time and project management skills. If the mean score is low, lectures on creating a project management plan may be added at the discretion of the instructor.
4	I am confident in my ability to convey technical information in writing.	Similar to question 2 in the current survey, reduces fluff to get at the core issue.
5	I am confident in my ability to convey technical information in a presentation.	Same as above, with regards to question 3 on the current survey.
6	I am confident in my ability to learn this class's material by attending lecture.	Assesses students' perception on learning material by attending class, expected to remain constant or improve over the semester.
7	I am confident in my ability to learn this class's material by reading lecture notes outside of class.	Assesses students' perception on learning material on their own time, related to research and learning skills from self-directed learning. Expected to improve over the semester. May be changed to refer to learning in lab instead of 'outside of class.
8	I prefer to learn on my own time rather than in lecture.	Assesses preferred learning strategies from students.

While these survey question will improve assessment of PBL learning outcomes, they do not allow for comparison with the previous course model. A potential avenue to assess whether the PBL-changes improved motivation is to look at retention and graduation rates. Mentioned before, the use of PBL in first-year design classes has been shown to boost retention. Future work could examine graduation rates among students who took AE 100 from 2016 to 2018 and compare them to graduation rates among students who took the class prior to 2015, disregarding 2015 due to a mix of the two courses being offered in that year.

6.2 Recommended Changes to Address Presentation Skills

The first recommendation to address presentation skills is the introduction of peer review for the video presentations that follow the rocket project. This could take two forms: providing assessment forms in class for students to fill out when presentations are watched at the beginning of lecture, or assigning each student to review two presentations on their own time. The latter is recommended, as with the first option students are not able to rewatch the videos and their ability to make specific recommendations may be limited. While option one could theoretically provide a larger volume of feedback, fewer but more detailed assessments will likely be more useful to students.

Another option to improve presentation skills, similar to a method proposed by researchers at Northeastern University [46], is implementing a rotating presenter in each group during the design projects. This presenter will take five minutes at the end of each lab session to speak to their group, summarizing the work the team completed and discussing what work remains to be done. Following this presentation, each group will take a few minutes to critique this mini-presentation and offer tips for improvement. This provides a low-stakes, informal method of practicing presentation skills for each student. This represents a minimal use of time that may also allow a more orderly ending to lab sessions, which has been an issue in past years. This method could be implemented in a single section of AE 100, allowing for a comparison of survey results with the other sections, which provides a control group.

6.3 Other Changes

Feedback from the presentation of this work at the 2019 ASEE conference included suggestions to ask students specifically what communication skills they think they need to improve, which has been captured in Table 8. A set time to discuss the importance of communication skills in engineering was also recommended, which could be implemented in an early AE 100 lecture, or at the end of the semester as time allows.

Another insight obtained at the conference was the importance of the method of grouping students for team projects. Visibly random grouping, or the process of making the randomized group apparent to students, has been shown to provide benefits to teamwork skills and to break down social barriers, and was presented by a team from Ohio State University [48]. Currently, students in AE 100 are randomly assigned groups, although this process is not visible to the students. A possible implementation of visibly random grouping in AE 100 would be to have students to pick numbers out of a hat during the first lab session, with groups immediately assigned using these numbers. During the discussion of this paper, other faculty noted additional ideas for grouping, including teaming up students based on peer review results. This would enable the instructor to place students who did not sufficiently participate in the rocket project with each other for the glider, which could potentially force these students to work harder on the next project. This idea, however, was controversial in the discussion following the presentation. Other reasons to avoid visibly random grouping include not being able to place minority students, particularly women, in groups where they can support one another. However, the researchers from Ohio State countered this suggestion, indicating that clearly grouping of minority students has the potential to reinforce social barriers. A final suggestion was to group students based on their class schedule, which would allow them greater flexibility in working outside of class.

Chapter 7: Conclusion

This paper summarized an effort to improve AE 100, an introductory aerospace engineering course at the University of Illinois. Prior course projects were modified to include design and testing, which are key components of PBL. Other changes were made to address technical presentation and writing skills. Survey data from over 200 students was analyzed to determine the effectiveness of this course between 2016 and 2018. The changes made to the course appear to have significantly improved learning in technical writing and presentation skills. A direct comparison of final report scores from 2014 and 2015 reveals a significant improvement in technical writing abilities for the modified version of the course over the prior model, validating the sequence of writing assignments instituted by the instructors, as well as the use of peer review. However, survey data does not answer the question of whether the changes made to AE 100 have improved educational outcomes due to the inclusion of PBL. The efforts made to improve this course have been successful in developing engineering communication skills among first-year students.

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Appendix A: IRB Approval Letter

I ILLINOIS

OFFICE OF THE VICE CHANCELLOR FOR RESEARCH

Office for the Protection of Research Subjects
805 W. Pennsylvania Ave., MC-095
Urbana, IL 61801-4822

Notice of Approval: New Submission

January 17, 2019

Principal Investigator	Brian Woodard
CC	David Degenhardt
Protocol Title	*Applying Project-Based Learning with an emphasis on Engineering Communication for First-Year Students*
Protocol Number	19433
Funding Source	Unfunded
Review Type	Exempt 4
Status	Active
Risk Determination	no more than minimal risk
Approval Date	January 17, 2019

This letter authorizes the use of human subjects in the above protocol. The University of Illinois at Urbana-Champaign Institutional Review Board (IRB) has reviewed and approved the research study as described.

Exempt protocols are approved for a five year period from their original approval date, after which they will be closed and archived. Researchers may contact our office if the study will continue past five years.

The Principal Investigator of this study is responsible for:

- Conducting research in a manner consistent with the requirements of the University and federal regulations found at 45 CFR 46.
- Using the approved consent documents, with the footer, from this approved package.
- Requesting approval from the IRB prior to implementing modifications.
- Notifying OPRS of any problems involving human subjects, including unanticipated events, participant complaints, or protocol deviations.
- Notifying OPRS of the completion of the study.

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Appendix B: AE 100 Surveys

AE 100 Student Survey – Start of Semester 2017

Please answer the following questions or evaluate the statements by circling the number that corresponds to your feeling regarding the accuracy of the statements using this scale:

Not at all True Completely True
1 2 3 4 5

1. I understand the career options that will be available to a person with an Aerospace Engineering degree. 1 2 3 4 5

2. I understand the fundamental concepts that govern the trajectories of rockets and airplanes.
   1 2 3 4 5

3. What object in the solar system will the Cassini spacecraft will crash into in September this year?
   ____

4. What is the most common type of aircraft covered by the news media? ________________________

5. List two questions about aerospace engineering that you hope to have answered by the end of this semester. 1. ____
   2. ____

6. I can effectively write a proposal detailing a plan to solve an engineering challenge.
   1 2 3 4 5

7. I am confident in my ability to give a presentation to my peers on a technical subject.
   1 2 3 4 5

8. I am effective at describing non-technical topics in a written format.
   1 2 3 4 5

9. I can create videos (in contrast to traditional written homework or presentations) to answer homework questions or present ideas to others.
   1 2 3 4 5

10. I am able to effectively edit and evaluate other students' work.
    1 2 3 4 5

11. What do you think will be the most efficient and effective way to communicate with **members of student teams** in this class this semester? (circle)
    E-mail Phone Call Text Social Media Other:____________________

    If Social Media, what platform? ____________________

12. What do you think will be the most efficient and effective way to communicate with **instructors and teaching assistants (TAs)** in classes this semester? (circle)

E-mail Phone Call Text Social Media Other:___________________

If Social Media, what platform? ___________________

Not at all True Completely True

1 2 3 4 5

13. I prefer to be the team leader in team-project situations.

    1 2 3 4 5

14. I can work with others to accomplish a team goal regardless of my personal preferences regarding a particular course of action once the team has made a decision.

    1 2 3 4 5

15. I can successfully delegate tasks to others in a team-project environment.

    1 2 3 4 5

16. I prefer to work on individual homework assignments on my own rather than with classmates.

    1 2 3 4 5

17. I am comfortable using computers for tasks such as word processing, spreadsheets, and plotting/graphing. 1 2 3 4 5

18. I can confidently utilize computer programming to solve engineering problems.

    1 2 3 4 5

19. I have significant experience using the program Matlab for writing computer code.

    1 2 3 4 5

20. I have significant experience using the program Python for writing computer code.

    1 2 3 4 5

21. What **computer programming** experience do you have? Please note the language and your proficiency level.

    ____

    ____

22. What **Computer-Aided Design** experience do you have? Please note the software package and your proficiency level.

    ____

    ____

Other Experience

23. Briefly describe any experience you have with projects related to model rockets and/or remote controlled airplanes and/or quadcopters or any other flying vehicles.

    ____

    ____

AE 100 Student Survey – End of Semester 2017

Please evaluate the following statements by circling the number that corresponds to your feeling regarding the accuracy of the statements using this scale:

Not at all True Completely True

1 2 3 4 5

The Field of Aerospace Engineering

24. I understand the diverse career options that will be available to Aerospace Engineers

1 2 3 4 5

25. I understand the fundamental concepts that govern technology like rockets and airplanes.

1 2 3 4 5

26. I know what object in the solar system was studied this past July by the New Horizons mission.

1 2 3 4 5

Bonus: Name the object: ____________________

Communication Skills

27. I can effectively write a proposal detailing a plan to solve an engineering challenge.

1 2 3 4 5

28. What part of the class was most helpful for learning to propose solutions to engineering problems?

____

29. I am confident in my ability to give a presentation to my peers on a technical subject.

1 2 3 4 5

30. I am effective at describing non-technical aspects in a written format.

1 2 3 4 5

31. I can create videos (in contrast to traditional written homework or presentations) to answer homework questions or present ideas to others.

1 2 3 4 5

32. List something that you learned by editing and evaluating one of your classmates' writing

assignments. ____

33. What style of communication did you prefer for describing your solutions to an engineering challenge? (circle) Video creation Writing assignments

Not at all True Completely True

1 2 3 4 5

34. What is the most frequent means of communication used among members of your teams in this class? (circle) E-mail Phone Call Text Social Media Other:_____________

Teamwork

35. I can take directions from others on a team regardless of my personal feelings regarding a particular course of action.

1 2 3 4 5

36. I can successfully delegate tasks to others in a team-project environment.

1 2 3 4 5

Computer Skills

37. I am comfortable using computers for non-programming tasks such as word processing and spreadsheets.

1 2 3 4 5

38. I can confidently utilize computer programming to solve engineering problems.

1 2 3 4 5

39. I am better at using Matlab now than at the beginning of the semester.

1 2 3 4 5

40. Please list 3 things that could have been done differently to improve the Matlab instruction portion of the class. (As I have told many of you, this method of teaching Matlab was an experiment. If it failed or could be improved, I want to know so that we can do it differently in the future)

    1. ____

    2. ____

    3. ____

41. Please list any other suggestions to improve this course to make it best fit its title “Introduction to Aerospace Engineering.”

____

____

____