Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #48594

Assessing the Impact of Evidence-based Programming in an Experimentation Course using Aerospace Engineering Applications

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Work-in-Progress: Assessing the Impact of Evidence-based Programming in an Experimentation Course using Aerospace Engineering Applications

Abstract

This study evaluates the impact of evidence-based programming – specifically active learning through hands-on experiments – within a course on experimentation and data science, focused on aerospace engineering applications. The course emphasizes evidence-based learning by integrating real-world data and practical engineering challenges, aimed at fostering deeper understanding, engagement, and retention of complex concepts such as data collection, statistical analysis, and experimental design. To assess the learning outcomes, the Student Assessment of their Learning Gains (SALG) survey was used as the primary evaluation tool. The course used in this study ran in the spring semester of 2025. The study results indicate that combining PBL with hands-on experiments significantly enhances students' evidence-based reasoning, problem-solving skills, and ability to apply theoretical knowledge in practical aerospace scenarios. The analysis of the SALG data reveals these active learning strategies not only improve conceptual understanding but also promote collaborative learning and student confidence in tackling open-ended, data-driven engineering problems. We also hope to tie some of these outcomes and impacts to certain demographics such as women and BIPOCs; however, more data is required for statistically significant conclusions. This paper discusses the implications of these findings for improving engineering education through evidence-based active learning methodologies.

Introduction

Despite an American population that only grows more diverse, the aerospace engineering industry's diversity numbers have been essentially flat over the last five years. According to the 2022 Aerospace and Defense (A&D) Workforce Study of end-use manufacturers, the number of women in A&D has stayed around 26%. A similar trend has been observed with underrepresented communities of color, with only 10% of respondent's workers identifying as Black and just less than 9% as Hispanic/Latino [1]. Thus, organizations are exploring different ways to improve talent attraction and retention by improving employee benefits, instituting flexible work models, upskilling existing employees and continuing to make diversity, equity and inclusion (DEI) a priority. Despite these efforts employee turnover and attrition rates remain a concern. The demographic numbers for aerospace engineering students across the US are better than the workforce numbers; however, there is still significant room for improvement.

There is also a projected significant drop in college-aged students beginning around 2033 which is expected to disproportionately affect Science, Technology, Engineering, and Mathematics (STEM) fields. This decline stems from demographic shifts, particularly a decline in birth rates following the 2008 financial crisis, leading to fewer high school graduates and intensified competition among colleges for a shrinking applicant pool. This is following a 15% decline in higher education enrollment between 2010 and 2021 [2]. STEM disciplines, already challenged by high attrition rates and barriers to entry such as rigorous prerequisites and perceived difficulty, may face even steeper declines in enrollment. This trend threatens to exacerbate existing workforce shortages in critical sectors like engineering, healthcare, and technology, especially aerospace and defense. To mitigate the impact, institutions must invest in targeted recruitment, support systems to retain underrepresented students, and innovative pathways like dual enrollment or STEM bridge programs to maintain a robust STEM pipeline. This underscores the need to enhance education methodologies to reach a broader demographic of students. This will require closing knowledge gaps through several means including more effective educational programming. One such option is evidenced-based active learning, which has been shown to improve student learning outcomes in STEM courses *reference*.

The Aerospace Engineering Department at Worcester Polytechnic Institute is proactively addressing industry demands and enrollment challenges by enhancing its program and expanding accessibility to a more diverse student population. A key component of this effort is the introduction of an experimentation and data science course, designed to meet ABET accreditation requirements while also enriching the student experience, aligning skill development with industry needs, and strengthening our curriculum. To achieve these goals, I developed and implemented this course as a means to improve learning outcomes for all students, with a particular focus on supporting women and BIPOC students. Additionally, the course provides valuable data to validate the SALG (Student Assessment of Learning Gains) tool within the aerospace engineering context [3]. This paper discusses the ongoing development of the course, its role in enhancing student outcomes through evidence-based programming, and its contribution to refining assessment methodologies in aerospace engineering education.

Background

The Aerospace Engineering Department at Worcester Polytechnic Institute (WPI) is a relatively new administrative unit, established in July 2020 on the foundation of a successful Aerospace Engineering Program (within the Mechanical Engineering Department). The Department has also been undergoing a rigorous evaluation of the curricular topics and offerings in an effort to address recent trends and developments in the aerospace industry. These trends were identified through student surveys and consultation with the Department's Advisory board. The Advisor Board is made up of professionals in all aerospace engineering sectors including research, academia and commercial industry. One such topic is "Experimentation and Data Analysis" which is also a required ABET Student Outcome for all graduating majors in aerospace engineering and is stated as "*An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions*."

The Department faculty have identified a deficiency in the coverage of "experimentation and data analysis" and communicated this finding to the Advisory Board and the Dean of Engineering at WPI. The Department has also been conducting annual surveys of aerospace engineering seniors which indicated there was a need to improve our experimentation curriculum for our students. To address these deficiencies in coverage of experimentation, the Department engaged with the WPI administration and donors who provided financial resources that allowed us to acquire some experimental modules.

These Department-initiated program reviews also identified that coverage of "data science" is needed to address the recent trends in the use and interpretation of "big-data" in the aerospace industry. *To address the modern experimentation and data science topics for aerospace engineer majors and address ABET Student Outcome, the Department has identified a transformative "Experimentation & Data Science Initiative" (EDSI) which has a "physical Lab" component and a "curriculum" component that will impact all AE majors.*

The Experimentation and Data Science (EDS) course is inherently an evidence-based program due to the heavy active learning component (hands-on laboratories). Such experiment-centric pedagogy has been successful in promoting motivation and enhancing academic achievement [4].

Active Learning in Engineering Courses

Active learning in engineering education refers to instructional strategies that engage students directly in the learning process through activities like problem-solving, group work, hands-on experiments, peer instruction, and inquiry-based learning. This encompasses a broad range of teaching methods considered *pedagogies of engagement*, including cooperative learning, inquiry-based learning, and problem-based learning [5]. Research shows that these methods improve student learning outcomes, particularly in STEM fields, by fostering deeper understanding and retention [6]. In engineering, active learning is widely used in foundational courses such as statics and dynamics, where it often includes physical demonstrations, projects of various forms, and flipped classrooms [7]. Consequently, the adoption of active learning strategies has grown significantly within mechanical engineering education. This growing complexity underscores the need for reliable, low-cost tools to assess the impact of these pedagogies in mechanical engineering education.

Despite its benefits, many studies assessing active learning rely heavily on course grades, which may not fully capture learning gains. More recent efforts incorporate tools like the Student Assessment of Learning Gains (SALG) to evaluate outcomes, though few studies validate such tools within specific classroom contexts. As active learning becomes more widespread, there is a growing need for rigorous, context-sensitive assessment methods to identify which approaches work best for different student populations and subject areas.

Course Design

The course employs a dual-instructional approach that combines traditional lectures with experimental-centric pedagogy (ECP) through hands-on laboratory experiments. Lectures provide essential theoretical background, worked examples, and instruction in analytical techniques necessary for conducting and understanding the experiments. For each experiment, students work in pairs and are provided with instructional materials, including an overview and a general guide. Students use these materials to complete the experiment with support from both the instructor and their teammate. Each team submits a formal Experiment Report for every laboratory activity conducted during the course.

The experimental component consists of approximately five multi-part experiments conducted over several lab sessions. Each experiment is aligned with a different core area of the Aerospace Engineering curriculum at WPI. In the lab, students are responsible for designing experiments and collecting relevant data. Outside of lab sessions, students analyze the data using techniques ranging from basic statistical methods to filtering and linear regression. They are expected to apply engineering reasoning to interpret the data and draw meaningful conclusions.

Laboratory sessions are structured to ensure nearly individualized attention, with a student-to-faculty ratio of approximately 4:1. Faculty provide guidance and set parameters for the experiments, but students are primarily responsible for the design, execution, and data analysis. This format encourages students to apply lecture content in a hands-on setting and to engage in trial-and-error learning. Real-time feedback from instructors during lab sessions supports iterative learning and fosters collaboration between students and faculty.

Clearly defined learning outcomes are presented at the beginning of the course. These outcomes guide students in assessing their own progress in designing and conducting experiments, analyzing complex data sets, and solving open-ended problems. Students will be evaluated through a combination of traditional exams and laboratory practicums that test their ability to apply course concepts to unfamiliar problems—mirroring real-world engineering challenges where solutions are not immediately evident.

The learning outcomes are as follows. Students successfully completing this course will be able to:

1. Apply fundamental principles of mathematics, fluid dynamics, controls, structures, heat transfer and thermodynamics to applications of aerospace systems and data science.
2. Develop and apply skills in modern engineering measurement methods
3. Develop and apply proficiency in electronic instrumentation and computer-based data acquisition systems.
4. Develop and apply methods in data science to solve engineering problems

While this course structure is beneficial for all students, it is especially impactful for BIPOC students, who often enter engineering programs with disparities in prior academic preparation. The active-learning environment and immediate feedback mechanisms are more effective at closing these gaps than traditional lecture-based or self-guided methods. Research has shown that evidence-based teaching strategies, such as those employed in this course, significantly enhance motivation and academic performance among African American engineering students. This initiative offers a meaningful opportunity to support underrepresented students and address longstanding inequities in the aerospace engineering field.

Methods OR Assessment Design and Analysis

To assess the learning outcomes, we plan to utilize the Student Assessment of their Learning Gains (SAGL) survey as the primary evaluation tool [3]. We anticipate the results will indicate that combining PBL with hands-on experiments significantly enhances students' evidence-based reasoning, problem-solving skills, and ability to apply theoretical knowledge in practical aerospace scenarios. The analysis of the SAGL data should reveal, for example, that these active learning strategies not only improve conceptual understanding but also promote collaborative learning and student confidence in tackling open-ended, data-driven engineering problems. We also hope to tie some of these outcomes and impacts to certain demographics such as women and BIPOCs. This paper will discuss the implications of these findings for improving engineering education through evidence-based active learning methodologies.

Sample size

This study relies on data collected directly from the students enrolled in the course. This was the first offering of the course and due to several factors, so enrollment was limited to 20 students, where ultimately 18 students completed the course. The response rate for the SALG survey was 67% (12/18). There was a good distribution of class year, including a first-year student and several fourth-year students. There were also students from various ethnicities, genders and backgrounds. The dataset includes three students with marginalized identities – two White women and one Latinx/Hispanic man.

Data Collection

Surveys were administered at the end of the course, through the WPI Morgan Teaching & Learning Center, directly to the students enrolled in the course. Students were asked by the instructor to complete the SALG survey in Qualtrics. Providing data was entirely optional and not incentivized in any way (e.g. dropping lowest assignment grade). In all cases, the SALG data did not include any identifying information about the student respondents.

Analysis and Findings OR Results: Gains in Student Learning

The analysis of the SALG data is expected to demonstrate that active learning strategies not only enhance students' conceptual understanding but also foster collaborative learning and increase confidence in tackling open-ended, data-driven engineering problems. We also aim to investigate how these outcomes may differ across demographic groups, particularly among women and BIPOC students. To explore these dimensions, we developed several research questions (RQs) to guide our analysis.

RQ1: What did students learn?

Students reported significant learning gains in several targeted outcomes, particularly in understanding the relationships between core concepts introduced in the course, how these ideas connect to other engineering courses, and the applicability of course content to real-world challenges. However, students did not report substantial gains in learning outcomes specifically related to data science. Encouragingly, students also reported increased self-efficacy, including greater enthusiasm for engineering and a stronger willingness to seek academic support from peers and instructors.

RQ2: To what extent did students find the learning activities helpful to their learning?

All respondents (100%) indicated that the laboratory experiments provided either "much" or "great" help to their learning. Feedback on their work was also rated highly, with two-thirds of students ranking it as a major contributor to their understanding. Among all instructional methods, laboratory experiments were rated as the most effective learning activity. Additionally, students identified the fairness of assessments, quality of feedback, and the clarity with which instructors connected course materials—activities, readings, and assignments—as especially helpful in supporting their learning journey.

RQ3: What did students find most valuable about the labs?
Students consistently noted that the laboratory component helped them "connect the dots" and build intuition by linking theoretical and mathematical concepts to real-world applications. Several specifically highlighted the free and forced convection experiments as instrumental in deepening their understanding of heat transfer. The ability to observe and physically interact with thermal responses gave them a clearer intuition for how energy systems behave in response to various heat sources and sinks.

RQ4: To what extent was the course design supportive of students with marginalized identities?
In alignment with ethical research norms, quantitative data involving fewer than five respondents is not reported to protect participant anonymity. However, when treated qualitatively, the responses offer meaningful insights. All three students from marginalized backgrounds reported that laboratory activities were highly beneficial to their learning, while traditional lectures and class discussions were less helpful. This indicates a possible compensatory effect, where the labs provided an essential learning support for these students. Further investigation of this trend is planned with an expanded dataset in the following academic year.

Marginalized students also ranked among the highest in self-reported gains related to applying principles of mathematics, fluid dynamics, controls, structures, heat transfer, and thermodynamics to aerospace systems. Additionally, they noted that the grading structure and course navigation supports were especially helpful.

As one student expressed:
"Real life examples always help me learn. If all classes were like this, I would be more prepared."

This feedback underscores the value of experiential, evidence-based instruction in fostering equitable learning environments—particularly for students from historically underrepresented groups

Conclusions and discussion

There is a clear and pressing need to broaden participation in STEM fields, particularly in aerospace engineering. Achieving this goal does not require compromising academic rigor—instead, it calls for the adoption of more effective, evidence-based teaching methodologies. Identifying and validating these methodologies is a critical step in ensuring continuous improvement in STEM education.

This work supports the Student Assessment of Learning Gains (SALG) as a useful and effective tool for evaluating student learning, particularly within the context of aerospace engineering. By collecting SALG data year over year, this study contributes to the ongoing validation of the instrument in discipline-specific settings and offers valuable insights into student learning and engagement.

Preliminary findings indicate that hands-on, experiment-focused learning is a highly effective strategy for aerospace engineering education. The course described is well-structured and designed to strengthen students' understanding across a broad range of aerospace topics, while simultaneously building skills in experimentation and data science. Importantly, these instructional strategies appear especially beneficial for women and BIPOC students, who may enter engineering programs with lower levels of confidence or self-efficacy. This suggests the course could serve as a powerful tool for increasing equity in student outcomes.

The SALG data also highlight areas for course improvement, particularly in strengthening the integration and application of data science concepts. These findings will inform future iterations of the course and guide instructional refinement to ensure broader and deeper student learning gains.

This course is part of a larger departmental initiative to embed project-based learning across the Aerospace Engineering curriculum at WPI. The goal is to incorporate experiential learning into every course, fostering a cohesive, practice-oriented educational experience. Such an initiative has the potential to produce a significant and lasting impact, especially for historically underrepresented groups in aerospace engineering. By modeling inclusive, research-informed pedagogy, this course—and the broader curriculum reform it is part of—can serve as a scalable model for improving STEM education and addressing disparities in graduation rates and workforce representation.

Acknowledgement

The author wishes to thank Dr. Kimberly LeChasseur, Senior Research and Evaluation Associate at the WPI Morgan Teaching & Learning Center, for administering the student survey and providing valuable support in interpreting the response data. The author also gratefully acknowledges the generous contributions of WPI alumni donors, whose financial support made it possible to acquire the equipment and instrumentation used in this course.

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