Student-Centered Instruction in a Joint Undergraduate-Graduate Mechanical Engineering Class

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Abstract

Student-centered philosophy emphasizes the shift from traditional teacher-centered pedagogies to instructional approaches that position students as active participants rather than passive recipients in the learning process. Educational research has developed many pedagogies to promote student participation in the learning processes, e.g., active learning, project-based learning, research-based learning, etc. Moreover, student-centered philosophy also recognizes individual differences among learners and encourages teaching practices that accommodate the full spectrum of students' preparation and needs.

The author designed and implemented the lesson plan for a joint undergraduate-graduate mechanical engineering course, Refrigeration and Cryogenics, grounded in the student-centered philosophy. The objective was to enhance student engagement and to accommodate diverse levels of preparation and needs, with the expectation of improving learning outcomes. Interactive and collaborative learning activities, such as in-class discussion with peers, team project, research plan design, peer presentation, peer evaluation, competitive polling, etc., were integrated with traditional instructor-led lectures. To foster a sense of community, the course began with a "speed-dating" icebreaker activity in the first class session, and a peer appreciation board was created using the "Discussion" feature of the Canvas LMS (Learning Management System).

This paper presents the design and implementation of the lesson plan. A survey instrument was designed and administered to collect students' feedback for measuring student self-reported engagement and learning outcomes associated with fourteen teaching strategies, ten of which are student-centered activities. The study also measured the preferred learning environments for motivation. The results show that although these activities were rated differently, undergraduate and graduate students reported similar perceptions of their influence on engagement and learning outcomes. The team project stands out in terms of both engagement and learning outcomes due to its significant collaborative and interactive characteristics, whereas the ice-breaker game, peer evaluation, and peer appreciation board were rated relatively lower by this student cohort. Furthermore, the data reveal a strong positive association between student engagement and learning outcomes. Notably, the evaluation also included the traditional instructor-led lecture, which was ranked in the top category of learning activities. This finding indicates that instructor-led lectures remain indispensable and highly valued by both undergraduate and graduate students.

Introduction

Student-centered philosophy has been studied for decades; however, a clear and comprehensive definition of student-centered learning remains challenging [1]. Bremner [2] developed a framework for student-centered learning that includes six aspects: active participation, adapting to needs, autonomy, relevant skills, power sharing, and formative assessment. Generally, student-centered philosophy is interpreted as the emphasis of the shift from traditional teacher-centered pedagogies to instructional approaches that position students as active participants rather than passive recipients in the learning process.

Psychology theories, such as constructivism [3] and self-determination theories [4], support student-centered learning by highlighting that learning is an active process where learners construct knowledge through interaction with their environment, and that motivation is enhanced when autonomy, competence, and relatedness are supported. From a sociological perspective [5], learning occurs through observation, imitation, and modeling within social contexts and can also be understood as participation in a community where members share and develop practices. Educational research has developed many pedagogies to promote student participation in the learning processes, e.g., active learning [6], project-based learning [7], research-based learning [8], etc. Moreover, student-centered philosophy also recognizes individual differences among learners and encourages teaching practices that accommodate the full spectrum of students' preparation and needs [2].

The author designed and implemented the lesson plan for a joint undergraduate-graduate mechanical engineering course, Refrigeration and Cryogenics, grounded in the student-centered philosophy. The objective was to enhance student engagement and to accommodate diverse levels of preparation and needs, with the expectation of improving learning outcomes. Interactive and collaborative learning activities were integrated with traditional instructor-led lectures for the student-centered philosophy.

This paper presents the design and implementation of the lesson plan. To examine and evaluate the impact of student-centered activities on engagement and learning outcomes, a survey instrument was designed and administered to collect students' feedback. Both quantitative and qualitative analyses were conducted to analyze the survey data. After a brief introduction of the research method, the emphasis was placed on the presentation and discussion of the quantitative and qualitative results regarding the fourteen learning activities implemented. The limitations of this research were also discussed before presenting the conclusions.

Student-Centered Lesson Plan

The course, Refrigeration and Cryogenics, covers the topics including the concepts of refrigeration and cryogenics, principles and equipment of refrigeration (e.g., vapor-compression refrigeration, absorption refrigeration, ejector refrigeration, and evaporative cooling), and cryogenic systems and engineering (e.g., cryogenic fluids, cryogenic refrigerators and liquefiers, cryogenic thermal insulation, cryogenic engineering materials, air liquefaction and separation, cryobiology and cryopreservation, and safety of cryogenic systems). Besides the concepts and principles, the applications and related issues (e.g., energy consumption and climate change) are also discussed. To strengthen students' computational skills for engineering problem solving, Python coding with the CoolProp library for the fluid thermal properties was introduced and practiced throughout the entire course.

Refrigeration and Cryogenics, as a graduate-level course, as well as an elective course for undergraduate students, generally has a joint class consisting of undergraduate and graduate students. Undergraduate students work for three credit hours, while graduate students work for four credit hours. This joint-class form brings a broad spectrum of student preparation regarding thermodynamics and heat transfer knowledge as well as coding skills, leading to instructional challenges.

To promote active and collaborative learning, the student-centered lesson plan was designed to include the following ten learning activities. Each learning activity was labeled with a number to facilitate data presentation in this paper.

- In-class discussion with peers (A1)
- Discussion with instructor (A2)
- Team project (A3)
- Designing a research plan (A4)
- Peer presentation (A5)
- Competitive polling (A6)
- Study summary (A7)
- Ice-breaker game (A8)
- Peer evaluation (A9)
- Peer appreciation board (A10)

In-class discussion with peers was used to encourage students to reflect on the topics covered in class, share their thoughts, and learn from their peers; meanwhile, it can break a long lecture into sections and provide students with an opportunity to refresh their mind. The instructor generally walked around the classroom and participated in the discussion with the students, so the instructor could learn the students' understanding and help individual students timely. The instructor and teaching assistant also offered office hours to help students with their questions. Nine team projects were implemented to promote collaborative learning. All of them are mini projects with a manageable workload, designed to be completed in one week, and may involve Python coding for solutions, open-ended questions, research questions by parametric study, design of research plan for a topic of interest, etc. In the implementation of the lesson plan, the enrolled graduate students are about twice as many as the undergraduate students. Thus, two graduate students and one undergraduate student were assigned to one team to work on two projects, and then all teams were regrouped in the same manner for the next two projects. This design is a compromise between facilitating collaboration with various peers and maintaining team stability. Every graduate student working for four credit hours is required to study a special topic and present it as a 40-minute lecture with at least one interactive learning activity. The instructor used the remaining 10 minutes to provide comments or additional discussions. Graduate students were required to discuss their lecture lesson plan with the instructor during lecture preparation. This was not only used to ensure the quality of the lectures for the audience but also offered an opportunity for graduate students to learn about the lecture lesson plan design. Competitive polling was conducted in a gamification environment to enhance student engagement. Students were also asked to complete a mind map as a study summary of all concepts discussed in this course. This study summary was designed as a review learning activity and was expected to encourage students to reflect on their study in this course.

To build a sense of community for collaborative learning, an ice-breaker game, peer evaluations, and a peer appreciation board were applied in this course. The ice-breaker game called ”speed dating” was conducted at the first lecture meeting. Students were asked to talk with as many of their peers as possible to learn their names, hometowns, and hobbies, followed by a Q&A session. Students who answered the question correctly were assigned extra classwork points. Peer evaluation was applied to team projects and lecture presentations by graduate students. For team projects, peer evaluation focused on participation and supporting team members. For graduate students' presentations, peer evaluation was used to encourage the presenters to engage and influence their audience, and was also used to enhance the attention and participation of the audience. The peer appreciation board was created using the “Discussion” feature of the Canvas LMS (Learning Management System). Students showed appreciation to their peers by posting a discussion topic and other students responded to the posts using the reply function of the discussion platform.

In Addition, the following four traditional learning activities were also included in the lesson plan. Here, the classwork activity refers to in-class individual work on worksheets, completed without interaction or collaboration with peers.

- Instructor-led lecture (A11)
- Classwork (A12)
- Homework (A13)
- Exam (A14)

Methods

The student-centered lesson plan was implemented in a Refrigeration and Cryogenics course with twenty-six enrolled students. A survey instrument was used to collect student feedback on the ten activities for active and collaborative learning, as well as on the four traditional learning activities, mentioned in the previous section. With an interest in engagement and learning outcomes, the survey includes the following questions.

- Rate the level of engagement each of the fourteen learning activities on a scale of 1–5: 1 = not engaging at all, 5 = very engaging.
- What activity engaged you most? How did this activity make you feel more engaged?
- Rate how helpful each of the fourteen learning activities was for your learning outcomes on a scale of 1–5: 1 = not helpful at all, 5 = very helpful.
- What activity is most helpful for your learning outcomes? In what ways did this activity help your learning?
- What types of learning environment do you find motivating?

Table 1: Student demographic data of class enrollment and survey participants.

	Class Enrollment		Survey Participants	
Total	26	100%	23	100%
Domestic Undergraduate Student	8	31%	7	30%
International Undergraduate Student	0	0%	0	0%
Domestic Graduate Student	2	8%	1	4%
International Graduate Student	16	62%	15	65%
Female	3	12%	3	13%
Male	23	88%	20	87%

Twenty-three students volunteered to complete the survey forms. The demographic data for class enrollment and survey participants are tabulated in Table 1.

Both quantitative and qualitative methods were used to analyze the data collected. The quantitative analysis focused on the rating questions for the fourteen learning activities in terms of engagement and learning outcomes. Descriptive statistics, e.g., mode, first quartile (Q_1), median, and third quartile (Q_3), were used to summarize the categorical and ordinal rating data, followed by a Friedman test [9] to rank these learning activities. The Friedman test is a nonparametric statistical method used to analyze categorical ordinal data in repeated-measures designs, e.g., the case of this study that twenty-three raters rated fourteen activities. A heatmap and the Spearman rank-correlation method [9] were applied to the rating data to analyze the relationship between engagement and learning outcomes. The Spearman rank-correlation method is a nonparametric measure of association that evaluates whether two variables are monotonically related. In addition, a Mann-Whitney-Wilcoxon test [9] was used to assess the differences in the ratings of learning activities between undergraduate and graduate students, while a Fisher's exact test [9] was applied to evaluate the differences in the votes for learning environments between the two groups.

Each rating question was followed by an open-ended question to encourage participants to further share their thoughts. The response data to the open-ended questions were summarized and analyzed by thematic analysis [10]. After coding the responses and grouping the codes into categories, the themes were developed. The findings were generated by analyzing the themes. An additional effort was made to investigate the connections between the results of the qualitative and quantitative findings.

Results and Discussion

Quantitative Results and Discussion

Twenty-three participants rated fourteen learning activities, yielding 23 x 14 = 322 ratings for each response measure, i.e., engagement and learning outcomes. During data cleaning, four survey responses with non-integer values were rounded to the nearest whole number. One rating for the peer appreciation board was missing in the learning outcomes question and was replaced with a rating of 1.

Figure 1 presents the percentage distribution of ratings from 1 to 5 for the level of engagement across all fourteen learning activities. Figure 2 shows the corresponding distribution for learning outcomes. The mode, Q_1, median, and Q_3 of the ratings for the fourteen learning activities, for both engagement and learning outcomes, are summarized in Table 2.

The data summary shows that the mode and median are either 4 or 5 for all learning activities, which indicates that these learning activities were generally perceived as engaging and supportive of learning outcomes. However, the Q_1 suggests greater variation for certain activities. 25% of respondents rated the level of engagement as 3.5 or lower for the peer evaluation and 3 or lower for the peer appreciation board. For helpfulness regarding learning outcomes, 25% of respondents rated both of these two activities as 2 or lower. Additionally, the Q_1 of 3.5 for the classwork in terms of engagement and the Q_1 of 3 for the ice-breaker game in terms of learning outcomes also drew the attention of the author, who served as the course instructor.

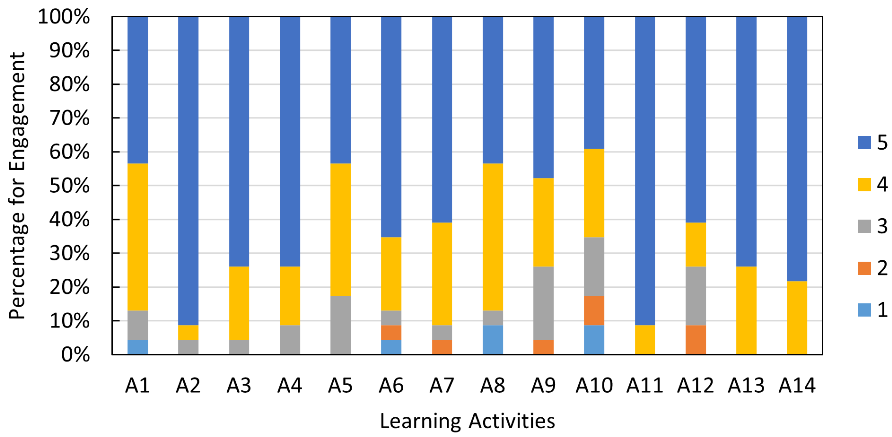

Figure 1: Rate the level of engagement each of the fourteen learning activities on a scale of 1–5: 1 = not engaging at all, 5 = very engaging.

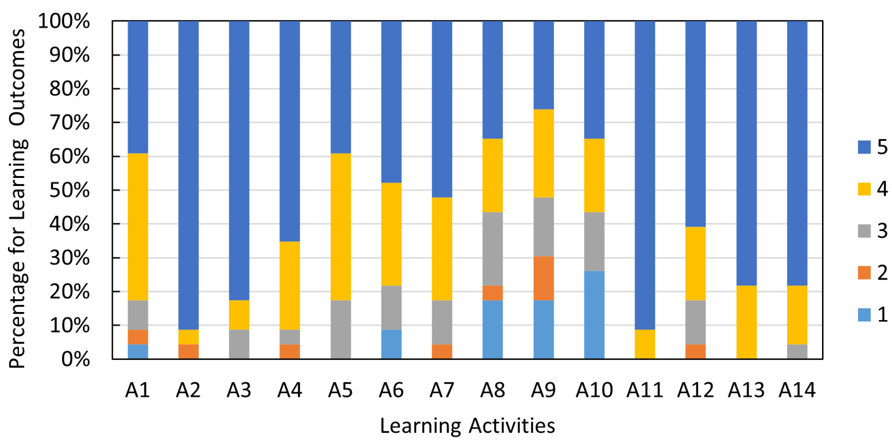

Figure 2: Rate how helpful each of the fourteen learning activities was for your learning outcomes on a scale of 1–5: 1 = not helpful at all, 5 = very helpful.

Table 2: Mode, Q_1, median, and Q_3 of the ratings for learning activities.

#	Activity	Engagement				Learning Outcomes			
		Mode	Q_1	Median	Q_3	Mode	Q_1	Median	Q_3
A1	In-class discussion with peers	4	4	4	5	4	4	4	5
A2	Discussion with instructor	5	5	5	5	5	5	5	5
A3	Team project	5	4.5	5	5	5	5	5	5
A4	Designing a research plan	5	4.5	5	5	5	4	5	5
A5	Peer presentations	5	4	4	5	4	4	4	5
A6	Competitive polling	5	4	5	5	5	4	4	5
A7	Study summary	5	4	5	5	5	4	5	5
A8	Ice-breaker game	4	4	4	5	5	3	4	5
A9	Peer evaluation	5	3.5	4	5	4	2	4	4.5
A10	Peer appreciation board	5	3	4	5	5	2	4	5
A11	Instructor-led lecture	5	5	5	5	5	5	5	5
A12	Classwork	5	3.5	5	5	5	4	5	5
A13	Homework	5	4.5	5	5	5	5	5	5
A14	Exam	5	5	5	5	5	5	5	5

Table 3: Ranks of learning activities for engagement and learning outcomes.

#	Activity	Engagement Friedman Rank Sum Test $\chi^2 = 55.6, df = 13, p = 3.2 \times 10^{-7}$		Learning Outcomes Friedman Rank Sum Test $\chi^2 = 94.7, df = 13, p = 1.7 \times 10^{-14}$	
		Mean Rank	Overall Rank	Mean Rank	Overall Rank
A1	In-class discussion with peers	9.04	13	8.87	11
A2	Discussion with instructor	5.63	2	5.26	2
A3	Team project	6.65	5	5.74	4
A4	Designing a research plan	6.72	6	6.70	6
A5	Peer presentations	8.65	11	8.24	10
A6	Competitive polling	7.43	8	8.15	9
A7	Study summary	7.30	7	7.57	8
A8	Ice-breaker game	8.63	10	10.07	12
A9	Peer evaluation	8.70	12	10.37	14
A10	Peer appreciation board	10.09	14	10.11	13
A11	Instructor-led lecture	5.46	1	5.09	1
A12	Classwork	8.04	9	7.35	7
A13	Homework	6.46	4	5.65	3
A14	Exam	6.20	3	5.85	5

To compare students' responses across the fourteen learning activities, their ratings were analyzed separately for the two response measures: engagement and learning outcome. A Friedman test was conducted for each measure, with the ranks reversed so that higher ratings corresponded to lower rank values (rank 1 = most preferred). The mean and overall ranks for each activity were calculated from the reversed Friedman ranks and are reported in Table 3. For both engagement and learning outcomes, the instructor-led lecture, discussion with instructor, exam, homework, and team projects ranked as the top five activities, while the peer presentation, ice-breaker game, in-class discussion with peers, peer evaluation, and peer appreciation board ranked as the bottom five. The activities of designing a research plan, study summary, classwork, and competitive polling fell in the middle range. For this student cohort, the traditional learning activities, such as instructor-led lecture, exam, and homework, were ranked as the top category. In contrast, the three strongly community-oriented activities, i.e., ice-breaker game, peer evaluation, and peer appreciation board, were perceived to contribute less to learning outcomes and were also rated relatively low in terms of engagement.

The ranks in Table 3 suggest a positive association between engagement and learning outcomes. A joint rating heatmap of engagement vs learning outcomes is shown in Figure 3. Most ratings lie close to the diagonal from the bottom-left to the top-right, which visually shows that the activities ranked highly for the level of engagement also tend to receive high ratings for the helpfulness to learning outcomes.

Figure 4 presents the Spearman rank-correlation coefficient r_s for the relationship between engagement and learning outcomes for each learning activity. Nine of the fourteen activities (64%) have r_s values greater than 0.5, which means a relatively strong positive association between the level of engagement and the helpfulness for learning outcomes. The remaining five activities (36%) have r_s between 0.3 and 0.5, which indicates a moderate positive association.

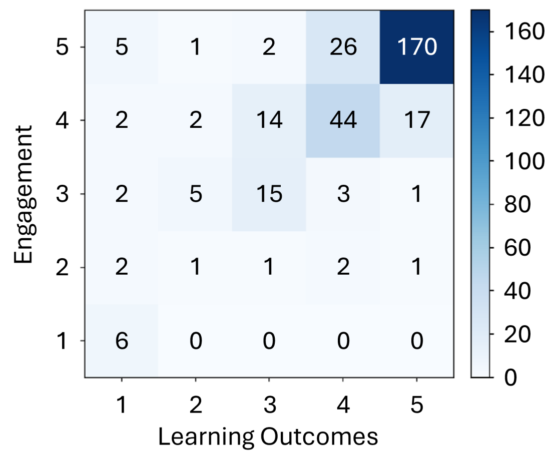

Figure 3: Jointing rating heatmap for engagement vs learning outcomes.

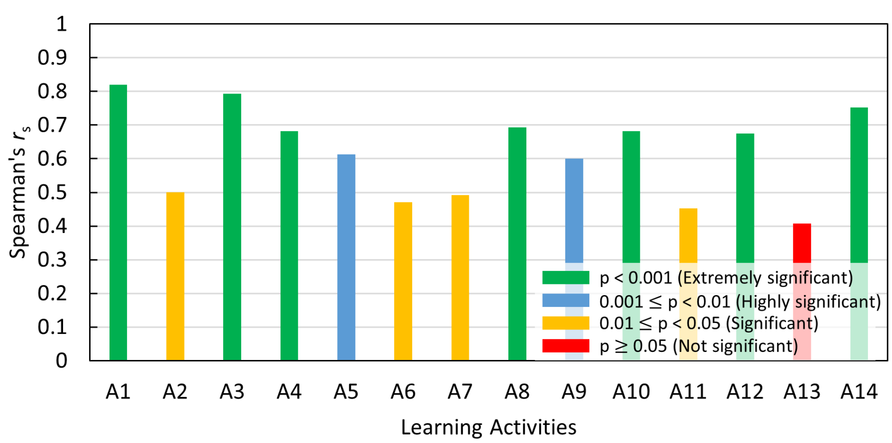

Figure 4: Spearman rank-correlation coefficient r_s regarding the relationship between engagement and learning outcomes across learning activities.

Meanwhile, the p-values for the thirteen of the fourteen activities (93%) are less than 0.05 (see Figure 4). We also applied the Spearman correlation method to the entire set of engagement ratings and the entire set of learning outcomes ratings and found the results of r_s = 0.69 and p-value = 9.6 x 10^{-48}. Therefore, we conclude that Spearman rank-correlation test revealed a statistically significant positive association between the level of engagement and the learning outcomes.

This joint Refrigeration and Cryogenics class consists of undergraduate and graduate students. The medians of the rating data for each learning activity are presented in Figures 5 and 6 to compare the responses between these two student groups. Figure 5 shows that the two groups have the same median ratings for eleven of the fourteen activities (79%) in terms of the level of engagement. Similarly, Figure 6 shows that the groups share the same median ratings for ten of the fourteen activities (71%) in terms of the helpfulness to learning outcomes. Overall,

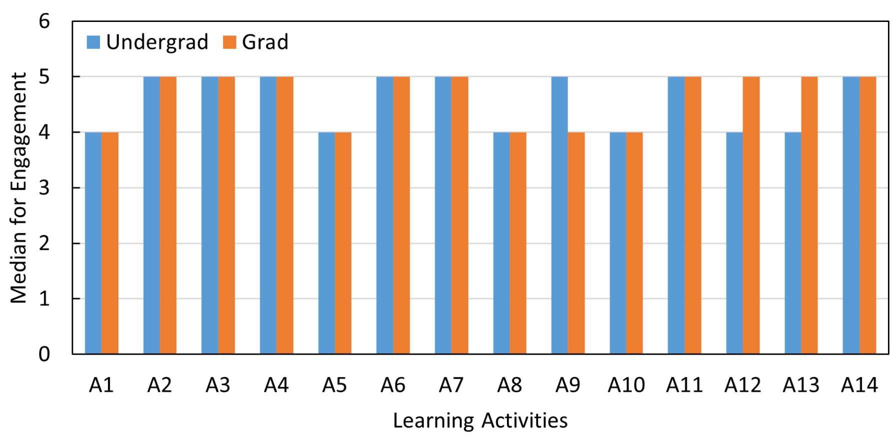

Figure 5: Comparison of the medians of engagement ratings for learning activities between undergraduate and graduate students.

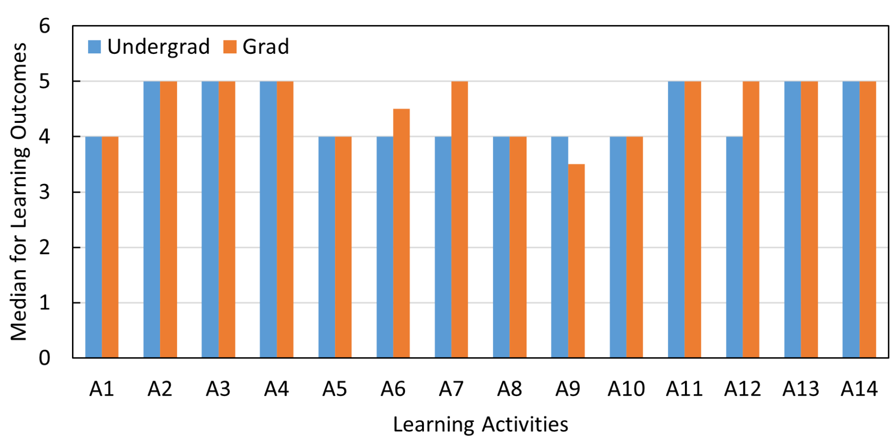

Figure 6: Comparison of the medians of learning outcomes ratings for learning activities between undergraduate and graduate students.

Table 4: Frequency of students reporting the environments as motivating (percentage in parentheses).

Environments	All Students ($n = 23$)	Undergraduate ($n = 7$)	Graduate ($n = 16$)	Fisher's Test p-value
Collaborative and interactive	18 (78%)	4 (57%)	14 (88%)	0.142
Structured and guided	17 (74%)	6 (86%)	11 (69%)	0.621
Flexible and self-directed	5 (22%)	1 (14%)	4 (25%)	1.000
Hands-on and practical	14 (61%)	5 (71%)	9 (56%)	0.657
Creative and exploratory	13 (57%)	4 (57%)	9 (56%)	1.000
Discussion-based and reflective	9 (39%)	1 (14%)	8 (50%)	0.176
Fast-paced and challenging	5 (22%)	2 (29%)	3 (19%)	0.621
Supportive and feedback-rich	9 (39%)	2 (29%)	7 (44%)	0.657

undergraduate and graduate students rated these learning activities similarly. Slight differences are observed in a few activities: undergraduates rated the peer evaluation as more engaging than graduate students, whereas graduates gave higher engagement ratings for classwork and homework; regarding learning outcomes, undergraduates again rated the peer evaluation higher, while graduate students rated the competitive polling, study summaries, and classwork higher. However, Mann-Whitney-Wilcoxon tests revealed that most of these differences were not statistically significant (p-values > 0.05), except for the engagement rating for homework, which differed significantly between the two groups (p-value $= 0.032$).

In addition, Table 4 presents the voting results for learning environments that students find motivating. Students were asked to select all the options that apply. The collaborative and interactive environment received the most votes, and the proportion of graduate students voting for it is greater than that of undergraduate students. The second most popular choice is the structured and guided environment, which was preferred more by undergraduate students than by graduate students. The flexible and self-directed environment and the fast-paced and challenging environment received the fewest votes from this student cohort.

We used proportion tests to compare the percentages of undergraduate and graduate students for each environment. Because many cell counts were low, Fisher's exact test was applied, which calculates exact probabilities and provides a reliable p-value regardless of sample size. The results show that all p-values were greater than 0.05 (see Table 4), indicating no significant differences between graduate and undergraduate students for any of the environments.

Qualitative Results and Discussion

Students' responses to the open-ended questions referenced a wide rage of learning activities. However, many students identified the team project and competitive polling as the most engaging activities, while the team project and instructor-led lecture were most frequently cited as the most helpful for learning outcomes. Tables 5 and 6 present a summary of the thematic analysis for the responses to the open-ended questions regarding engagement and learning outcomes, respectively. Our findings are as follows.

1. Collaboration effectively promotes student engagement and perceived learning outcomes. Collaboration was most frequently mentioned when students identified the team project as

Table 5: Themes, descriptions, and example quotes for engagement.

Theme	Description	Example Quote
Project-Based and Collaborative Learning	Students felt most engaged when working on mini team projects that required collaboration, shared responsibility, and application of knowledge.	• "The mini-projects made me engage the most with my peers through collaboration and contribution." • "Collaborating as a team, participating in meetings, … contributed to solving complex problems." • "it teaches us how to use industrial-level knowledge and programming to simulate an actual cycle." • "I think the projects, because they were group projects, felt less pressure, which helped to work collaboratively and having a source to ask questions to helped as well."
Active Learning and Peer Interaction	Engagement increased when students actively participated through discussions, presentations, and exchanging ideas with peers.	• "I really did like the lecture with the in-class discussion because it allowed me to learn from my peers and understand their train of thought." • "I felt most engaged with the two mini projects in which we had to make presentations to share with the class."
Gamification Enhances Motivation	Kahoot, quizzes, and competitive polling created a fun, motivating environment that encouraged attention and participation.	• "The kahoot games and general quizzes incentivized a fun learning environment." • "Competitive polling w/ the Kahoots. Good for people who like to have some friendly competitiveness."
Value of Clear, Structured Lectures	Traditional lectures in which explanations are clear and detailed.	• "I found the lectures given by the professor to be the most interesting, given the level of explanation and detail, it was easier to follow the new topics."
Sense of Belonging and Learning Community	Activities that supported social connection helped students feel comfortable and engaged.	• "The Ice-breaker game… made me feel more comfortable with my classmates."

both the engaging activity and the one that most supported their learning outcomes. Collaboration involved in the learning activities not only provided the opportunity to learn from their peers' perspectives but also promoted deeper individual thinking. Meanwhile, collaboration reduced pressure during the activity and encouraged greater participation.

2. Active learning is a significant contributor to student engagement and learning outcomes. Students' comments indicate that the active learning activities, e.g., in-class discussion with peers, competitive polling, team-project, peer presentation, etc., effectively encouraged participation in the learning process. The participation shows as rewording, thinking, researching, communicating, discussing, imitating, presenting, and reflecting through various learning activities. These interactions between learners and their environment are the essence of the study process stated by the constructivism theory [3] from the perspective of psychology and were also recognized by students.

3. Traditional learning activities are still valued by students for both engagement and learning outcomes. The instructor-led lecture was frequently highlighted in students' responses. Lectures that provided sufficient explanation and details were perceived as easy to follow and effective to engage students. Meanwhile, clarity, a well-designed structure, and a focus on core concepts were emphasized as important factors in improving students' perceived learning outcomes.

Additionally, the gamification, e.g., competitive polling, benefited engagement. However, competition involved in the gamification may not always improve the particiation motivation [11].

Table 6: Themes, descriptions, and example quotes for learning outcomes.

Theme	Description	Example Quote
Mini-Projects Support Deep and Applied Learning	Students viewed mini team projects as the most helpful activity because they required application of theory, repeated practice, problem-solving, and deeper conceptual understanding.	• "The mini projects helped me to learn the material the best… simulating thermodynamic cycles… is very helpful for learning." • "Mini projects. I had to think to solve it." • "The mini projects were the most helpful to understand and apply the concepts."
Lectures Provide Essential Conceptual Foundations	Instructor-led lectures were perceived as effective due to clarity, structure, and focus on core concepts.	• "The lectures are well planned and well explained." • "Lectures … helped me learn a lot." • "The lectures… didn't include unnecessary information, just the core central concepts."
Integration of Lectures and Projects Strengthens Learning	Students explicitly emphasized that learning was strongest when lectures and projects complemented one another.	• "The best way to learn is through doing the Mini project and listening to lectures." • "Mini projects were great for further expanding on lecture."
Collaborative Learning Enhances Understanding and Confidence	Group-based activities helped students learn from peers, reduced pressure, and strengthened problem-solving.	• "Collaborating with peers on mini-projects improved my teamwork, problem-solving…" • "Other people can see things you don't at first." • "Group projects felt less pressure… having a source to ask questions helped."
Active Learning and Cognitive Engagement Promote Deeper Understanding	Students valued activities that required thinking, discussion, explanation, and synthesis, describing these as both engaging and effective for learning.	• "It made me think very critically and share ideas…" • "Mini projects. I had to think to solve it." • "Explaining in words how it works is very helpful for learning." • "…Mini projects which makes us research and present our findings on our own." • "Peer presentation. It gave me a chance to study deep on the topic I was charged with."

An effort needs to be made to create a healthy, friendly competitive environment. The sense of belonging is a foundation for engagement. The ice-breaker game was highlighted to build the learning community. Through many collaborative activities, students saw the change from nobody talking at the beginning of the semester to everyone saying goodbye and commenting on the course at the end. The learning community promoted student engagement and supported learning outcomes.

The comparison shows that the qualitative and quantitative results are not perfectly aligned; however, they are generally in agreement. For example, the qualitative analysis indicates that the team project was most frequently mentioned by students as the activity that both engaged them the most and contributed most to their learning outcomes. In contrast, the quantitative analysis ranks the team project fifth for engagement and fourth for learning outcomes. Although it is not ranked first, it still falls within the top five activities. The agreement is also evident in the findings related to the instructor-led lecture: both qualitative and quantitative analyses demonstrate students' recognition of this activity, particularly with respect to learning outcomes. In addition, both sets of results clearly show that students preferred the collaborative and interactive environment and benefited from it in terms of both engagement and learning outcomes.

Efforts were made to examine the qualitative data to understand why community-oriented activities, such as the ice-breaker game, the peer evaluation, and the peer appreciation board, were rated relatively lower by this student cohort. However, no significant evidence of weaknesses or shortcomings in these activities was identified in the students' responses. The student demographics, e.g., a predominantly male population and mostly international graduate students, may be part of the reason. Further research is needed to explore this possibility and gather supporting evidence.

Limitations

Two limitations of this study merit careful consideration.

- This research was implemented in a mechanical engineering class based on the author's teaching assignment. The survey participants are the volunteers from this class. There is no control of the participants. The demographic data in Table 1 shows all the undergraduate participants are domestic students, while most of the graduate students are international students. Additionally, 87% of participants are male students. These demographics may affect the generality of the conclusions.
- All the data collected through surveys are subjective data, which are the perceptions of respondents, rather than objective measurements. This is a common limitation in the research on student-centered learning [12]. Objective measurements and data are expected in future research.

Conclusion

Based on student-centered philosophy, the lesson plan for the Refrigeration and Cryogenics course was redesigned, characterized by fourteen learning activities, to enhance student engagement and to accommodate diverse levels of preparation and needs, with the expectation of improving learning outcomes. The redesigned lesson plan was implemented in a joint undergraduate-graduate mechanical engineering class. A survey was administered to collect students' feedback on the learning activities. The quantitative and qualitative analyses of the survey data indicate:

- Although all fourteen learning activities were generally perceived as engaging and supportive of learning outcomes, the team project is outstanding due to its significant collaborative and interactive characteristics. Note that the team projects implemented in this course were all mini projects, each designed with a manageable workload that could be completed within one week.
- Collaborative and interactive learning environment was recognized as the most motivating by the students in this joint undergraduate-graduate mechanical engineering class. Collaboration and participation are the two significant contributors to engagement and learning outcomes.
- Traditional learning activities, such as instructor-led lecture, classwork, homework, and exam, are still valued by students for both engagement and learning outcomes. Students prefer lectures that provide sufficient explanation and details, making them easy to follow. For lectures, instructors should focus on clarity, a well-designed structure, and a clear emphasis on core concepts.

- There is a strong positive association between engagement and perceived learning outcomes.
- No significant differences were observed between the feedback of undergraduate and graduate students.

In addition, the authors plan to continue implementing and evaluating these fourteen learning activities in future teaching practice, with increased attention on community-oriented activities. Ultimately, this study will help the authors optimize the course lesson plan.

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