Applying Project-based Learning with an Emphasis on Engineering Communication for First-Year Students

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Abstract

This complete evidence-based paper summarizes work 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 redesign the class around project-based learning, which research has shown improves learning outcomes for students. Additional changes were identified to improve education in engineering presentation and technical writing 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. The model rocket project required students to submit a narrated video presentation that included video of their rocket's flight, analysis of their trajectory, and various images and videos collected during the design and construction phases of the project. For the glider project, the student teams were required to submit a written technical report detailing design decisions, construction, and flight performance. Prior to the changes, students wrote similar written reports which the authors deemed generally unimpressive, so the structure of the class was changed to address this deficiency. Students now submit two individual written assignments prior to the final technical report, which are returned with inline feedback from the instructor. Additionally, students are assigned to blind peer review reports from classmates. Evidence has been collected to compare similar final reports between offerings of the course, and evaluations show a drastic improvement in the quality of the final reports with these additional writing assignments and feedback as part of the course. Surveys are taken at the beginning and end of the semester to assess student perceptions of their skills in several areas. The results of these surveys are compiled and presented in this paper, and show broad improvement across a variety of subjects. 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 Aerospace Engineering Department at the University of Illinois.

1. Introduction

First-year students in the aerospace engineering program at the University of Illinois are strongly encouraged to take Aerospace Engineering 100, a two-hour introductory course during their first semester. This class introduces students to aspects of aeronautical and astronautical engineering through team-based competitive projects. Prior to this effort these projects had major deficiencies, and the researchers used the principles of Project-Based Learning (PBL) to make improvements to the course. Research in engineering education has shown that PBL enhances student interest and retention in engineering [1-3]. The modified course features two projects: a model rocket and a large hand-thrown glider. Each project has technical goals that the students must design to. The primary assessment for the rocket project is a narrated video presentation, and for the glider project a technical written report is assigned. 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 impetus for changes to the course emerged from comments and critiques on the quality of students graduating from the program made by the Aerospace 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. The researchers 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 [4,5]. Changes to this course were implemented starting in 2015.

The researchers implemented several new writing assignments in the modified course designed to improve technical writing skills. Instructor feedback and peer review are used to provide additional benefits to students. These assignments culminate in a final written report for the glider design project. These changes will be discussed in Section 2.3, and an analysis of the benefits they provided is in Section 3.2.

Survey data for over 200 students taking the course in 2016, 2017, and 2018 has been collected and analyzed for this paper. These surveys are taken at the start and end of the class to provide specific feedback for the course each semester it is taught, allowing a year-by-year analysis of the effectiveness of the course. Final reports from the modified and unmodified sections of the course have been compared, which allowed the researchers to directly analyze the effect of the changes made to students' writing abilities.

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.

2. Course Changes

Prior to 2015 the introductory course was split into two separate classes, one focusing on astronautics and one focusing on aeronautics. In the astronautics section, students learned about space engineering and built model rockets. The aeronautics section had students learn about aircraft and build a remote-controlled model airplane. Students were restricted to register for only one section, forcing them to choose which topic to focus before they even began their college careers. Students in the aerospace engineering program at the university eventually need to choose between astronautics and aeronautics for their senior design classes, but the researchers believed that imposing this choice on first year students was unnecessary. The reasoning was that exposing students to both subjects freshman year would allow them to make a more informed choice later on and avoid pigeonholing them into one topic or the other. This motivated combining the two separate courses into unified format. In the new course format, both aeronautics and astronautics would be taught. The two projects that accompanied these prior classes were modified and brought together into the new, unified course. This reform had the additional benefit of extending the use of projects throughout the entire semester with one lecture and one lab per week, 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.

While the prior class had projects and technically could count as project-based, they did not conform well to the theory underlying PBL. Typically, projects in the PBL context are *design-oriented* or *problem-oriented*, and both themes rely on the synthesis of knowledge to create a solution to a problem [2]. Described in more detail below, the prior classes' projects boiled down to students following a set of step-by-step instructions to assemble a final product. Neither project involved much design or problem-solving, and they fell outside the bounds of what is normally considered PBL. The primary focus of the improvements made to these projects were to bring them more in-line with the principles of PBL.

2.1 Rocket Project

Prior to the course modifications, the astronautics version of the course had students build part of a model rocket project in groups of four. Specifically, students would follow an instruction manual to assemble an altimeter and camera payload for a prebuilt model rocket, which would then be launched with a local rocketry organization near the end of the semester. The researchers felt that this project failed to introduce engineering design as students simply followed a set of instructions. The researchers were motivated to improve this project by a desire to introduce more aspects of engineering design in the project. Additionally, they wanted to speed up the schedule so that students launch their rockets at the end of their first month in school. Allowing students to create their own design in pursuit of a goal introduces components of Learning by

Design (LBD) that were expected to provide a more rigorous introduction to engineering practices [6]. The components of LBD that the researchers sought to introduce were:

- Tasks based on real-world applications
- Open-ended design tasks
- Instructor feedback for designers
- Discussion and collaboration
- Experimentation and exploration
- Reflection

The researchers also 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 retention [4].

The improved 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 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, several 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 a rocket would achieve a maximum altitude far above goal altitude. As a maximum, each team is limited to a certain quantity of building materials. Students must apply lecture materials, as well as computer simulations, to design a rocket that will meet the altitude goal. Figure 1 shows one of the rockets that survived both the launch and recovery.

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

Students received lectures in rocket trajectories, rocket propulsion, and aerodynamics over the course of the project. Lecture material was taught directly for the project, with applicable takeaways pointed out, such as the effects of fin sizing on flight stability. A tutorial for the open-source simulation software OpenRocket was also provided in lecture, during which students were asked to follow along on their own computers. 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 screenshots submitted by students 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.

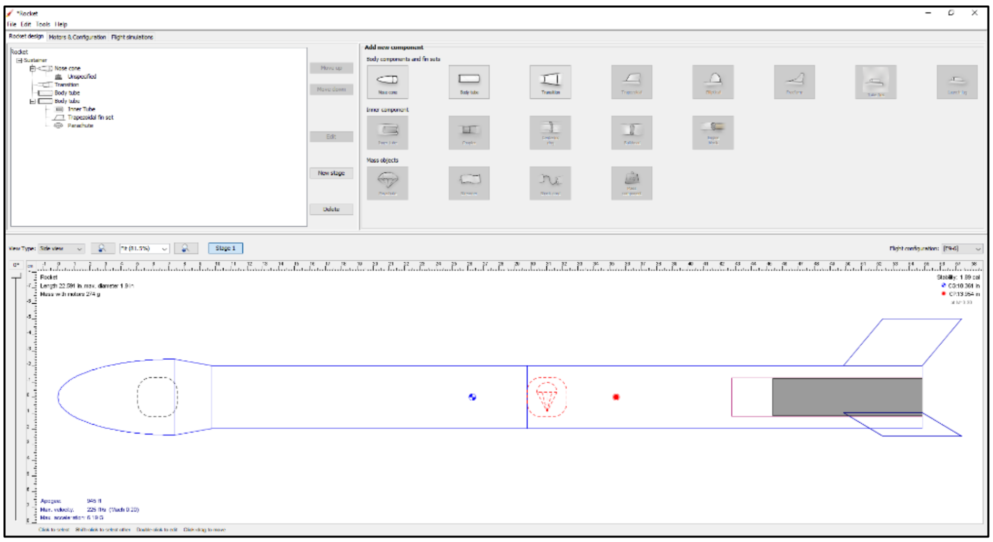

Figure 2. OpenRocket Vehicle Editor

On launch day, students and instructors gather in a local park. 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.

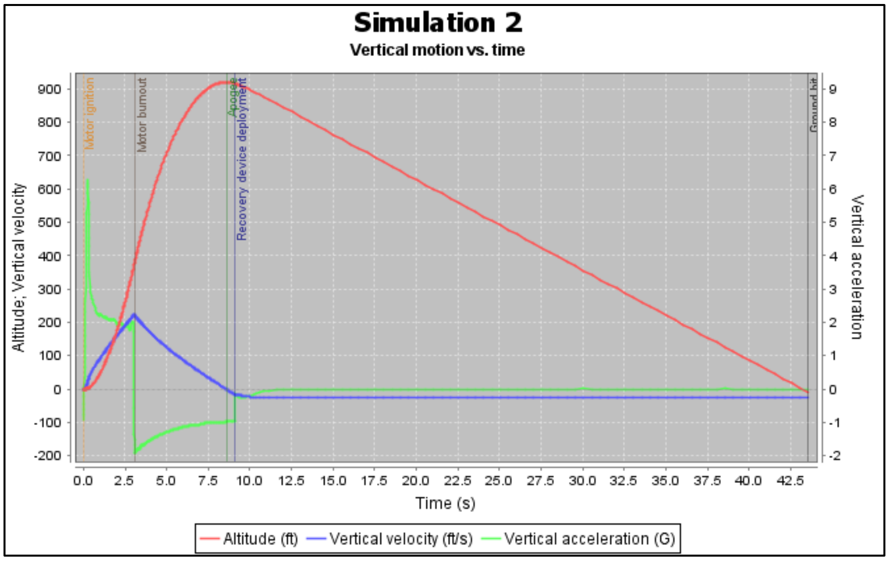

Figure 3. OpenRocket Trajectory Simulation

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 researchers 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 researchers believe that these factors could contribute to improvements in technical communication skills.

2.2 Glider Project

The prior model for the aerospace project was a remote-controlled aircraft built in groups. The researchers 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 section in 2015 and 2016, and finally replaced in 2017 by the project described below.

A new project was designed where 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 would allow students to apply engineering principles learned in lecture to a real-world design challenge. Unlike the prior project, no instructions were given on the design of the gliders. Instead, students would have to rely on a trial-and-error approach informed by lecture material. Working in groups of four, the students would be 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 would then use a computer-aided design tool to create a template for glider components to be laser cut out of thicker sheets of foam board. Once assembled, these gliders could be test flown and optimized by the students. A prototype glider and full-sized glider are shown in Figure 4 and Figure 5.

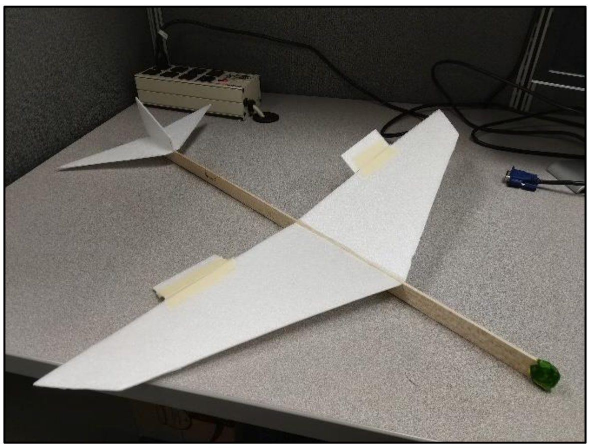
Figure 4. Prototype glider from the modified course section (2 ft wingspan)


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

Lectures for this project covered basic aerodynamic principles such as lift and drag, as well as aircraft stability. These lectures were given in between prototyping build sessions, allowing students to apply these newfound principles to their glider prototypes. The instructors provided few guidelines for the glider, which resulted in a wide variety of prototype designs. Full-sized gliders were then constructed over another three build sessions, which allowed the students plenty of time to optimize their designs. Finally, these gliders were flown in competition at a large indoor facility.

After the glider competition, the students were 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.

2.3 Written Communication Assignments

The modified course instituted a sequence of three written assignment. 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 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 on which to focus in lecture. Due to the significant emphasis on grammar and structure in grading, students often find their grades 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. 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 feedback.

Writing assignment #2 is used to introduce several aspects of technical writing. Students are asked to research a topic that will 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 laying out their reasons why this particular topic is important. Grading for this report is split between quality of technical content and grammar, structure, and references. In addition, all of the students grade two of their classmates' reports with the same rubric used by the instructor. This peer review is double blind and provides an opportunity for students to receive feedback from their classmates. In past research peer assessment has been shown to lead to improved outcomes in college writing [7]. This peer assessment engages students by the process of *learning-by-teaching*, which helps place the student in the mindset of the review. The researchers 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, in which case 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 was due about one week after the reviewed drafts are returned to the students.

3. Data Analysis

3.1 Survey Results

In 2016, 2017, and 2018, students provided feedback on the course through anonymous surveys given at the start and end of the semester. 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 initially intended to be used for research. While the questions compared for this analysis were consistent across the years evaluated, other questions on the survey not evaluated here saw some modification. In 2016, 73 students filled out the starting survey, while 56 filled out the end survey. 2017 saw 57 initial surveys and 54 end surveys returned, and in 2018, 127 and 111 surveys were filled out, respectively.

In these surveys, 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 can confidently utilize computer programming to solve engineering problems

The results for these questions are provided in Table 1. An independent t-test was used to determine the statistical significance of improvements in the survey responses across the semester [8]. In addition, the end surveys also asked students whether they preferred the video presentation over the final written report, which is reported in Figure 6.

Table 1. 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	2.32/3.49	+1.17	0.000	3.00/3.39	+0.39	0.106	3.03/3.22	+0.19	0.255

Analysis of the survey results show statistically significant improvement ($p < 0.05$) across the semester for most 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 researchers. Unfortunately, survey data is not available to compare these results to the previous version of the class.

Confidence in technical reporting and presentation skills likewise saw significant improvement. However, the results from 2017 for questions 3 and 4 did not show statistical significance. The researchers were not able to identify changes made between 2016 and 2017 that would account for this discrepancy, however the smaller sample size for 2017 may be a contributing factor. Confidence in presentation skills saw smaller gains relative to technical writing, likely due to the use of a video presentation rather than one given live in-class. While not discussed in the course of this paper, some course material and homework assignments related to programming were removed after 2016. This was prompted by a change in the aerospace curriculum that added a programming course for freshman, so overlapping material was removed. This may explain the non-significant results for question 6 in 2017 and 2018, as students were not required to take the programming course their first semester.

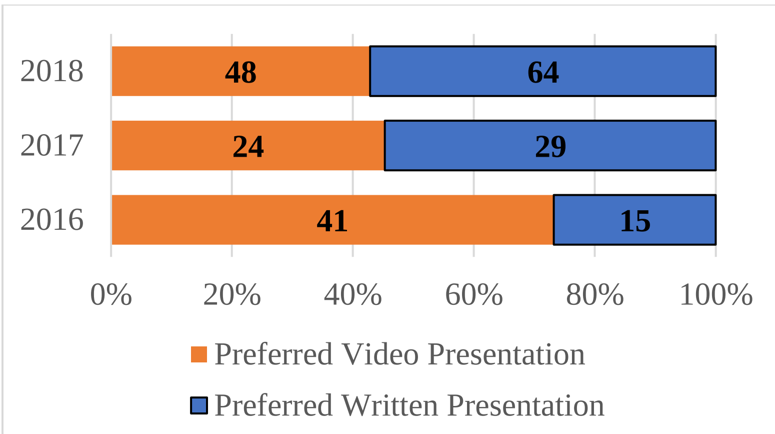

Figure 6. Student Preferences for Presentation Format

As shown in Figure 6, 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. Interestingly, the technical writing skills assessed in Question 2 indicates larger improvements in 2017 and 2018 than 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, there are many possible sources of error that have not been accounted for, so this should not be viewed as strong evidence. Instead, this may indicate an area of future study.

3.2 Final Report Grades

To assess the impact of the course changes on technical writing skills for first year students, final written reports from the researcher's 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 science 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 2. 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 2. 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 for 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 several 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 researchers judged that many important factors remained consistent. For example, the two course sections that provided data for this analysis were both taught by one of the researchers. 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 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. 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 researchers, as well as the use of peer review. The efforts made to improve this course have been successful in developing engineering communication skills among first-year students.

Future changes may be made to address deficiencies identified by this analysis. Additional assignments designed to teach the proper use of tables and figures in technical writing will likely improve the quality of the final written reports. A written analysis of the prototype glider design would provide additional opportunities for feedback on technical writing. Future pursuits to improve the course may include applying peer review to the video presentation, as it proved popular for the written assignments. Modifications to the surveys to collect data on student confidence with regards to design abilities and creativity may also prove useful for future iterations of the course.

5. Acknowledgements

We thank Prof. Phil Ansel, Prof. Tim Bretl, Laura Gerhold, and Vishwah Shah for their involvement in and dedication to this project. We thank AE3 for their support in enabling this project with the SIIP grant. We thank Prof. Karl Kelley (North Central College) for his assistance with the analysis for paper.

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