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Work in Progress: Project-Based Homework: An Ongoing Study on Engineering Analysis-Dynamics

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WORK IN PROGRESS: PROJECT BASED HOMEWORK: AN ONGOING STUDY FOR ENGINEERING ANALYSIS-DYNAMICS.

Abstract

Previous studies on engineering education have shown that teaching based solely on lecturing, does not adequately prepare today's students to succeed in their majors and engineering careers. High impact learning practices such as hands-on project-based homework (PBH) as previously implemented by one of the authors in a Statics course have demonstrated better results regarding student success. As a logical consequence, efforts were made to extend this practice to the next course in the curriculum: Engineering Analysis Dynamics.

This ongoing study presents some very promising results of incorporating collaborative active learning hands-on project-based homework (PBH) as a strategy for improving the students' success in a large sophomore engineering class: Engineering Analysis Dynamics. Several hands-on project-based collaborative learning assignments on selected topics such as curvilinear motion, equations of motion, energy and momentum conservation, were prepared to improve the students' comprehension of these topics. The PBH assignments complemented the regular homework assignments and were offered as extra-credit assignments to persuade students in completing these assignments. Students were asked to demonstrate the tested concepts through physical models, experimentation, and analysis and calculations. For each PBH assignment, the students were required to submit a formal project report and a brief video clip explaining their set-up and results. The impact of PBH on the student's success are summarized and presented in this paper.

1. Introduction

Dynamics is a fundamental course in the critical graduation path of almost every engineering major. This is an important pre-requisite class as it lays the foundational concepts for other advanced courses such as Mechanical Vibrations, Feedback Controls and Intermediate System Dynamics. In addition, At the University X, the failing (DFW) rate for Dynamics have been around 21% in average for the past 10 years (this translate in around 200 students failing per year), reaching sometimes even 37% (Figure 1). High failure rates have adverse consequences such as delay in many students' graduation timeline, dropping from engineering majors and thus reducing the university 4-year graduation rate.

One of the primary reasons for students' withdrawing from engineering programs as identified by some authors is implementation of poor teaching strategies. Engineering education research has shown an increase in class success, retention, and graduation rates when the students participate in relevant active learning experiences [1], [2]. Traditional lectures coupled with practical classroom applications and demonstrations have shown to better prepare students to successfully graduate and culminate in their engineering majors. The benefits of using physical models, manipulatives, multidisciplinary teamwork, and experiential learning to bridge the fundamental theory with previous knowledge, and real life situations have been very well documented by several authors. [3]–[9] A meta-analysis of 225 studies shows the positive impact of active learning when compared with traditional lecture. [10]

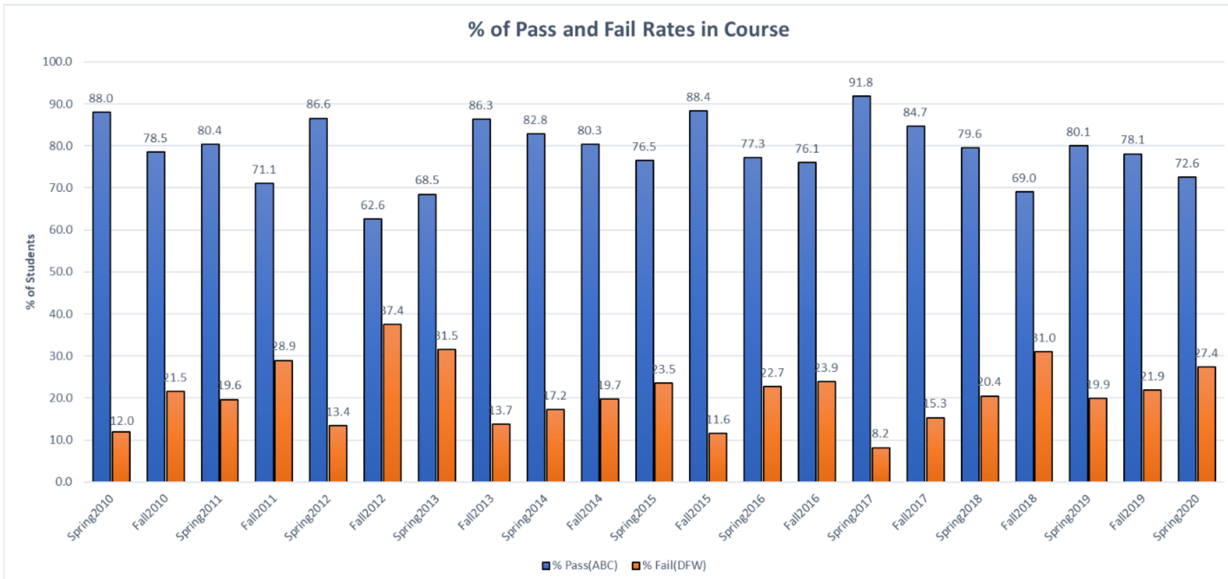

Figure 1. Students' performance in Dynamics for the past 10 years at University X

For Dynamics, some authors have incorporated projects and demonstrations as part of the course.[11] Efforts for improving Dynamics includes projects from egg-drop and motion of a projectile to the use of Lego® models to analyze kinematics mechanisms, including even roller coasters. [12]–[14] All of them show promising results with respect to understanding concepts, teamwork, and overall students' class experience.

The new language of the Accreditation Board for Engineering and Technology (ABET) approved in 2017 emphasizes on 1) the student's ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics; 2) ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions; 3) an ability to function effectively on a team; and 4) an ability to communicate effectively with a range of audiences. [15] Therefore, it is extremely important to include these outcomes while structuring the course content of foundation courses such as Dynamics to better prepare students for real-life scenarios.

Based on the above-mentioned reasons, coupled with the benefits associated with project-based assignments in pedagogical literature, the authors decided to incorporate Problem-Based Homework (PBH) in the undergraduate Dynamics class at the authors' institution. This is an ongoing study, and in the first round of implementation, the authors introduced collaborative active learning hands-on project-based homework (PBH) on select concepts in Dynamics as a strategy to improve students' success and address some of the ABET requirements. Students were asked to demonstrate the tested concepts through physical models, experimentation, analysis and calculations. In this paper we present the results of this first round of implementation of PBH in teaching Dynamics.

2. Methods

The first step in implementation of PBH assignments into the Dynamics course involved introducing collaborative project-based learning assignments on selected topics into one of the sections of the fall 2020 class. The section enrollment was 239. The PBH assignments were optional assignments and were given out as a separate extra-credit PBH assignment category that was distinct from the standard weekly problem-solving homework and reading assignments requirements for the class. Students were given the option to complete the PBH assignments for 5 extra-credit points that would get added to the cumulative grade that they received out of 100 at the end of the semester. The topics that were given out in the first step of implementation included the following:

- Curvilinear motion – projectile motion
- Newton's second law
- Principle of conservation of energy and coefficient of restitution

The students were asked to either build a model or run experiments using commonly available items for the above three concepts. This approach was taken since the class was taught in a virtual format due to the COVID-19 pandemic which restricted the students from being on campus. There were two submission requirements for the PBH assignments: a final project report and a 5 minute presentation video on their experiments and results. Students were highly encouraged to work in teams of two while completing these PBH assignments.

For the first PBH assignment topic (projectile motion), the students were required to develop a plan to measure the variables that affect the two-dimensional motion of a launched projectile. The learning objective of this assignment was to allow the students to analyze the motion of a projectile using a Cartesian coordinate system and the effect of the different parameters such as launch angle, launch height, etc. on the projectile motion path. Students were provided with a project report document that included guidance on materials to use for the projectile (e.g. marble, ping-pong, aluminum foils), easily available measuring devices to use, instructor created video and YouTube videos for ideas, experiments to run once they build their model, tables for data recording and, analysis and observation criterion. Figure 2 shows three samples of the launching devices created by the students for the experiment. The figures are taken directly from the student project report submissions.

Figure 2: Student created projectile launching devices for the first PBH assignment (projectile motion).

The second PBH assignment topic required the students to set up an experiment that allowed them to apply Newton's second law of motion to a sliding object on an inclined surface. The learning objective of this assignment was to allow the students to analyze forces on an object in inclined plane motion and to determine the coefficient of static and kinetic friction values for surfaces of different roughness. Similar to the first assignment, the students were provided with guidance on easily available objects to use and surfaces to study in the project report document and with ideas on conducting experiments through video links. Figure 3 shows some example setups used by students for the second PBH assignment.

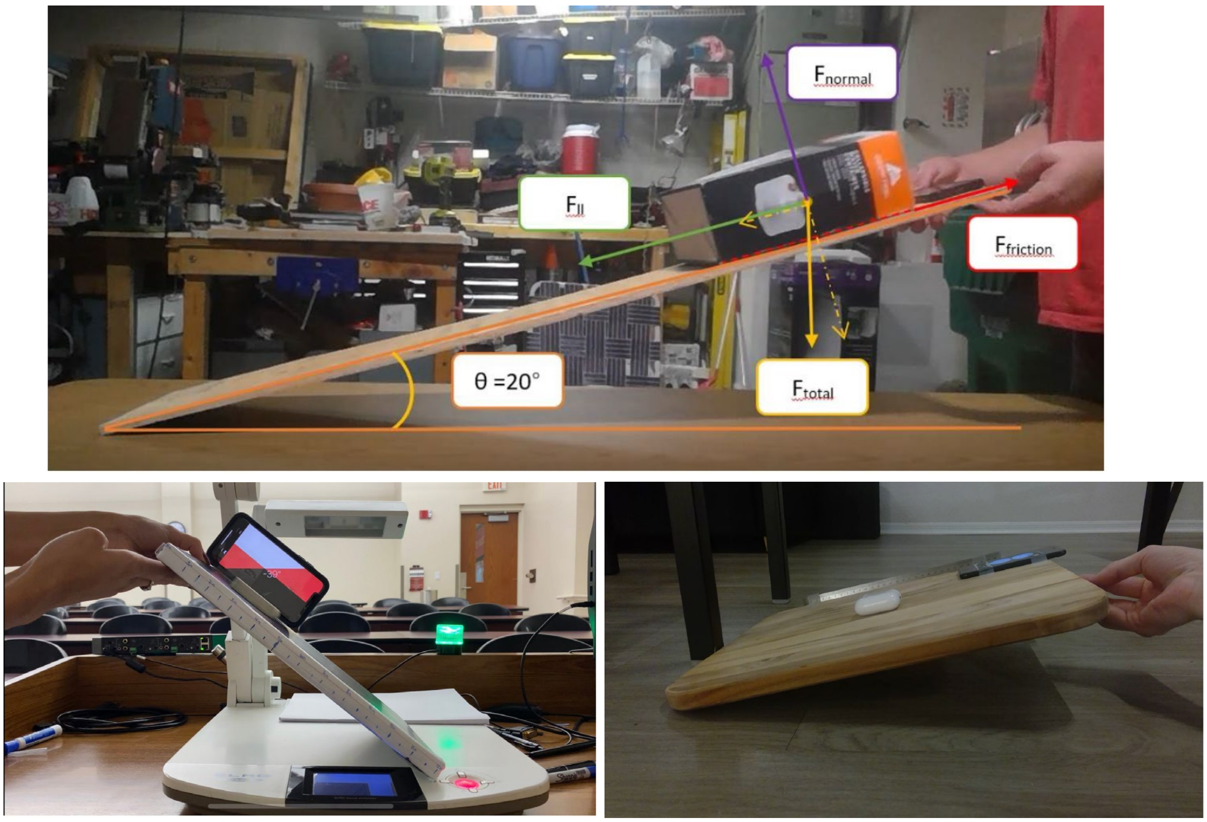

Figure 3: Student experimental setups for the second PBH assignment (Newton's second law).

In the second PBH assignment, the students needed to determine the co-efficient of static friction by applying Newton's second law to the sliding object and finding out the critical angle of sliding. For the co-efficient of kinetic friction, the students used the same set-up and used an angle greater than the critical angle of sliding to allow the object to slide through the surface. The students applied Newton's second law again this case, and they also needed to calculate the acceleration of the object from the distance travelled and time required to slide by the object. This experiment was designed based on one of the simpler experimental friction models as compared to other complex and non-linear models that exist in the literature considering that it was geared toward undergraduate students exposed to Dynamics for the first time in their course of study. The students were made aware of the assumptions made in this simple experimental model, such as uniform contact between the surfaces while sliding and uniformly accelerated motion of the object while sliding through the surface by clearly mentioning them in the guidelines provided to the students. For simple verification of their co-efficient of friction experiments, the students were asked to compare their obtained static and kinetic coefficient of friction values and ensure that the later value is smaller than the former value for any given surface. The students were also asked to verify and report their obtained values against those reported in the literature as much as possible. Additionally, the students were also asked to identify the sources of error in their experimental model that would have resulted in deviations (if any) of their calculated friction coefficient values. Majority of the students (greater than 90%) were able to report values and reflect upon their results and the deviations they observed. Considering that this is not a controlled laboratory experiment where all the equipment and parameters are strictly controlled, the simple experimental models built by the students worked quite well to help improve their understanding.

The third PBH assignment topic involved the students in setting up simple drop tests to learn about the dynamic behavior of objects. The learning objective of this assignment was to apply energy conservation and momentum equations in determining the coefficient of restitution of different bouncing objects such as balls. Similar to the other PBH assignments, some guidelines were provided to students on the methods to use for conducting the experiment. Figure 4 shows some of the experimental setups of students from their project reports.

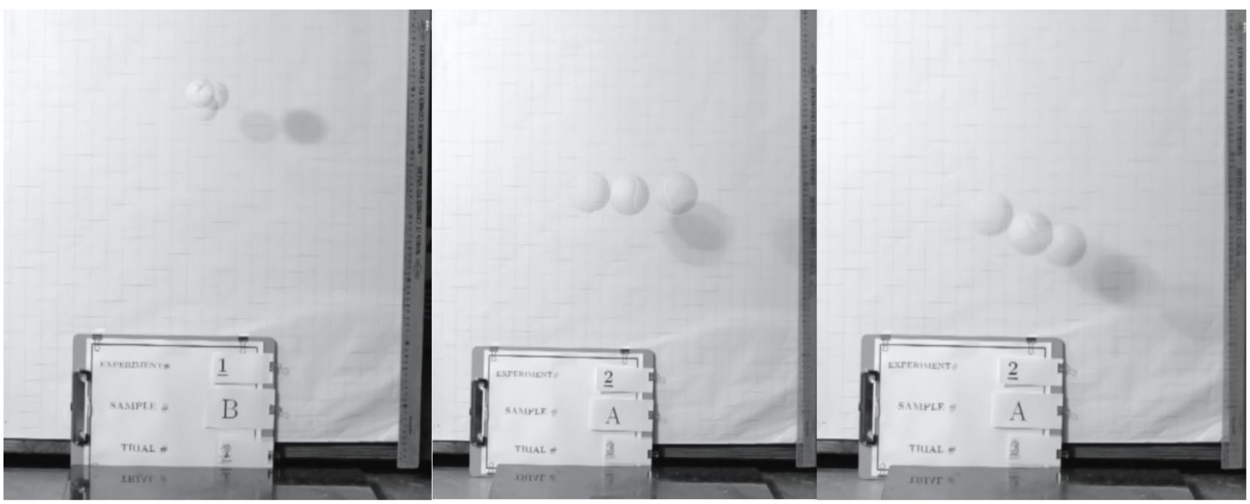

Figure 3: A student experimental setup for the third PBH assignment (conservation of energy and coefficient of restitution).

3. Results

The effectiveness of the PBH assignments in improving the learning process of Dynamics, in improving success rates of students in the course, and in providing additional benefits that are well documented for project based learning assignments in literature was assessed through the following mechanisms: an online survey that was administered to the class at the end of the Fall semester and through comparison of course performance amongst PBH and non-PBH students. 118 of the 239 students (~49%) in class completed one or multiple PBH assignments, while the remaining 51% opted to not complete the assignments.70 (30%) of the 118 PBH students in the class participated in the administered online survey at the end of the semester. As mentioned before, the PBH assignments were not mandatory and were supplemental to the regular homework assignments and the submission rate for the different PBH assignments varied in between 30% and 50% throughout the semester. Of all the students who participated in the survey, 72% were mechanical & aerospace, 20% were civil and environmental and the remaining 8% were industrial, computer science, or construction.

Figure 5 shows student survey responses to questions pertaining to the effectiveness of PBH assignments in improving the learning process. As observed in figure 5, 76% of the students taking the survey agreed to the fact that the PBH assignments helped in better understanding and better retention of concepts. A slightly lower fraction of students (69%) reported that the assignments improved their class performance, while 81% of the students reported that the assignments stimulated their creative and critical thinking skills. The survey results presented in Figure 5 affirms some of the benefits associated with project based assignments that have been reported in literature. Hadim and coworkers have reported advantages such as improved class participation and better promotion of critical thinking skills, while Felder and coworkers have reported improved comprehension and retention with project based assignments. [16], [17] Other benefits of project-based learning that extend beyond improved learning capabilities include development of soft-skills in students. Figure 6 shows student survey responses to questions related to the development of soft skills through project-based assignments. Students were asked if the assignments had helped them in enhancing their technical writing and oral communication skills and if the assignments promoted teamwork and better relationship building amongst peers. In all three categories, approximately 55-64% of the students agreed that the project-based assignments enhanced these soft-skills. Development of these skills are also an integral part of the learning outcomes outlined by the ABET accreditation board.

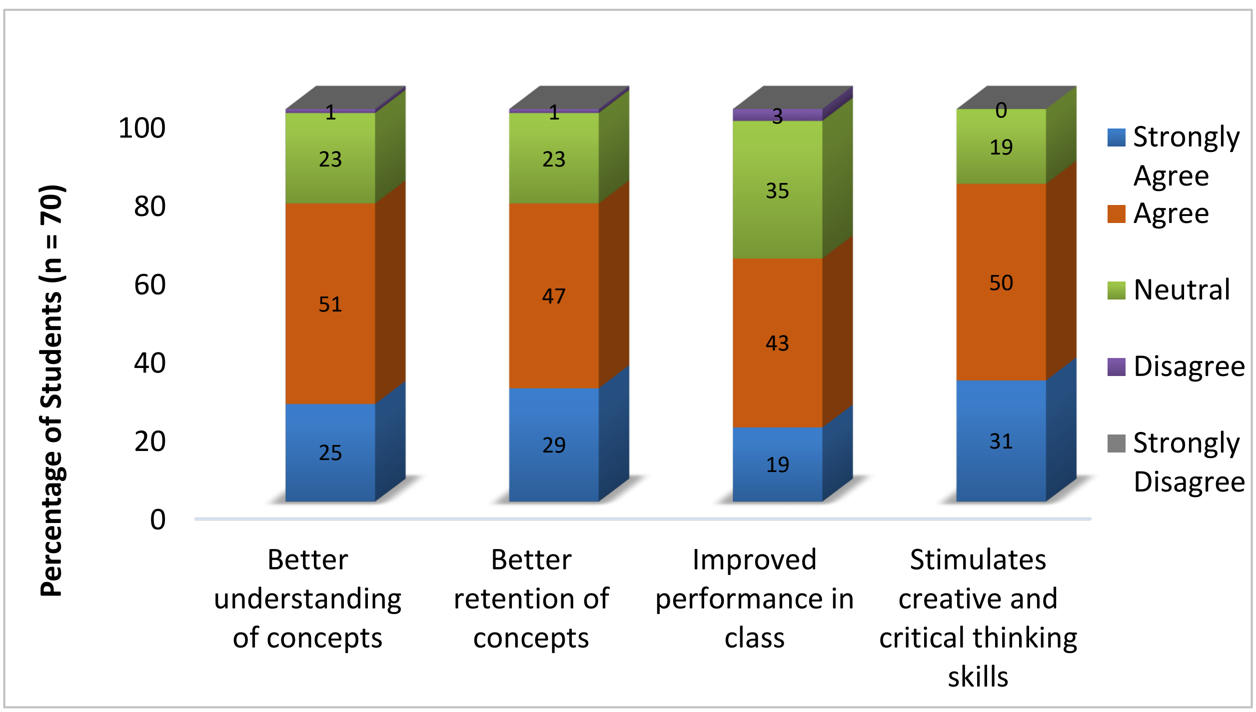

Figure 5: Effectiveness of the PBH assignments in improving the learning process.

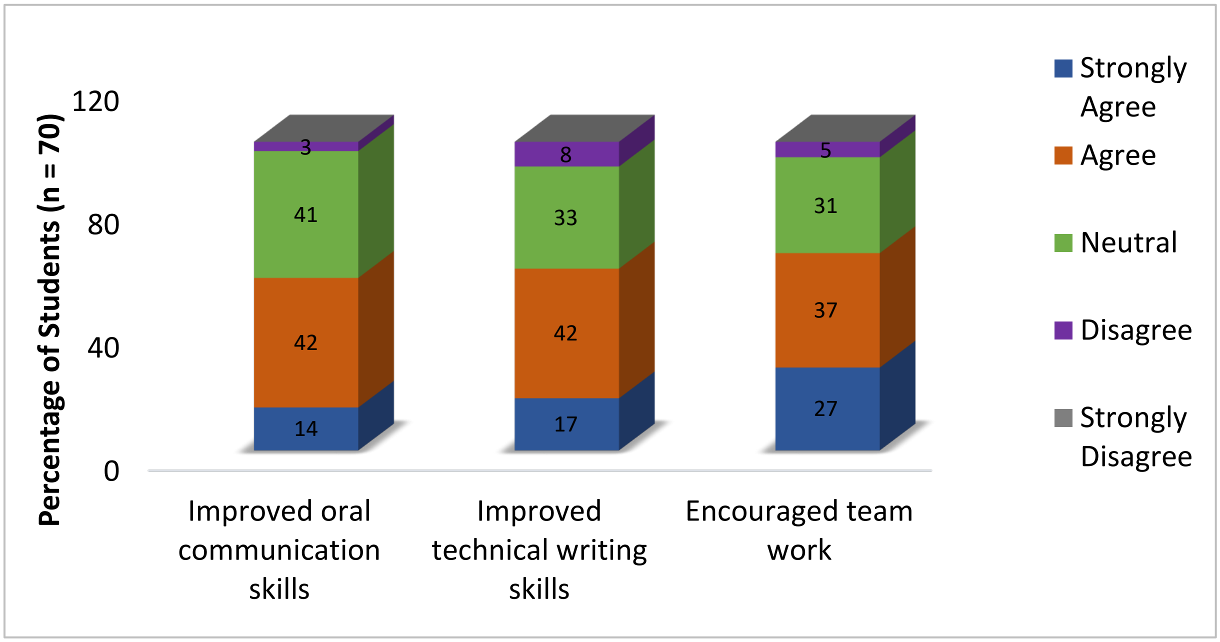

Figure 6: Effectiveness of PBH assignments in enhancing soft skills.

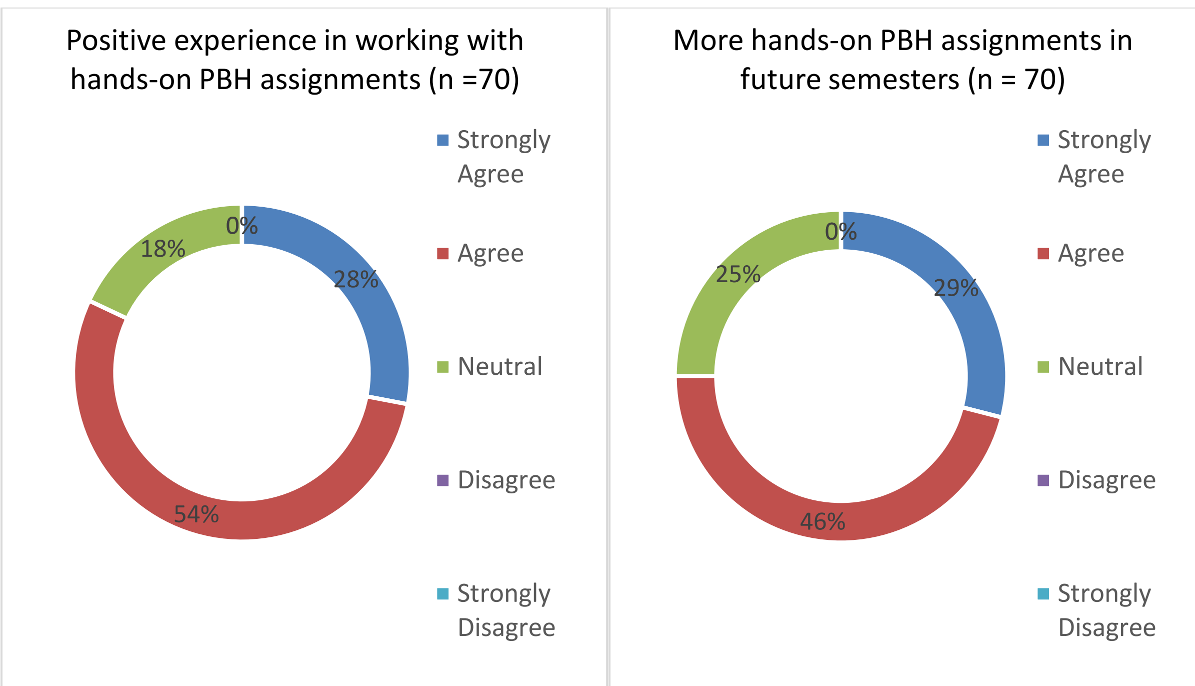

Figure 7: Student satisfaction and attitude toward PBH assignments in Dynamics.

Student satisfaction and student attitude toward PBH assignments were also gauged through survey questions. In the administered survey in the Dynamics course, the students were asked about their overall experience in completing the PBH assignments and their recommendation for future such assignments in the course. The survey results for the above questions are evident in

Figure 7. 82% of the students strongly agreed or agreed to a positive experience in working with hands-on assignments in the course. Similarly, 75% of the students recommended to more hands-on PBH assignments in future semesters of the Dynamics course. These responses reveal that the students are well receptive to having hands on project-based assignments for learning Dynamics.

The performances of the students who participated in the PBH assignments in the Dynamics course were compared with that of the students who opted to not participate in the PBH assignments. Figure 8 shows the results as percentage of students achieving a certain cumulative score in the PBH and the non-PBH category. Since the PBH assignments were assigned for 5 extra-credit points to the students in the course, the scores of the students in the PBH category in Figure 8 were normalized (i.e. the extra-credit points were deducted) while comparing the cumulative scores. The scores of the non-PBH students were kept intact as they did not receive any extra-credit points. This was done to ensure that a uniform basis was used for score comparison. As observed in Figure 8, the failure rate diminished by 2.1% in the PBH students in comparison to the non-PBH students. The percentage of students scoring in the greater than 90 range (corresponds to grade A) and in the greater than 70 range (corresponds to grade C) was also higher for the PBH students in comparison to the non-PBH students. As observed in Figure 8, a score improvement was observed in very good to excellent students (grade A) and also in the weaker students (grade C). These preliminary results are promising and has motivated the authors to further expand the PBH implementation in future sections of the class with a more robust study design where the effect of individual PBH assignments on targeted assessment (exam) questions will be compared to further evaluate the effect of PBH assignments.

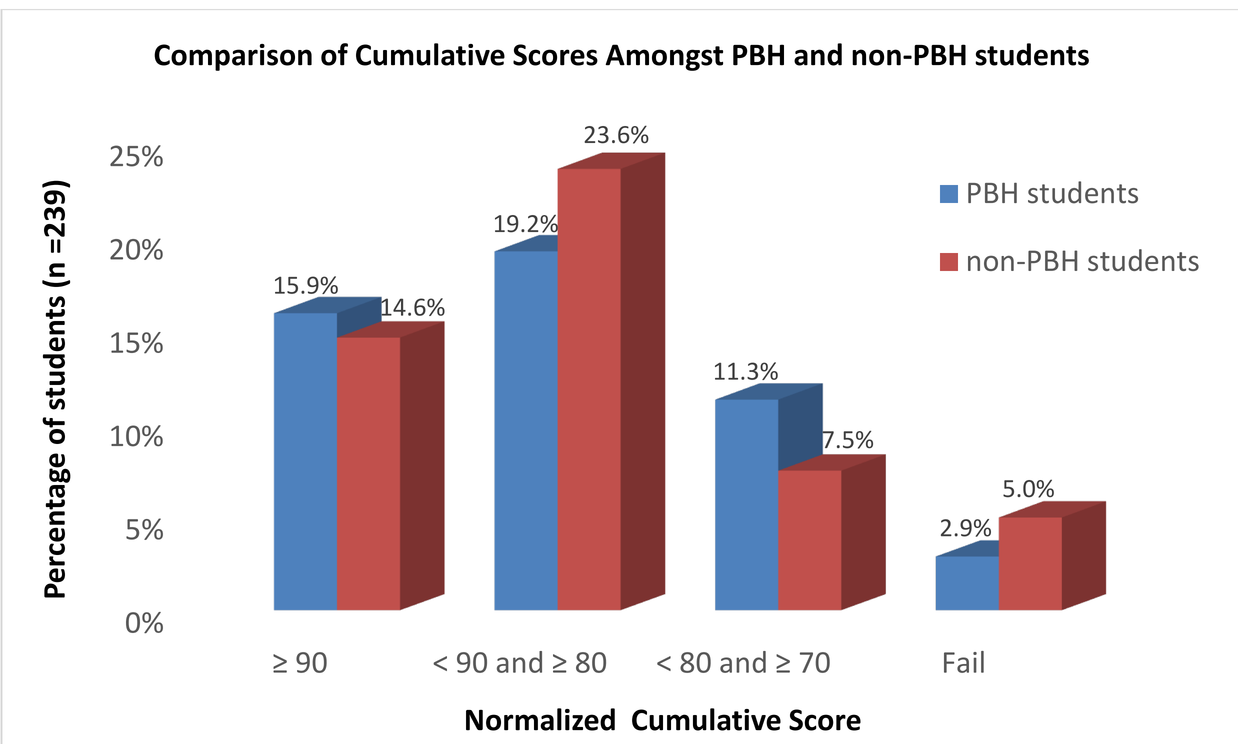

Figure 8: Comparison of course performance amongst PBH and non-PBH students.

4. Conclusion and Future Work

The results of the first round of implementation of hands-on active learning assignments in the Dynamics course are promising. After the initial success of this teaching pedagogy in one of the foundation courses in the engineering curriculum, Engineering Analysis: Statics, by one of the authors, the idea was extended into the next foundation course, Engineering Analysis: Dynamics in the sequence. In the first round of implementation, the hands-on PBH assignments were assigned on selected topics and were kept optional and approximately 50% of the class participated in the hands-on assignments. Student satisfaction and student success were gauged through surveys and course grades. Majority of the students participating in the survey indicated that the PBH assignments helped them with better comprehension and retention of topics in Dynamics. More than 80% of the students reported improvement in creative and critical thinking skills while working on the PBH assignments. Since the students were not provided with a very strict experimental set-up, but were rather given general guidelines on the models to build, the experiments to conduct and the analysis necessary, it forced them to think deeply and creatively while completing the PBH assignments. Building communication and team-work skills in engineers are an integral part of ABET outcomes. More than half of the students participating in the survey reported improvement in these areas after completing the PBH assignments. Overall student satisfaction and student experiences in the first round of implementation were positive. Student suggestions for improving the future implementation of PBH in the course included assigning more build projects, making the PBH assignments as required activities, more weightage on PBH assignments, providing all PBH assignments at the beginning of the semester and random pairing of students in the teams. The amount of effort required in completing each assignment was a minor concern expressed by a few students who took the survey. Comparison of course success rates amongst PBH and non-PBH students' shows improvement in grades and lower failure rates in the PBH students than the non-PBH students.

Inspired from the first round of PBH implementation in Dynamics, the authors plan to refine the PBH implementation process in future offerings of this course. Specifically, the authors plan to conduct a multiple semester based study. In the second round of implementation, the PBH assignments will be kept optional in the first semester. The students who do not opt to complete the PBH assignments will serve as the control group of students for data comparison for the PBH students. The incoming grades of all students will be looked at by obtaining student grades from the previous "Statics" course in sequence through the University IKM (institutional knowledge management) database to gauge the type of student and their interest. The effectiveness of the PBH implementation will be evaluated by comparing the effect of select PBH assignment topics on PBH student scores in targeted assessment (exam) questions, against the performance of non-PBH students. A two-tailed t-test will be used to establish statistical significance amongst the control group and the PBH group in select assessment questions. Additionally the cumulative grades of PBH and non-PBH students will also be compared. The performances of the PBH students in future advanced courses that require Dynamics as prerequisite will also be tracked through the IKM database. This will allow better evaluation of the effect of PBH in improving student success rates. If positive results are obtained in the first semester, the authors will further expand the PBH implementation by increasing the number of project-based activities and making the PBH assignments a required course activity in the next semester and continue to evaluate the student performances. The preliminary data obtained in this study from the first round of PBH implementation is encouraging considering these experiments were devised and completed by the students using simple objects and items while in the middle of the COVID-19 pandemic. The authors will continue their efforts in improving the PBH implementation process in future studies through the above mentioned measures to enhance student learning and student success rates in the Dynamics course.

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