Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #46656

Enhancing Student Learning in a Blended Undergraduate Dynamics Course through Hands-on Mini-Projects

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ENHANCING STUDENT LEARNING IN A BLENDED UNDERGRADUATE DYNAMICS COURSE THROUGH HANDS-ON MINI-PROJECTS

Abstract

This study aims to assess the impact of hands-on active learning activities in the form of mini projects on student learning in a blended undergraduate Dynamics course. The study was conducted as part of an NSF-funded project through the "Improving Undergraduate STEM Education: Hispanic Serving Institutions (IUSE-HSI)" program. Dynamics is a fundamental gateway course required for many engineering majors, which students find very challenging. Traditional face-to-face instructional approaches involving concept discussion and problem-solving sessions are often insufficient to promote student self-regulated learning and motivation, as well as comprehension and retention of the required course concepts, thereby creating knowledge gaps that propagate to upper-level courses. The historical success rates of students in this course at the authors' institution are typically low among all students, including the underrepresented minority student groups such as Hispanic Transfer students.

To enhance the learning experience of all students in the Dynamics course, several hands-on collaborative mini-project assignments were introduced in tandem with regular homework assignments in a blended classroom. Previous studies have shown that project-based activities in a collaborative learning environment promote critical thinking skills and improve student comprehension and retention of concepts. Grounded on the benefits of project-based activities from the literature, several mini-project assignments were designed and implemented in the undergraduate Dynamics course using simple and inexpensive experimental setups. The mini-project assignments targeted critical course concepts where students often struggled and were given out to students concurrently with the course lecture videos and in-class lectures covering those topics in the blended class. Some examples of concepts covered in the mini-project assignments include Newton's second law approach to analyze forces and friction coefficients in particle kinematics and the application of rigid body rotational kinetic equations to solve for moments of inertia. Due to the large class enrollment, a three-week window was assigned to complete each mini-project activity. Student groups were required to submit a written report and a short video clip on each mini-project assignment upon completing their experiments. The impact of these active learning activities on student learning was assessed through course and exam grades, while self-reported self-regulated learning and motivation and self-efficacy were gauged through IRB-approved student surveys and interviews. Preliminary results indicate promising and positive effects of the hands-on mini-project activities on student learning for all students including underrepresented minority student groups such as Hispanic Transfer students.

Introduction

Project-Based Learning (PBL) is an instructional methodology that encourages students to learn and apply knowledge through engaging projects. In modern education, PBL has evolved to address core content through relevant, rigorous, hands-on learning experiences. [1] It involves students in complex tasks based on challenging questions or problems and promotes sustained inquiry and critical thinking. PBL has been widely used in many disciplines, including medicine, engineering, and economics, to prepare students for real-world challenges. [2] PBL in engineering education offers multifaceted benefits that extend beyond conceptual understanding. When students engage in hands-on projects, they develop critical professional competencies that are highly valued in the industry. [3] Hands-on projects simulating real-world engineering scenarios require students to work within constraints, manage resources, and make practical decisions. The collaborative nature of hands-on projects also fosters essential soft skills such as teamwork, communication, and management, which are increasingly emphasized by accreditation bodies such as ABET and employers. [4], [5]

Research has shown that PBL significantly improves student engagement and motivation by providing clear connections between theoretical principles and their practical applications. This approach particularly benefits students with diverse learning needs, as it accommodates learners who might struggle with traditional lecture-based instruction. [6] Furthermore, the iterative nature of project work helps develop the engineering mindset necessary for solving open-ended problems and dealing with uncertainty. Literature shows strong evidence of the effectiveness of PBL activities in engineering education. Mills and Treagust (2003) conducted a comprehensive review demonstrating that PBL-taught engineering students developed stronger problem-solving abilities and team skills than traditionally taught students. Their study showed improved retention rates and higher student satisfaction.[7] Prince and Felder (2006) presented evidence that PBL increased long-term content retention, helped students develop an integrated understanding of concepts, and improved students' self-directed learning abilities. [8] Their meta-analysis showed statistically significant improvements in student performance. Similarly, Liu and coworkers (2022) observed improved self-directed learning ability in students when implementing MATLAB-based PBL projects in a Vibrations and Controls course in mechanical engineering. [9] Furthermore, the authors reported enhanced benefits in teamwork, communication, and project management skills in students when implementing industry-sponsored group projects in a senior design mechanical engineering course. [10], [11]More recent work by Graham (2010) and Kolmos (2017) demonstrated that PBL courses increased student motivation, as reported by 85% of studied institutions, and resulted in higher course completion rates (12-15%). [12], [13]

This paper explores the implementation of PBL in the form of mini projects (MP) in an undergraduate Dynamics course, a foundational subject in the engineering curriculum. Dynamics, with its complex concepts and mathematical rigor, often poses significant challenges to students. [14] Traditional lecture-based teaching methods may not fully address the diverse learning needs of students or adequately prepare them for practical engineering problems. To bridge this gap, the Dynamics course was restructured to incorporate several hands-on MP activities to enhance student engagement, comprehension, and application of course material. The mini-project assignments targeted critical course concepts where students often struggled. The effectiveness of this pedagogical shift was assessed through student surveys, course grades, and comparative analysis with traditional teaching methods.

Methods

Study Design – MP Implementation

The study examines the implementation of hands-on collaborative mini-project (MP) activities in a high-enrollment blended undergraduate Dynamics course at the authors' institution. The section enrollment in the semester of implementation and this study (Fall 2024) was 259. The instructor has traditionally taught this course in the blended format in the past years. In the blended format, approximately one-third of the face-to-face lecture time is replaced with weekly lecture videos, where students watch one to two lecture videos (total watch time of ~ 50 min) and attend one 110-minute face-to-face lecture every week. The lecture videos introduce the weekly concepts with some example problems, while the in-class lectures focus heavily on concept application through extensive problem-solving exercises and pop quizzes for concept checks. Post-class reading and homework (HW) assignments allow practice opportunities for students, and one or two optional project-based assignments are typically assigned for extra credit points. The major assessments for this course include three multiple-attempt exams administered digitally through a proctored testing center.

In the semester of MP implementation, the instructor redesigned the blended course to introduce multiple MP assignments as a required course activity for all students. The blended format was identical to the previous semesters, with the same lecture videos and in-class lectures. The major assessments (exams) in the course remained the same as previous semesters. For the post-class assignments, MP assignments targeting important learning outcomes in Dynamics were designed. The MP assignments were released simultaneously in the week when the concepts were introduced to the students through lecture videos and face-to-face lectures. The students completed the MP assignments alongside the regular post-class reading and HW assignments covering the same concept. Students were placed in groups of 3 or 4 for the MP activities at the beginning of the semester, and the students worked with the same group members for all MP assignments. Due to the large class size, a three-week window was given to students to complete each MP assignment. Four teaching assistants (TAs) (two graduate and two undergraduate students) assisted the instructor with the MP implementation and course assessment grading. For the MP experimental part, the student groups signed up for sessions (two-hour timeslots) to construct the setup and conduct the experiments for each MP activity. Each session had an assigned TA. At the beginning of each session, the TA conducted a demonstration and a trial run for the students and then assisted them with troubleshooting during the remainder of the session as the student groups conducted their experiments. After completing the experiments, the student groups collaboratively worked on the analysis and calculations independently. They prepared and submitted a 7-page project report and a 5-minute video clip on each MP activity within the assigned three-week period. The group project reports followed a standard report format with "Introduction," "Materials and Methods," "Results and Analysis," "Observations and Conclusions," and "References" sections, and the video clip involved students describing their experiment and findings. The course homework and reading assignments were autograded through McGraw-Hill's Connect platform. The course exams were digitally administered and underwent an initial autograding in Canvas, followed by a review of student scratchwork by TAs and the instructor for partial credit adjustment. The MP group project reports and videos were graded by the instructor and the TAs using an instructor-created detailed rubric.

Study Design – MP Design

The instructor designed the MP activities using inexpensive experimental kits purchased from PASCO [15]. An advantage of using the PASCO kits was the flexibility of designing multiple experiments on the same or different concepts using the same experimental kits. In the semester of implementation, the instructor designed four MP experiments centered around the concepts of curvilinear motion/projectile motion, Newton's second law/ friction coefficients, momentum and energy conservation principle/collision, and rigid body rotation/moment of inertia. The experiments were intentionally designed to align with problems solved in the lectures and lecture videos or assigned HW problems to allow students to grasp the concepts better through the hands-on activities. Details of each experimental setup have been elaborated below.

i) MP1 – Curvilinear motion/Projectile motion: For the first MP activity, the learning goal was to study the two-dimensional motion of a projectile and to analyze the effects of launch angle and launch elevation on the projectile's path. Each student group was tasked to assemble a projectile launcher using an experimental kit and then use the launcher to conduct experimental trials for the learning goal. For real-time data collection of parameters such as launch velocity and time of flight, a wireless photogate sensor and a timer accessory were used, which allowed data to be synced through a smartphone application. Figure 1 shows a schematic of the projectile setup (left) and an experimental setup (right) assembled by a student group. Using different launch angles and launch elevations, student groups analyzed a projectile's path while determining parameters such as maximum projectile height and validating calculated launch velocities with experimentally recorded velocities. Apart from the experiments and analysis, the project report also asked open-ended and observation questions to encourage critical and analytical thinking.

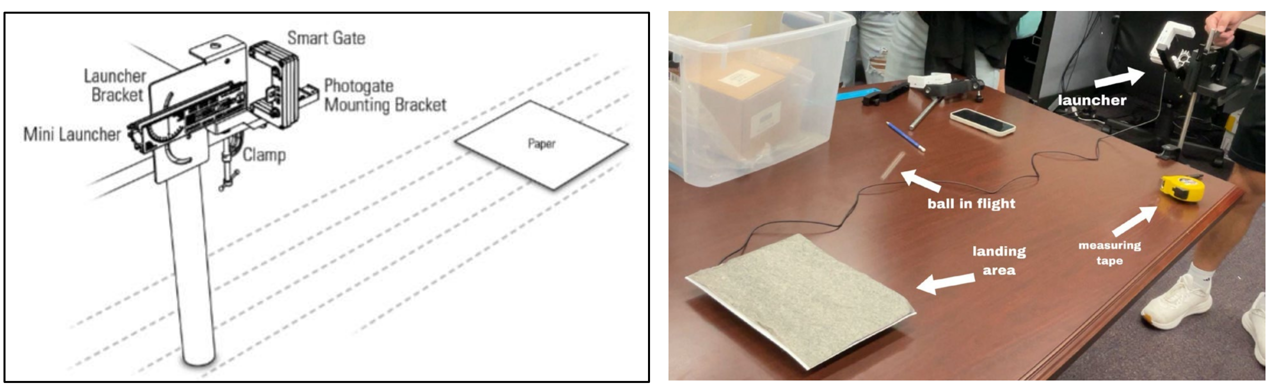
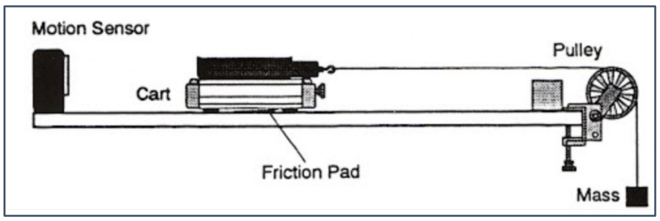


Figure 1: Schematic and student experimental setups for projectile motion MP activity

ii) MP2 – Newton's second law /friction coefficients: The second MP activity involved the application of the laws of particle kinetics, specifically Newton's second law. The learning goal of this activity was to analyze the forces and friction coefficients of moving objects on different surfaces. The setup involved assembling a track and a friction block with different surface roughness capable of sliding on the track through a pulley system attached to a hanging mass. A wireless photogate sensor allowed real-time recording of the velocities of the moving objects. Figure 2 below shows a schematic of the setup (left) and the actual setup. The images were obtained from student report submissions (left) and the PASCO website (right). The student groups analyzed the forces acting on the friction block and calculated the static and kinetic friction coefficients for three different surfaces: wood, rubber, and paper. Open-ended questions on the accuracy of the calculated friction coefficients and assumptions made in calculations were asked in the project reports.



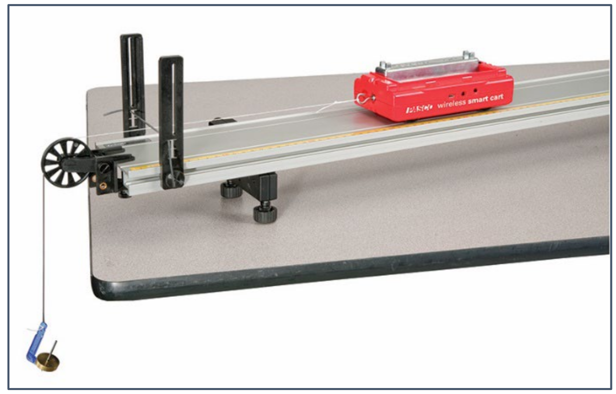
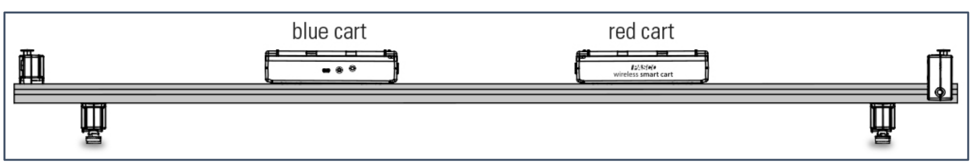


Figure 2: Schematic and student experimental setups for Newton's Law MP activity

iii) MP3 – Momentum and energy conservation principle /collision: Student groups simulated real-world collision scenarios in this MP activity. The learning goals were to analyze the effect of a collision on a system of particles' momentum and energy and characterize the different types of collision. The student groups set a track (the same as used in MP2) and two-cart assembly to simulate the collision and used photogate sensors to record cart velocities during the collision process. Students estimated linear momentum change, energy loss, and coefficients of restitution for both elastic and inelastic collision conditions from their experimental trials and answered open-ended questions to justify their findings in the project reports. Figure 3 shows a schematic (top) and the assembly setup by a student group (bottom).



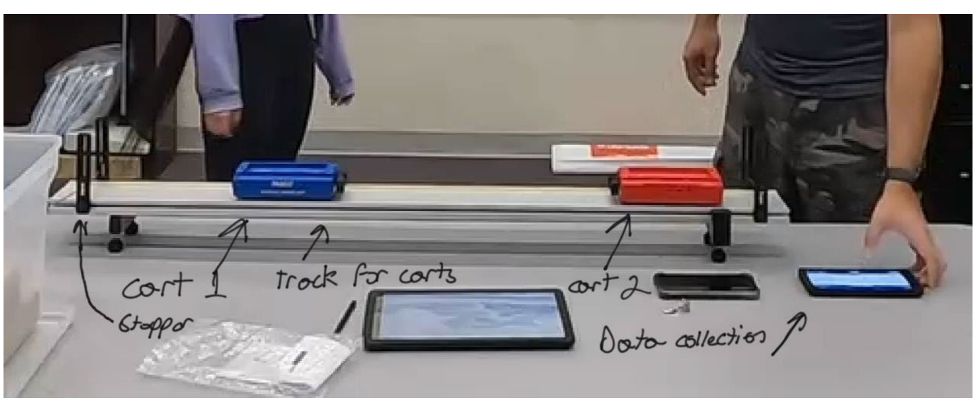


Figure 3: Schematic and student experimental setups for momentum and energy conservation MP activity

iv) MP4 – Rigid body kinetics /rotational inertia: In this MP activity, the learning goals for students were to study the dependence of the rotational inertia of an object on its mass distribution and to experimentally determine the rotational inertia of different objects by using Newton's second law rigid body rotation equation. The student groups set up a rotational assembly attached to a mass and pulley system, as shown in the figure (left - schematic, right - student setup) below, and experimentally determined the rotational inertia of a disk and a ring. A photogate sensor and a phone application were used to record the angular velocities of the rotating assembly. Student groups compared their experimentally determined rotational inertia values with the theoretical values of the objects in different orientations.

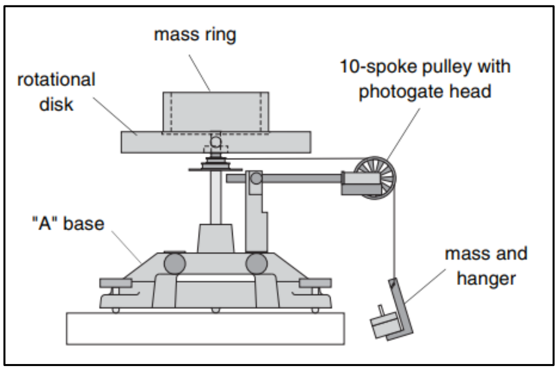


Figure 4: Schematic and student experimental setups for rotational inertia MP activity

Study Design – Data Collection and Analysis

The impact of the MP implementation on student learning and performance was assessed by comparative analysis of cumulative student grades in the MP section (Fall 2024) and a baseline section taught by the same instructor in the previous Fall semester (Fall 2023). The course content, assignments, blended format, and multiple-attempt assessments were all kept the same in both sections, except for the redesigned MP activities offered in tandem with regular HW assignments in Fall 2024. Course grade and assignment data for both sections were obtained from the learning management system Canvas. Demographic data on minority student groups (Hispanic Transfer) enrolled in both sections was obtained from the institutional knowledge management database maintained by the authors' institution. Students' perceptions of the effectiveness of the MP activities on course content learning were assessed through IRB-approved entry and exit surveys administered in the MP section. Survey items on assessing student self-efficacy in the experimental design and analysis of the MP activities as adapted from Ford and coworkers were also added to the exit survey. [16] A 5-point Likert scale, with responses ranging from "Strongly Agree" (5) to "Strongly Disagree (1) was used for rating the survey questions. The entry and exit surveys were administered in the first and last weeks of classes.

Results and Discussion

Figures 5 (A) and (B) show the comparative cumulative grade distribution data for the MP section and the baseline section for "All" students and "Hispanic Transfer" students. The MP and the baseline sections had a total enrollment of 259 and 236, respectively. Data from the entire student population was used to report for "All" students. The Hispanic Transfer student enrollment in both MP and baseline sections was 15 and 21, respectively. For "All" students, the percentage of As and Cs increased in the MP section while the percentage of Bs, Ds, and Fs decreased. The course withdrawal rates also declined by 1.3 percentage points for "All" students in the MP section. The grade distribution trend for the "Hispanic Transfer" student group in the MP section, as compared to the baseline section, showed a decrease in As with an increase in Bs and Cs. The course withdrawal rates for "Hispanic Transfer" students declined by 4.7 percentage points for the MP section compared to the baseline section. The results indicate that the MP activities did yield benefits to the students. Student retention in the course, as observed through the (diminished withdrawal rates) increased across the entire class, with higher retention rates for the "Hispanic Transfer" students. In terms of course performance, "All" students did slightly better with improvements in "A" grades in the MP section, while the "Hispanic Transfer" students scored lower As and higher Bs and Cs.

To further examine the effect of the MP activities on student learning and performance, the average grades received by students in the MP assignments were compared with their course letter grades. Table 1 shows the data for "All" students and the "Hispanic Transfer" students. The MP assignments were scored following a rubric that weighed the report writing and video clip to 60% and 40%, respectively. The MP assignments were graded less strictly than exams, although points were taken off for missing important elements in both reports and videos. A general trend observed for "All" students between the MP score and the course letter grade was a concurrent decrease in both grades, suggesting a weak correlation between how students performed in the MP activity as an indicator of their course performance. For "Hispanic Transfer" students, no such trend was observed between the MP assignment score and letter grade. Contrastingly, "Hispanic Transfer" students scoring lower letter grades performed better in the MP activities. A possible reason for such deviation might be that the lower performing students relied more on assignments and MP grades to maintain their course letter grades. This interesting trend calls for further studies on possible reasons for such trends and validation across different semesters.

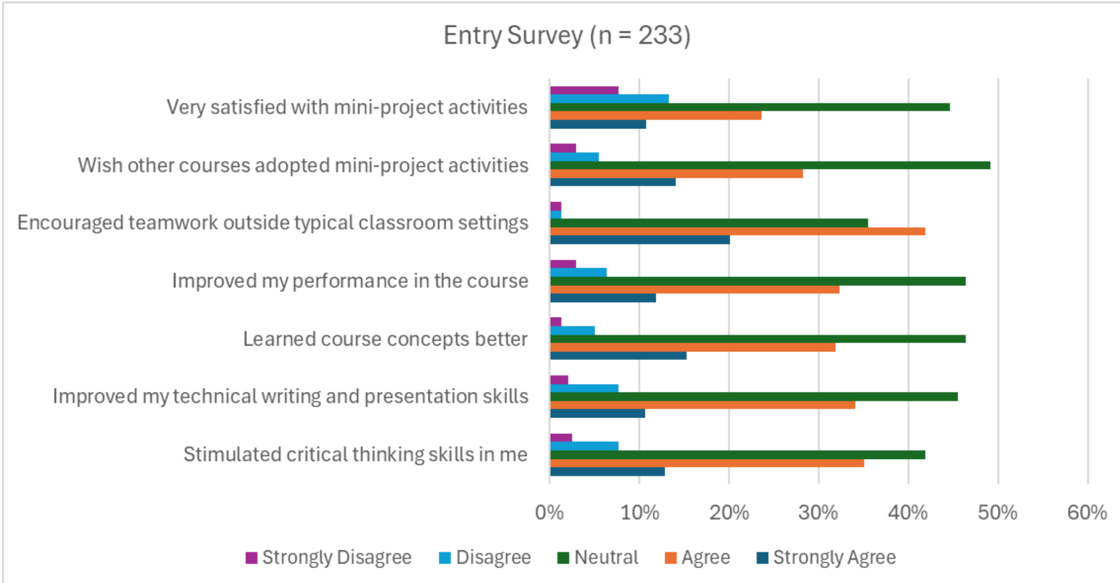
Figure 5: Cumulative grade distribution in baseline and MP sections for (A) All and (B) Hispanic Transfer students. (ALL = all students, HT – Hispanic-Transfer students, W - withdrawals)

Table 1: Average MP assignment scores versus cumulative letter grade

Average MP Assignment Score	Cumulative Letter Grade			
	A	B	C	DF
All Students	93.8	91.6	89.9	77.5
Hispanic Transfer Students	94	93.5	96.3	none

Figures 6 (A) and (B) show student perception responses from the entry and exit surveys administered in the MP section of Dynamics. Of 259 students, 233 completed the entry survey, while 258 completed the exit survey. As evident in the figure, student perceptions of the effectiveness of the MP activities shifted to a more positive side as the semester ended and the student groups completed the MP activities. 79% of the students who took the exit survey reported (strongly agree to agree) that the MP activities improved their critical thinking skills, as opposed to only 48% in the entry survey. Similarly, 76% of students perceived that the MP assignments improved their technical writing and presentation skills after completing the MP activities, in contrast to only 45% at the beginning of the semester. Student perceptions of the effectiveness of MP activities in learning course concepts and improving course performance increased by 26 to 31 percentage points, respectively. Perceptions of teamwork skills and continuation of MP activities in other courses improved by a smaller margin of 9 and 13 percentage points, respectively. For “Hispanic Transfer” students, only 9 completed the entry survey, and 12 completed the exit survey. A 10-percentage point increase in perceptions was observed (not shown in Figure 6) only in survey questions 1 and 4, which were related to the critical thinking skill development and improved performance in the course from the entry to the exit survey. For all other survey questions, student perceptions among the “Hispanic Transfer” students remained the same.

Although the students appreciated the learning aspects of the MP activities, open-ended question responses revealed some dissatisfaction among students with group conflict resolution during the activities and the extra work associated with these activities. The overall satisfaction with the MP activities in the course was 66% at the end, with a 31-point gain from the beginning to the end of the semester. The survey responses corroborate the benefits of hands-on project-based activities in promoting critical thinking skills and concept learning, as reported by researchers in the literature. [4], [5], [17], [18]



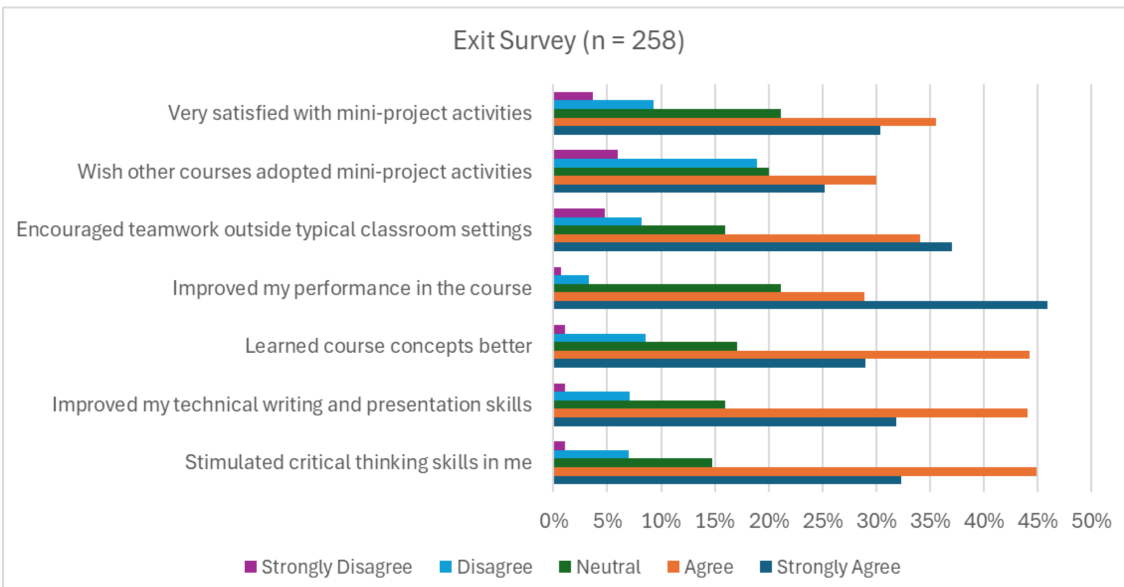


Figure 6: Student perceptions on MP assignments in (A) entry [top] and (B) exit [bottom] surveys

Figure 7 shows results from the self-efficacy assessment items in the exit survey for the MP section. The mean Likert scores (5-point scale) for the survey items have been reported here. As evident in the figure, at the end of the course, students scored high in performing data analysis by applying concepts learned in class, making accurate predictions on experimental outcomes, and generating further questions based on experimental outcomes, with mean scores ranging from 4.31 to 4.5. The self-efficacy scores were slightly lower in data interpretation, considering experimental uncertainties and overcoming problems during experimentation, with mean scores in the range of 3.58 to 3.7. The results indicate that the students had higher confidence when applying the course concepts in the experimental analysis and outcome part of the activity and lower confidence in accounting for uncertainties and troubleshooting. Ford and coworkers reported similar confidence level trends in these self-efficacy items in a materials laboratory course. [16]

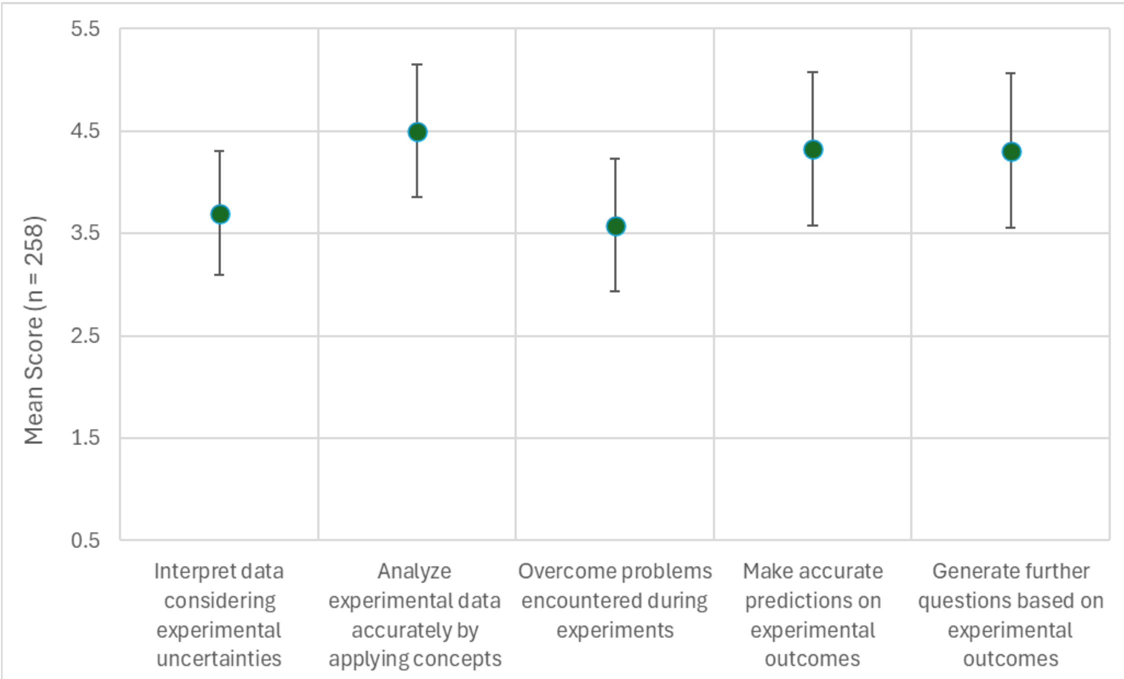


Figure 7: Student mean scores for self-efficacy questions in the exit survey.

Conclusion and Future Work

Several hands-on MP activities were implemented along with regular HW assignments to enhance student learning in an undergraduate Dynamics course. The effectiveness of these MP activities was measured through comparative analysis of course grade data with a baseline section and entry and exit surveys administered in the MP section. The study results indicate that the MP activities positively impacted the students' learning experience in the course. An increase in A or B grades and a decrease in D grades were noted in the MP section for all students, including the Hispanic Transfer students. Student retention, as measured through declined withdrawal rates, was also higher for all students, including Hispanic Transfer students in the MP section. The entry and exit survey results noted significant gains in self-reported creative and critical thinking skills and communication and teamwork skills that align with the ABET requirements, along with improvements in survey scores for course performance, content learning, and MP activity satisfaction at the end of the semester. Survey results on students' assessment of self-efficacy traits demonstrated high confidence in analyzing experimental data and outcomes from course concepts at the end of the course. Overall, student feedback on the MP implementation was positive, with minor concerns on course load, random team pairings, and low MP assignment weightage. A limitation of the current study is its short duration, spanning two semesters, one control and one implementation semester. Future efforts would include conducting multiple-semester studies to gather more comprehensive data and long-term tracking of MP section students in advanced courses requiring Dynamics as a prerequisite to understand the long-term benefits of hands-on activities.

This study demonstrates that MP hands-on assignments can lead to a deeper understanding of complex engineering concepts by encouraging creative and critical thinking, resulting in improved student success rates. Such assignments can also help students develop essential skills such as problem-solving, teamwork, and communication that are crucial for their future careers and align with ABET outcomes, making graduates more well-rounded and industry ready. Overall, integrating hands-on MP activities into the curriculum can transform engineering education by making it more interactive, practical, and aligned with the needs of the modern engineering landscape.

Acknowledgement

This work was supported by the National Science Foundation under NSF IUSE: HSI Award No. 2225208. The authors thank Dr. Melissa Dagley for assisting with student demographic data collection.

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