# Implementing Agile Methodologies in a Project-Based Learning Laboratory

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In this study, students at Engineering Dynamics, a distance-learning course offered to engineering technology students, were engaged in a design-based laboratory assignment. Teams of students from multiple campuses worked on design, manufacturing, and testing of a dynamic mechanism. Due to the cross-campus collaborative nature of this project and in the absence of little to no face-to-face interaction between team members, a key factor in success of the team was to manage team effort through an effective project management strategy. As a solution, ideas from agile way of thinking were incorporated in this design-based project. Agile rituals such as stand-up meetings, retrospectives and iterative reviews were implemented for transparent teamwork and timely feedback. The effectiveness of how this intervention helped students was assessed through multiple tools, such as online surveys and targeted design-based questions during mid-semester exams.

## I. Introduction

While teaching methods in engineering education have been historically dominated by the "chalk talk", online, hybrid and distance teaching methods are revolutionizing college education. Engineering education needs to not only provide students with hands-on experiences and practical learning skills, but also improve personal and teamwork skills among the students to enable them become competitive graduates. Schools need to prepare engineering students for future world through education practices that emphasize problem solving skills [1-2]. In order to reach this goal, students need to be exposed to projects that are related to real-world problems that include the typical complexity and uncertainty associated with these problems [3]. Students need to learn how to frame a problem, analyze, design, manufacture and test it [4]. To meet these needs, educators need to revise and fit new contents to their courses, to shift the learning objectives to focus on including design thinking and professional practice elements in courses. This has also been set as goal by the US Accreditation Board for Engineering and Technology (ABET): "students should develop higher order thinking skills of analyses, synthesis and evaluation" [5].

This becomes particularly important and challenging to execute when it comes to distance teaching methods, where there is little to no face-to-face interaction between students and the instructor. Engineering and engineering technology courses are among the topics that are highly in demand to be offered through distance learning program. Through distance learning programs, the lectures are simultaneously delivered to local students who take the face-to-face classes and distance students. Distance students connect to the classroom through distance learning equipment such as Interactive Video Distance Learning (IVDL) and/or online WebEx meetings. Since most technical engineering courses are highly laboratory oriented, it is challenging to develop a physical laboratory experience that can equally serve and benefit both local face-to-face and distance-learning students in the same course.

On this basis, among the instructional strategies for effective laboratory teaching, incorporating a project-based learning laboratory combined with agile methodologies is studied here as an intervention introduced to a core course in engineering technology distance learning program. Over the last few years, project-based learning has rapidly gained acceptance by the educational community and is now being applied in a wide spectrum of engineering disciplines, at various types of academic institutions. Available literature on project-based learning studies developed and implemented in technical engineering courses have provided a good layout for this project [6-10].

A design-based project is proposed to be introduced into "Engineering Dynamics" course. Through this design project, the students were engaged in design, manufacturing and testing of the dynamic principles involved in a mechanical mechanism they have selected and agreed to work on at the beginning of the semester. The students solved the same problem from three different approaches: experiments, hand calculations and software simulations. This innovative semester-long project mimics the real-life industrial process of design, development, testing, and optimization. Using analysis and comparison of the experimental data to those obtained through students' hand calculations and software simulation, we have studied how this intervention have helped students to be more engaged in their learning process.

Due to the cross-campus collaborative nature of this project and in the absence of any face-to-face interaction between team members, a key factor in success of the team efforts is to have an effective strategy to manage their team effort. As a solution to the need for an effective project management strategy, ideas from agile way of thinking were implemented to improve project management in this group projects. Agile ideas date back to the development of Extreme Programming in the 1990s, but reached fame with the appearance in 2001 of the "Agile Manifesto" [11]. While agile practices began in the area of software development, all of the principles are applicable to other types of projects [12-14]. In agile methodologies, such as Scrum [15], the key objectives are delivering value quickly while mitigating risk and managing uncertainty. Following agile project management, the entire project is considered in small modules to allow the team to prioritize the modules that can be done quickly and are of the highest priority.

In our study, the principles of the Agile Manifesto was mapped into pedagogical principles [16], with the goal of streamlining communications between group members on different campuses working in one group and boosting the team-work efficiency and transparency. The traditional course objectives for this course are

- Demonstrate an understanding of the mechanics of accelerating bodies.
- Analyze and solve dynamic problems related to Engineering applications.
- Use computer-aided tools to study the dynamics of moving bodies
- Improve presentation skills and generate a technical design report

Additional teaching goals and objectives through the intervention pursued in this study are the following:

- Engaging students in real-world, hands-on tasks and improve cognitive learning of students: By incorporating this hands-on laboratory experiment in the aforementioned course, the goal is to provide a platform for students to test engineering concepts learned through lectures. In doing so, the project has the potentials to improve the cognitive learning of engineering technology students through integration of theory with practice.
- Cooperation and team work in a self-regulated environment: Using the project-based laboratory in this course and teaming up students from different campuses to work in one group, the goal is to create opportunity for students to practice effective collaboration tactics and communication skills, which was absent in the traditional offering of this course through distance learning program.
- Leveraging creativity and pro-activeness: Students were encouraged to find their own solutions to a problem, make decisions and be creative, coping with incompleteness and unexpected situations during the design, manufacturing and assembly of their setup.
- Reuse and revisit of course materials learned in previous pre-requisite courses: working on this project, junior level students needed to integrate and reuse the knowledge from courses they had taken during their sophomore and freshman years. In doing so, not only this would be a good practice and a refresher for them but also they could see the connection between the materials they learn at school over the years.

In this paper, we analyze and evaluate the results of applying project-based laboratory with practices from agile project management in Engineering Dynamics course, a junior level course offered to engineering technology students. In order to evaluate the effectiveness of the design project, the class was taught in the traditional lecture/software laboratory base in one semester. Data from this class is used as the baseline. The intervention took place in the next two successive semesters. Online assessment survey and questions were designed such that they would directly target the effectiveness and students' satisfaction of the design project.

The remainder of this paper is organized as follows: Section II describes the project-based laboratory methodology followed in the courses, Section III describes the agile practices used as a project management tool, section IV describes the assessment techniques used in this work as well as the results from those assessments. Finally, the most important conclusions are drawn in Section V.

## II. Project-based Laboratory

The project was introduced during the first week of the classes as a semester-long laboratory assignment. The project was organized as follows: Two dynamic mechanisms were introduced and the students were ask to select one as a team and work on it; Rock Crusher Mechanism or Compressor Mechanism [17]. First, the students were required to solve the dynamics of the problem through hand calculations based on what they have learned in the lectures. Next, they should run computer simulations of the same problem, using Working Model software, available to the students through the school. Finally, they were required to design and manufacture an actual physical model of the same problem and run experiment, gather and analyze the experimental data. The experimental data was compared to the analytical hand calculations and simulation results from the software. Only 2D drawings of the mechanism design with their corresponding overall dimensions were provided to the students (Figure 1). Students needed to decide about other details such as scaling, converting 2D design to 3D, manufacturing techniques, material and assembly of the parts. For each project, a SolidWorks® CAD (computer-aided design) model was required and students were expected to procure their own components, often cleverly scrounging zero-cost raw materials on their own.

During the first week of the classes and after introducing the assignment, a survey was designed and conducted at which students were asked to indicate their skills level necessary for this project, previous experiences related to design projects and group work, manufacturing and machine shop resources available for each student at their host campus, and their teammate preferences. The survey data was used by the instructor to form “resourceful” groups. Forming each group, it was made sure that at least two group members have access to manufacturing resources on their host campuses, there is at least one member who is confident in their 3D design and modeling skills, and students from the same campuses are teamed up together.

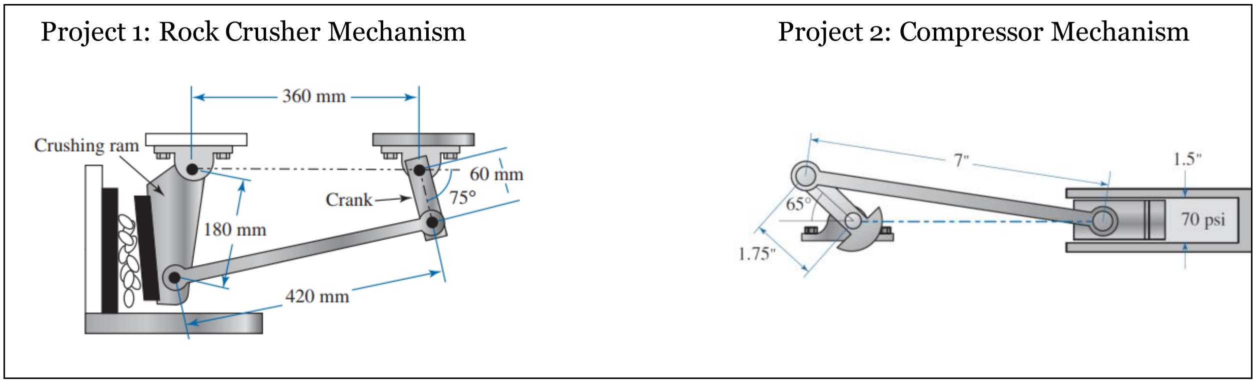


Figure 1. Samples of 2D design provided for students as their design-project.

This semester-long project was divided into 5 steps (sprints), with specific deliverables:

Step 1: 3D design of the parts for the selected project: For each project, a SolidWorks® CAD (computer-aided design) model was required. Only 2D drawings of the mechanism design with their corresponding overall dimensions were provided to the students. Students needed to decide about other details such as scaling, and converting 2D design to 3D.

Step 2: Manufacturing and Assembly: Students were expected to produce their own components, often cleverly scrounging zero-cost raw materials on their own. Selection between different manufacturing techniques, materials and assembly of the parts were up to students to decide based on their team’s available resources.

Step 3: Testing and data collection (Using Tracker software): Once the prototype was ready, each group tested their design. An open-source video analysis tool (Tracker) was introduced to the students to use it as a sensor. The Tracker software can track the motion of individual points already marked on the setup in time and provide them with graphs and data about the kinematics of those tracked points.

Step 4: Working Model Simulation: Each group created their own software simulation model using Working Model software. It was important to set the system parameters in software simulation such that they follow the exact values as those used in actual testing of the prototype, as well as hand calculations

Step 5: Hand calculation and comparison between simulation and experimental data: Hand calculations were done based on the theory learned in the first 5 weeks of the class.

For each step, groups were asked to assign at least one “leader” as the person in charge for that step. However, engagement in all the steps, even if they were not in the leader role for that part was highly encouraged. If a team consisted of collaboration between students from two different campuses, wise selection of roles between group members were encouraged. For example, if the manufacturing and testing was taking place in one campus, other campus members were in charge of 3D design, simulation and comparison of the results that do not need the access to the physical prototype. Shipping the parts of the design between two campuses was not recommended, as it would have caused more complexity into the logistics of this team project. At the end of the semester, the students were required to make an oral presentation to the class, presenting the work developed and the goals achieved. The design project had a weight of 20% on the overall course grade.

Figure 2 shows a sample of student’s work on a compressor mechanism. 3D design and modeling, together with 3D printing and assembly of the parts created the opportunity for the students to practice the skills they have learned in the previous sophomore and freshman year on design and manufacturing. In some groups, if the desired manufacturing technique failed the students, they creatively recycled some parts of the setup from scrap materials that were available to them in machine shop or their work place. Figure 2 (c,d) shows a sample case where the students have recycled scrap materials to build and assemble their setup, once the 3D printer available to them on their host campus went down.

## III. Agile Practices

The intervention has taken place in two successive offering of this course, Spring 2018 and Fall 2018. During the first time offering of this project (Spring 18), traditional project management strategies were used. Each deliverable had a pre-defined deadline and little to no communication happened between the students and the instructor during the assigned deadlines. An important lesson learned from the first time offering of this project was the need to have a better supervision over the teams’ workflow and create an environment for a better and more transparent team communication. Since most groups consisted of members located on different campuses, there were occasions that the team members were completely blindsided on the progress of the project by the other members.

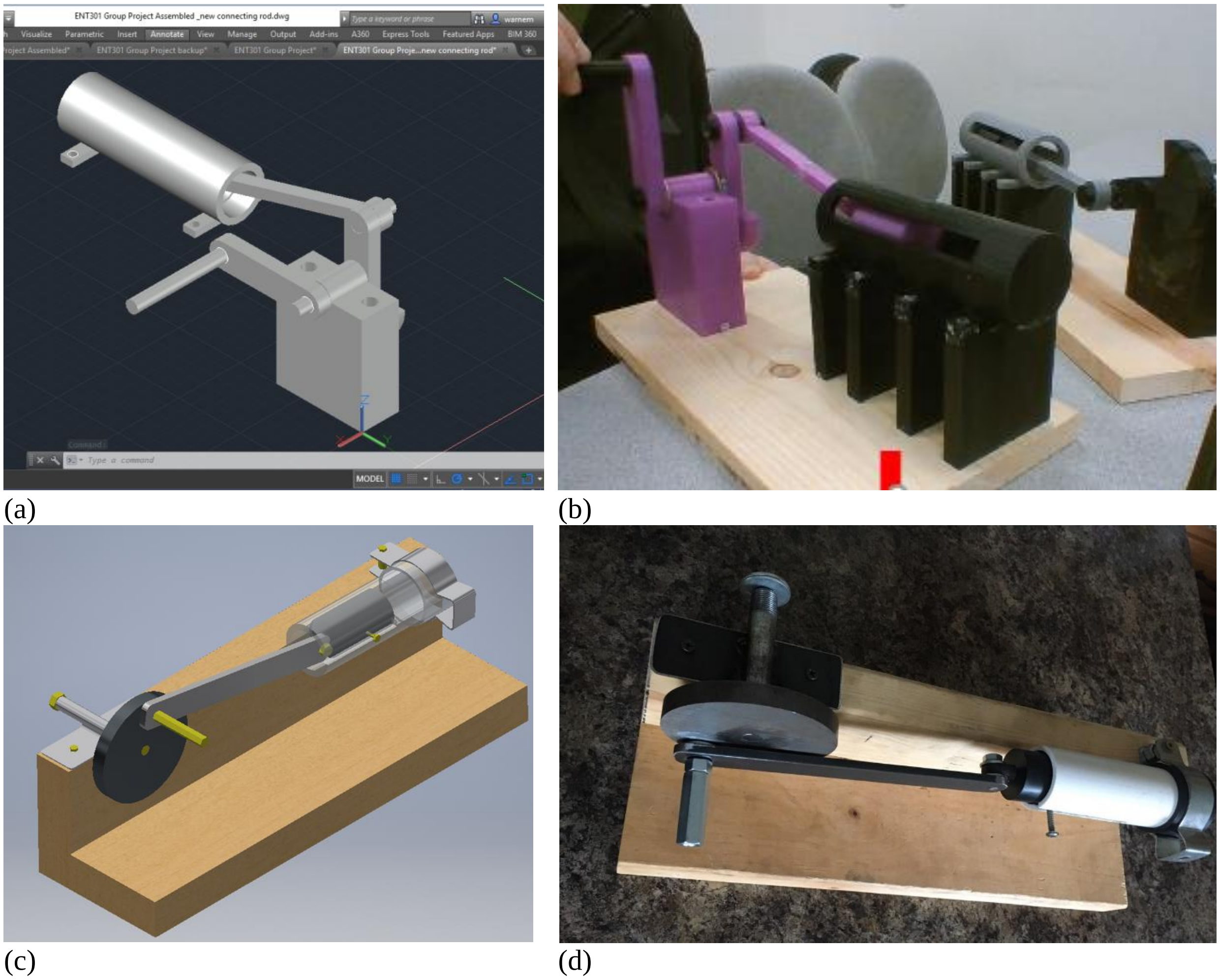



Figure 2. Sample of student's work on compressor mechanism (a, c) 3D design and (b) 3D printed assembly of the setup, and (d) creative use of scrap materials in building the mechanism.

Reflecting on this observation, agile based project management tool was incorporated in the second semester of implementing the project. While the project was still divided into 5 steps (sprints), the deadlines for the deliverables were designed such that different group members could work on their part at the same time, without waiting for the other components to be completed. In each sprint, tasks were prioritized and students estimated the effort needed to complete each task. Depending on the effort estimation, more than one group member might have been assigned by the team to work on the task.

Trello board, a free web-based platform was used to better organize and streamline the workflow of each team. Trello is a list-making, task-delegating, collaboration tool that is available for no-cost to the students. Using Trello board for each group, each member would clearly monitor the progress of different tasks and sprints of the projects and they could share and communicate with their teammates all in one platform.

Students were required to hold weekly team stand-up meetings that allowed them to be aware of the progress of the overall project. The stand-up meetings were limited to 5 minutes per group, designed to ensure that the entire team is aware of impediments, what tasks are done or not-done. At the end of each sprint, iteration reviews were conducted. Students in each group were required to give a short phase-gate presentations (~5 minute presentations) to briefly discuss the progress in their team project and get feedback from the instructor. Those presentations were not graded and mainly were hold to keep the class and the instructor updated about each team's progress and get timely feedback during the semester on their project.

Following iteration reviews, retrospectives were performed at the end of each spring. During the retrospectives, the team discussed two topics: "What went well in the sprint" and "What could be improved". The goal of the retrospectives was to create opportunity for the teams to inspect themselves and create a plan for improvements to be enacted during the next sprint. The retrospectives were done using online questionnaire and the results from all groups were shared the following week in the class.

## IV. Results

In this section, we evaluate the advantages and drawbacks of the project-based laboratory, when compared to traditional method of laboratory delivery in this course, i.e. software simulations only. In order to evaluate the effectiveness of the dynamics design project in accomplishing the defined goals, total of 47 engineering technology students were surveyed during the mid-semester and end-of-the-semester questionnaires. Also, performance of the students working on a targeted design-based question was evaluated in mid-semester exams. The targeted design-based question was directly related to the practices used in the project, for which the students were required to visualize and identify the dynamic motion at different parts of a mechanism, similar to those introduced during the design project.

At the beginning of the semester, the students were also asked to evaluate their skills and level of proficiency in a broad range of topics, including 3D design, manufacturing skills and the manufacturing sources they have access to. Students were also surveyed regarding i) their major (MET: Mechanical Engineering technology, EMET: Electro-Mechanical Engineering Technology or ECET: Electro-Computer engineering technology), ii) their out-of-school work experience (being employed part-time or full-time by local industries), and iii) preferences in their teammate and the leader role selection.

### a. Group formation probe questions

Figure 3 (a) shows the distribution of the class in terms of different engineering technology majors: MET, EMET and ECET in the class. Figure 3(b) also shows the distribution of the students in terms of being local or distance students during the three semesters of Fall 17, Spring 18 and Fall 18. As the data shows, the Engineering Dynamics class in all three semesters has been a mixture of students from all three engineering technology majors. Therefore, when the students were surveyed to rate their skills and proficiency level in 3D design and manufacturing, their responses (Figure 3(c)) varied in a wide range. This information obtained through the beginning of the semester probe questions played a crucial role for the instructor to form "resourceful" groups. At each group, it was made sure that there existed at least one group member who felt comfortable playing the role of the "leader" for certain tasks. Figure 3(d) shows the students response when asked if they think their group was resourceful enough once the teams were formed by the instructor. The high level of students' satisfaction from their team formation emphasizes on the importance of gathering detailed and careful information at the beginning of the semester.

### b. Targeted design-based question

To evaluate the effectiveness of the design-project used in this course, a targeted question was implemented in each semester's mid-term exam. To correctly answer the question, the students would need to have a good visualization of the type of motion happening at different components of a dynamic mechanism. This is a practice that requires students to have a better understanding of the physical system. Figure 4 shows the average of the correct answers to this targeted question in each class. As the data shows, when project-based laboratory intervention happened (treatment groups of Spring 18 and Fall 18 semesters), the average of the students who correctly answered this question increased (93% and 87%), compared to the control group in Fall 17 (85%). Sample of the targeted question used in the exam is provided at Figure 4(b).

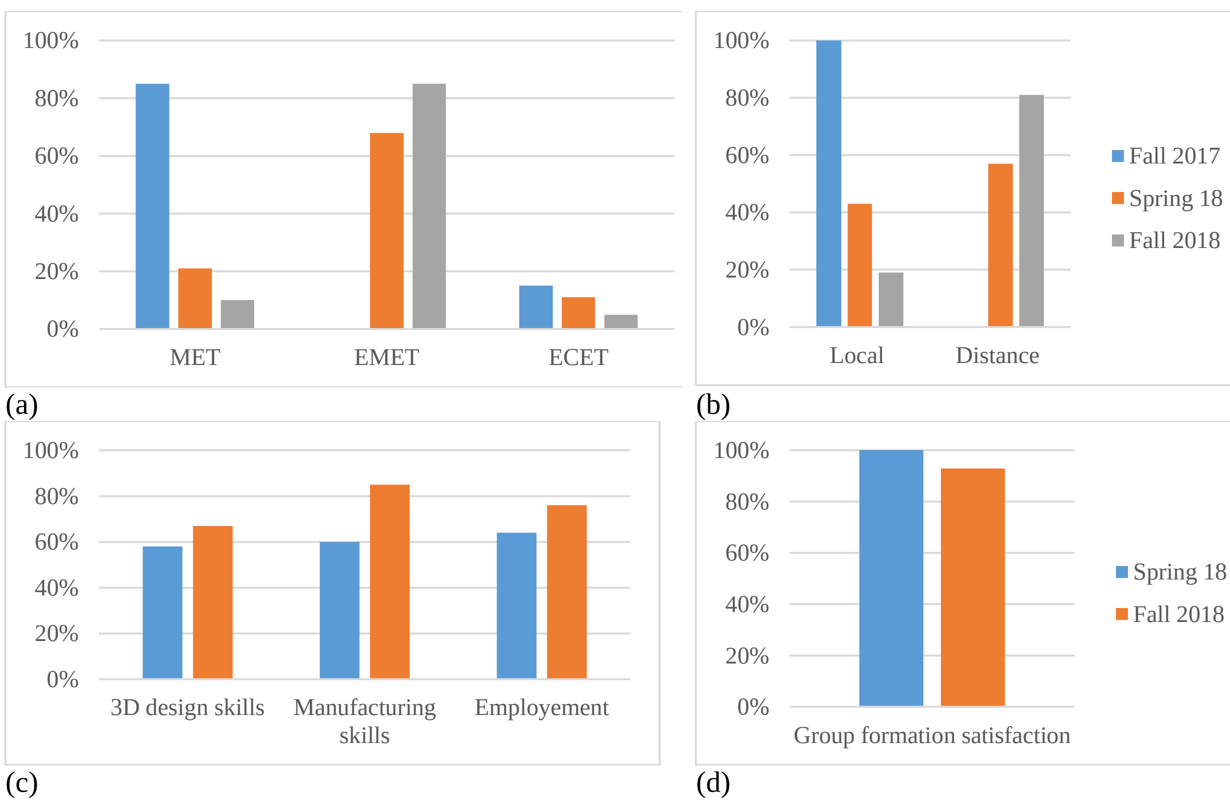
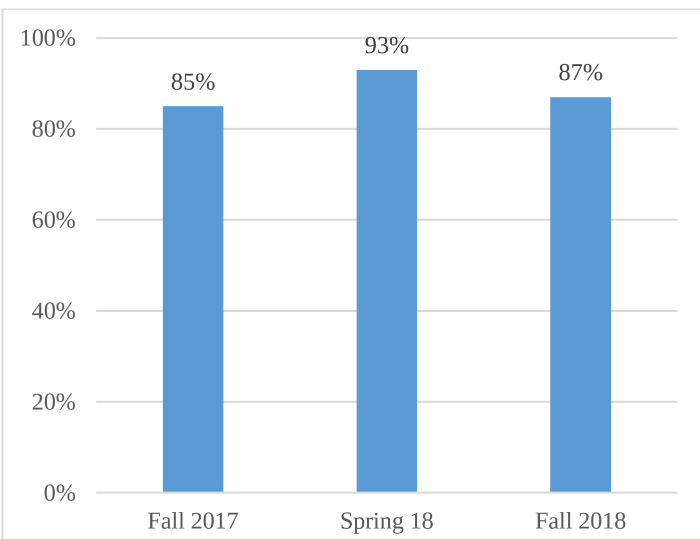



Figure 3. Class distribution in terms of (a) engineering technology majors (MET, EMET and ECET), (b) local and distance students, (c) students' skillsets and their employment status, and (d) group formation satisfaction rate.

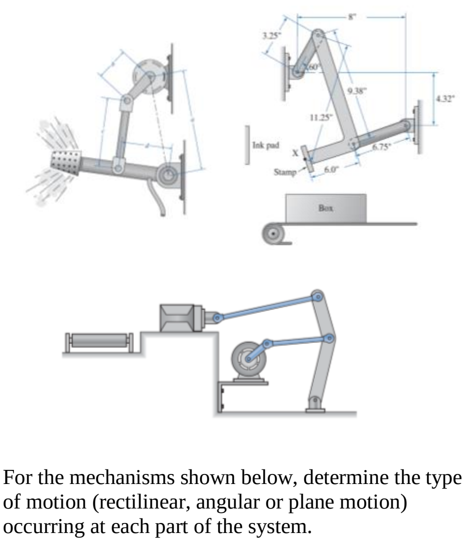
### c. End-of-the-semester survey

Students in treatment groups in both semesters, when the design-based project was implemented, were asked to weight the effectiveness of each teaching technique, i.e., lectures, software simulations and design-project, in their overall learning of the subject. Figure 5(a) shows that the design-project was rated by the students as the most effective one, with the highest weight in both semesters compared to lectures and software simulations. Along the same line, students in the treatment groups were surveyed about the advantages of implementing design-project in their course. Figure 5(b) shows the students' agreement percentages regarding the following questions:

Q1: Working on the design project, it encouraged me to see and relate the course subject matters to real-life examples.
Q2: The design project gave me an opportunity to exercise creativity.
Q3: The design-based project helped me to remember the design-process and decision making tools learned in Freshman and Sophomore engineering courses.
Q4: The design-based project enhanced the course curriculum.




(a)

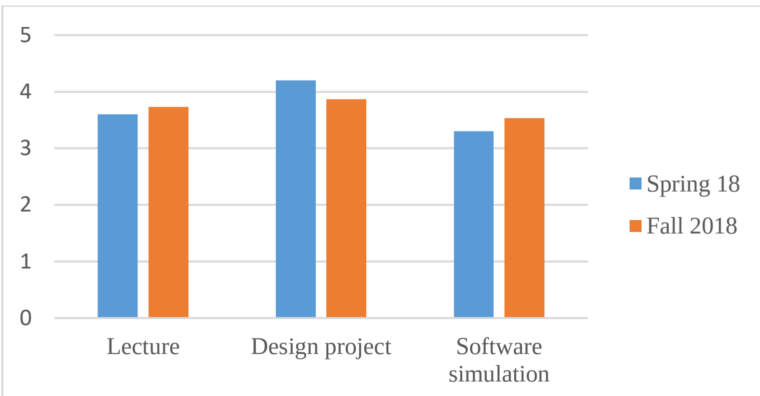



(b)

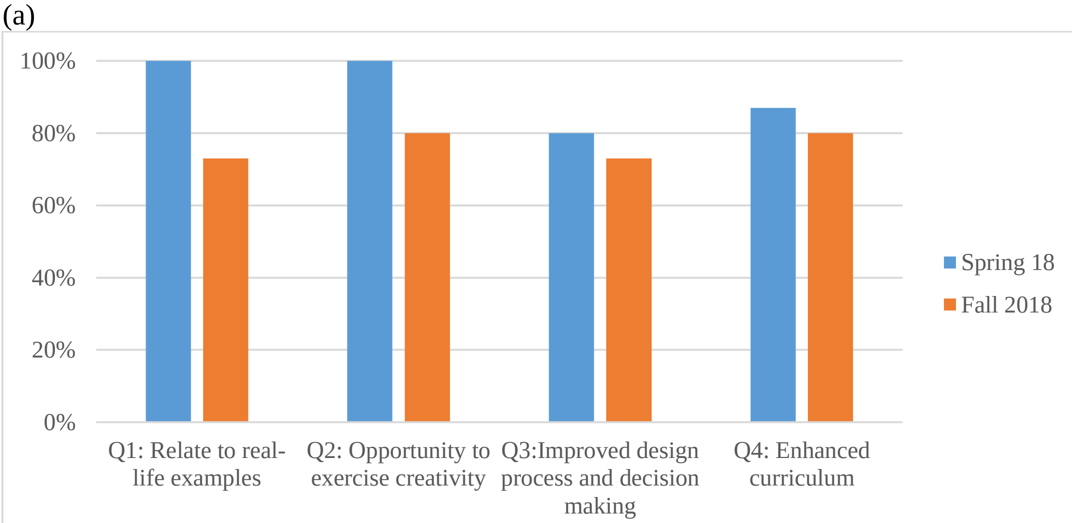
Figure 4. Class average on a targeted design-based question during midterm exam (a), and sample of the design-based question (b).

The challenging nature of the cross-campus collaboration between the group members were also surveyed. In both treatment groups, the students agreed on the challenging nature of this collaboration. However, they also believed that working in groups across multiple campuses on this project was a good practice for future collaborative projects at school and workplace (Figure 6(a)). When Agile-based practices were used as a project management tools for treatment group during Fall 18, the students were also surveyed on the following questions regarding Agile practices:

Q1: Using stand up meeting to briefly discuss the progress in team project helped me to be more engaged in the group's progress and makes team work and communication between the students and the instructor more transparent.
Q2: My group actively used Trello board for management of the group project efforts
Q3: Using Trello board helped the team's effort to be more efficient and transparent.
Q4: Giving phase-gate presentations (~5 min presentations on Hand-calculations, simulations and design and manufacturing) to briefly discuss the progress in team project helped me to be more engaged in the group's progress and makes team work and communication between the students and the instructor more transparent.



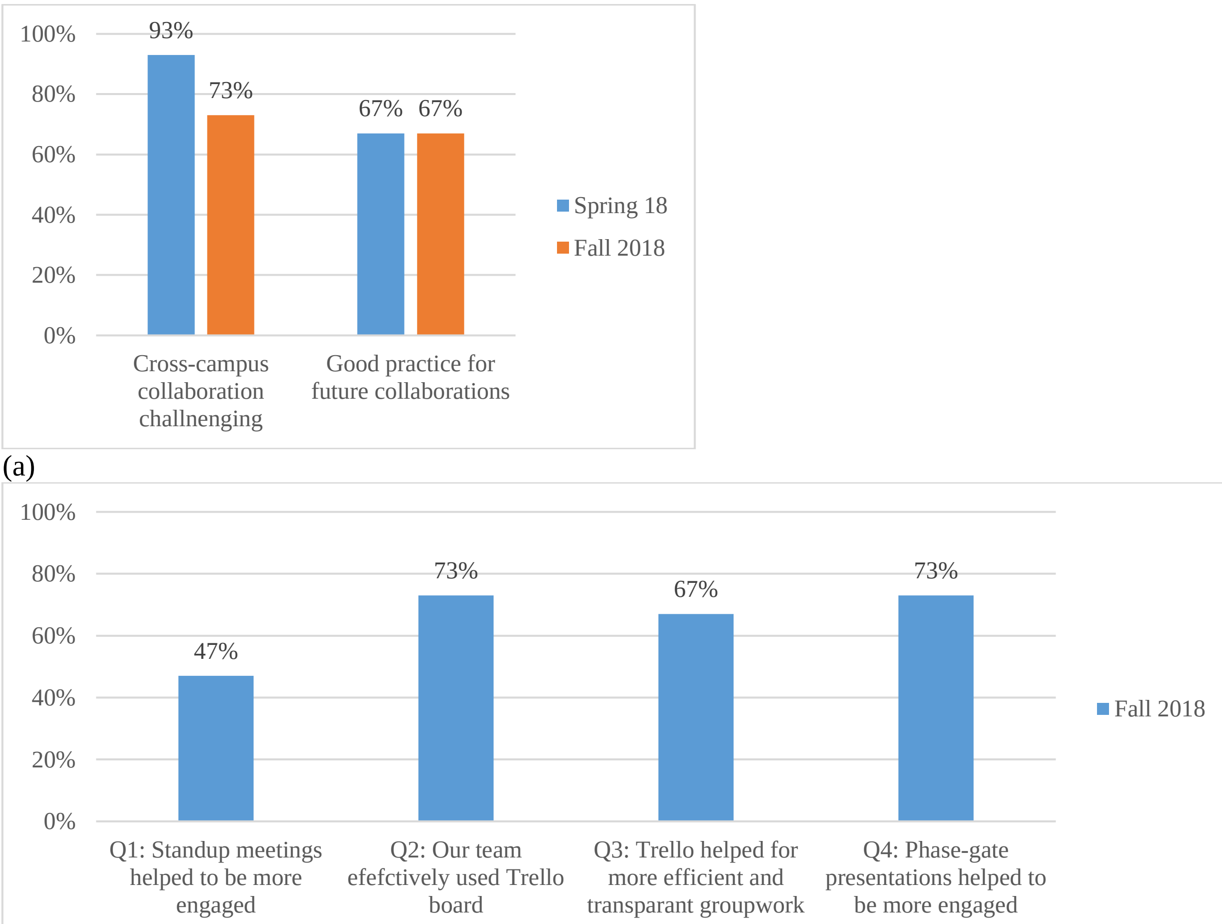

(a)




(b)

Figure 5. Student's rating to (a) the most effective technique helpful for their learning, (b) advantages of the design-based project.

Figure 6(b) shows the answer to the above questions regarding the effectiveness of implementing agile rituals as a project management tool. As the data shows, most students have effectively used the Trello platform for their project management. Also, the students believed the agile rituals used have helped them in better communicating between team members and having a better transparent team work. Interestingly, looking at the students’ response to how challenging the cross-campus collaboration was (Figure 6(a)), those who used the agile practices rated the challenging nature of the collaboration less than those who used traditional project management (73% vs 93%). This data might suggest that implementing agile rituals have reduced the challenges of cross-campus collaboration between the team members.



(b)
Figure 6. Students' rating to (a) challenging nature of cross-campus collaboration, (b) effectiveness of agile rituals implemented in the class.

## V. Conclusion

In this study, a design-based project was incorporated as a hands-on laboratory assignment to students enrolled at Engineering Dynamics course, offered through distance-learning program. Students from multiple campuses worked on design, manufacturing, and testing of a dynamic mechanism. Agile project management strategies were incorporated to manage the teamwork efforts in this design-based project. Each student in their group took the role of “leader” in one aspect of the laboratory assignment. The effectiveness of how this intervention helped students was assessed through multiple tools, such as online surveys and targeted design-based questions during mid-semester exams.

The results from this study suggests that project-based learning can be used as an effective hands-on laboratory component for engineering courses, especially if there is imitation on having a physical laboratory space and location on campus. Project-based learning, when used with effective project management strategies, such as agile project management tools, can lead to a very transparent and effective cross-campus collaboration and streamlined team effort between the students.

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