Assessing Best Practices of a Multidisciplinary Experiential Learning Engineering Course

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ABSTRACT

This complete paper describes the implementation and evaluation of a two-term lower-division engineering course, which provides a team-based experiential learning approach to all engineering majors. The course focuses on the design-build-test of a remote controlled (RC) and an autonomous system respectively across the two terms while integrating the engineering design process. The project is designed to engage multiple engineering majors by focusing on the engineering design process and introducing each engineering discipline to the students. Technical topics directly related to the project across different fields are instructed during lecture. By working in teams with others from different majors, students also acquire engineering skills in CAD, basic machining, advanced manufacturing (3D printing and laser cutting), electrical fabrication, and microprocessor programming during lab sessions. A specific task was assigned for the RC and autonomous system respectively with students participating in a final competition at the end of each term. In addition, the course provided multi-faceted instructions on project management and teamwork, professional development, and entrepreneurship training, along with opportunities to interact with industry speakers from different engineering disciplines.

The course modality and implementation have been adapted throughout the pandemic from remote learning, hybrid learning, and in-person learning, seeking the best practices of instruction. The effectiveness of the course based on various course features, student outcomes and student motivation were evaluated through self-assessed surveys at the beginning, middle and end of the two-term class. Survey results were compared across multiple years during the pandemic to assess the impact of the course on retaining student motivation. Furthermore, results were compared with pre-pandemic data and highlighted that experiential learning had a greater impact in retaining student motivation during and post-pandemic.

Introduction

Engineering programs in higher education are designed to allow students to gain analytical and technical skills needed for their further education and career, however, many lower-division programs exclude hands-on projects, and are solely based on basic sciences courses such as math and physics. Within the first and second years of engineering curricula, many programs report a higher attrition rate [1-2] and a drop due to a variety of factors including difficulties understanding concepts, classroom climate, and a lack of interest [1-3]. Experiential learning courses offered during the lower-division years of an engineering program is one proposed solution to increase retention.

Experiential learning has demonstrated many proposed benefits such as increasing student motivation, allowing students to gain fundamental technical skills, and improving students' teammate and collaborative skills [4-7]. Furthermore, such courses have been reported to improve academic performance in subsequent engineering courses [8]. By implementing multidisciplinary design projects, further benefits can be seen, such as allowing students to gain a wide breadth of experiences and work with peers from different engineering disciplines which is important for first- and second-year students who are still searching for their future career path [9-10].

We implemented a two-term lower-division multidisciplinary experiential learning course at a large public university including projects such as rovers, quadcopters, fitness trackers and microfluidic devices. Students spent the first term (Fall) working in teams to understand the engineering design process and to develop basic skills in computer-aided design (CAD), manufacturing and electronics in order to apply the learned skills to a radio-controlled device. In the second term (Winter), students expanded their knowledge by integrating advanced manufacturing such as 3D printing and laser cutting into their designs, and learned how to program a microcontroller to autonomously complete a task. In addition, each engineering major was introduced in the course to provide a basic understanding of various engineering disciplines. Instructions on project management and teamwork, professional development, and entrepreneurship training were also integrated in the course along with invited lectures from industry speakers. There were no prerequisites to the course, and therefore often this course was many students' first exposure to engineering. This was an elective lower-division course offered to all engineering majors, where upon the completion of the course, students would receive an elective credit toward graduation.

Due to over enrollment, the program was designed to be offered in a hybrid format since the Fall quarter of 2016. Prior to the pandemic, the in-person teaching model had students attend a one-hour per week lecture in the traditional format in a lecture hall, while the online model allowed students to watch the lecture through video recordings in segments. Both classes feature a two-hour in-person lab session per week where students meet with their teams and work on their project. Additionally, the course offered learning communities on a social media platform using Facebook which had allowed students to interact with peers and the instruction team to post inquiries regarding the course. Prior research has been conducted on course modality and minimal difference was found between the fully in-person and hybrid mode [11-12].

The Covid-19 pandemic brought unique challenges to learning for engineering students. Many reported difficulties, for example, transitioning to remote learning, a decrease in motivation, and a shift in learning behaviors to be successful among other challenges faced [13-17]. Both educators and students reported that these effects were still prevalent post-pandemic [18-20]. This shift in student learning has prompted unprecedented challenges and required educators to be adaptive and innovative in maintaining the education experiences for students.

For our course, though the integration of online asynchronous learning prior to the pandemic eased the transition to remote synchronous learning [21], the course still faced many other challenges for practical implementation, such as how to train students with necessary fabrication skills remotely, how could students work in teams on a hands-on project remotely, etc. Starting with the 2020-2021 academic year, the course format underwent necessary modifications to accommodate the campus lock-down and social distancing requirements. The course project changed from a quadcopter to a rover for safety reasons. Training kits were assembled and sent to all students. Students were grouped into teams based on proximity. Lectures became fully remote, and labs were offered to be hybrid where some students who were living on-campus or local participated in hands-on learning opportunities, and other students who were remote or oversea, were mailed parts kits. This allowed for students to still gain hands-on skills and interact with their peers during the pandemic, even remotely. When the university resumed hybrid learning during the 2021-2022 academic year, the course utilized a mixed teaching modality for both lecture and labs depending on the surge of Covid-19 cases. In the 2022-2023 academic year, in-person lectures were re-introduced. Since Fall of 2020, all students in the course have had access to lecture recordings as an adjustment during the pandemic to provide students with all possible education resources.

Table 1 displays the student enrollment information from the 2019-2020 to 2022-2023 academic year according to majors and grade levels. The course is mainly open to lower-division engineering students with a few upper-division students enrolled with exceptional approval.

	2019 - 2020		2020 - 2021		2021 - 2022		2022 - 2023	
	Fall Term	Winter Term	Fall Term	Winter Term	Fall Term	Winter Term	Fall Term	Winter Term
Major								
Aerospace Engineering	40	32	36	30	36	37	42	41
Biomedical Engineering	31	23	12	8	12	6	38	33
Biomedical Engineering (Premed)	16	5	6	8	6	6	21	15
Chemical Engineering	9	7	4	4	10	9	8	5
Civil Engineering	34	30	21	21	41	43	56	55
Computer Engineering	27	20	20	12	37	31	37	32
Computer Science and Engineering	13	6	10	4	7	2	8	8
Electrical Engineering	12	11	7	7	23	18	27	23
Environmental Engineering	10	11	13	12	8	8	20	16
Material Science and Engineering	6	3	7	6	10	5	18	17
Mechanical Engineering	93	83	46	45	65	61	57	56
Undeclared Engineering	15	6	9	5	14	11	5	3
Non-Engineering Major	14	7	6	1	10	8	7	5
Status								
Freshman	214	91	126	59	201	104	231	116
Sophomore	88	130	65	93	67	120	96	152
Junior	9	14	4	9	9	16	13	32
Senior	9	9	2	2	2	5	4	9

Table 1. Student majors and grade levels from 2019-2020 to 2022-2023.

Survey data was collected from students enrolled in the course ranging from the 2019-2020 academic year to the 2022-2023 academic year. The survey was administered to obtain the student's self-rated engineering skills and abilities as part of their learning outcomes, including their ability to design and fabricate a device, use computer-aided design software, implement the design process, use a Gantt chart for project management and complete an interdisciplinary project. During the second term, the ability to program a microcontroller was added as a learning outcome due to the autonomous nature of the project.

In addition, students were asked to evaluate the effectiveness of the provided course resources, and their self-perceived ratings on their motivation.

The survey data provided important insights into the students' shifting perspectives regarding learning during the pandemic and in a post-pandemic environment in a lower-division experiential learning course. To better understand and assess the data from the student surveys, the following research questions were developed:

1) Did student motivation change during or after the pandemic when compared to pre-pandemic?
2) Did student-perceived ability to achieve learning outcomes of engineering skills change during the pandemic in comparison to the pre-pandemic students?
3) Did students' preferred course resources and teaching modality change in comparison to pre-pandemic students?

Methodology

A survey was administered to the students at the beginning of the first term, at the end of the first term, and at the end of the second term. The student enrollment and number of survey responses are tabulated below for each of the four years, as shown in Table 2.

	T1			T2			T3		
Academic Year	Responses	Enrollment	Percentage	Responses	Enrollment	Percentage	Responses	Enrollment	Percentage
2019-2020	300	320	300/320 (93.75%)	248	320	248/320 (77.5%)	174	244	174/244 (71.3%)
2020-2021	186	194	186/194 (95.88%)	163	194	163/194 (84.0%)	140	163	140/163 (85.9%)
2021-2022	234	279	234/279 (83.87%)	232	279	232/279 (83.2%)	166	245	166/245 (67.8%)
2022-2023	332	344	332/344 (96.51%)	300	344	300/344 (87.2%)	245	309	245/309 (79.3%)

Table 2. Course Enrollment and Survey Response Rate

T1 marked the responses from the pre-survey at the beginning of the first term, T2 marked the responses from the post-survey at the end of the first term, and T3 marked the responses from post-survey at the end of the second term. The following statements were used to assess student motivation at T1-T3. Students' responses were recorded on a scale from 1 to 5, where 1 is “does not describe me”, 2 is “describes me slightly well”, 3 is “describes me moderately well”, 4 is “describes me very well”, and 5 is “describes me extremely well”. The questions differed at the Fall pre-survey (T1) where the language was in future tense, while in the two post-surveys the language was in past tense.

- I will be/was able to master the skills taught in this course
- I will be able to/was certain I could figure out how to learn even the most difficult course material
- I will be able to/could do almost all the work in this class if I didn't give up

Students in the course were expected to develop a variety of engineering skills such as learning to use computer-aided design (CAD), design and fabrication, applying design process, etc. When analyzing the students’ perceived ability to achieve learning outcomes of engineering skills, we asked the students to rate their ability for the following skills on a scale of 1 to 5, where 1 is "very unconfident", 2 is “unconfident”, 3 is "somewhat confident", 4 is “confident” and 5 is "very confident", at T1, T2 and T3 respectively.

- Ability to design and fabricate a device
- Ability to use CAD (SolidWorks)
- Ability to implement the design process
- Ability to program microcontrollers (second term only)
- Understanding of Gantt chart and time management

- Ability to complete an interdisciplinary project

Students' perspectives on the importance of different course resources and features to their learning were assessed on a scale of 1 to 5, where 1 is "very unimportant to my learning", 2 is "unimportant to my learning", 3 is "somewhat important to my learning", 4 is "important to my learning", and 5 is "very important to my learning". The following course features were listed in the survey.

When thinking about the course, how important were the following features to your learning?

- Lecture
- Lecture PDF slides
- Homework assignments
- Office hours
- Lab sessions
- Online learning communities (a forum hosted on Facebook or Discord created to allow students to post questions and receive assistance from instructors and fellow students)

In addition, we assessed student attendance across the years by asking the following question.

- What percentage of the lectures did you attend for this course?

Students chose among the following answers for the above-mentioned question:

- Less than 40% of the lecture, scored as 1.
- Between 40-59% of the lecture, scored as 2.
- Between 60-79% of the lecture, scored as 3.
- Between 80-99% of the lecture, scored as 4.
- 100% of the lecture, scored as 5.

The statistical analysis measured the difference between the student experiences across and within the academic years through the Student's *t*-test for evaluation.

Results and Analysis

We refer to the student groups in the four separate academic years as the following.

- 2019-2020 academic year: the 2019 cohort
- 2020-2021 academic year: the 2020 cohort
- 2021-2022 academic year: the 2021 cohort
- 2022-2023 academic year: the 2022 cohort

Research question 1: Students' motivation change across the pandemic

Figure 1 compares the student ratings on their perception of the following,

a) whether they were able to master the skills taught in the course.
b) whether they could figure out how to learn the most difficult course material.
c) whether they could do almost all the work in the class if they didn't give up.

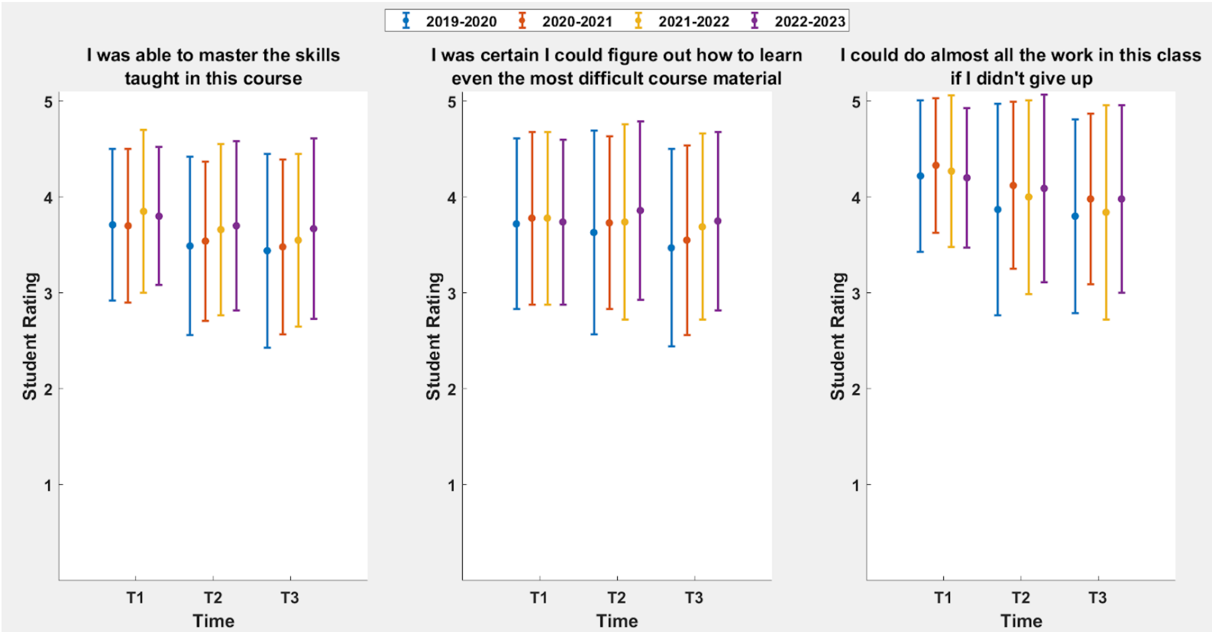

Figure 1. Comparison of student motivation questions for the four pre-, during and post-pandemic cohorts, 2019 – 2022, on (a) whether they were able to master the skills taught in the course, (b) whether they could figure out how to learn the most difficult course material, and (c) whether they could do almost all the work in the class if they didn't give up.

During 2019, the pre-pandemic cohort had a significant decrease ($p<0.05$) consistently in all three questions at the end of second term (T3), in comparison to the beginning of the course (T1). In subsequent years, the 2020, 2021 and 2022 cohort exhibited a similar trend of a significant decrease within the same academic year for these three statements, except for (b). The 2021 and the 2022 cohort maintained the student motivation to figure out how to learn the most difficult course materials. On the contrary, the 2022 cohort even exhibited an increase in the mean for (b) at T2, which is the end of the first term. The course was able to foster a greater sense of self-efficacy for students post-pandemic.

Moreover, across the years, students in subsequent years (during and post-pandemic) exhibited higher motivation levels in comparison to the 2019 pre-pandemic cohort at T1, T2, and T3 respectively. Table 3 lists comparisons across the years including means, standard deviations, sample sizes and p-values. Using 2019 pre-pandemic cohort as a baseline for comparison, at the end of the first term T2, the 2020 cohort had a significantly higher mean than the 2019 cohort for (c); the 2021 cohort had a significantly higher mean than the 2019 cohort for (a), and the 2022 cohort had a significantly higher mean than 2019 cohort for (a), (b) and (c), with $p<0.05$.

At the end of the second term, T3, the 2021 cohort had a significant increase for (b), and the 2022 cohort had a significant increase for (a) and (b) in comparison to the 2019 cohort, with $p<0.05$. As shown in Table 3, although the remaining data might not have displayed a significant increase at T2 and T3 across the subsequent cohorts during and post-pandemic, the means had shown increased numerical values in comparison to the 2019 data. An experiential learning course may have become more effective in motivating students in comparison to pre-pandemic era to since the pandemic has reshaped the students' patterns of social interactions, and this course has fostered interactions through teamwork [19].

Time	2019 Mean ± S.D., N	2020 Mean ± S.D., N	p-value (Compared to 2019)	2021 Mean ± S.D., N	p-value (Compared to 2019)	2022 Mean ± S.D., N	p-value (Compared to 2019)
(a) I was able to master the skills taught in this course							
T1	3.71 ± 0.79, 320	3.70 ± 0.80, 197	0.902	3.85 ± 0.85, 251	**0.046**	3.80 ± 0.72, 358	0.142
T2	3.49 ± 0.93, 248	3.54 ± 0.83, 163	0.587	3.66 ± 0.89, 232	**0.040**	3.70 ± 0.88, 300	**0.007**
T3	3.44 ± 1.01, 174	3.48 ± 0.91, 140	0.781	3.55 ± 0.90, 166	0.309	3.67 ± 0.94, 245	**0.024**
(b) I was certain I could figure out how to learn even the most difficult course material							
T1	3.72 ± 0.89, 320	3.78 ± 0.90, 197	0.462	3.78 ± 0.90, 251	0.404	3.74 ± 0.86, 358	0.826
T2	3.63 ± 1.06, 248	3.73 ± 0.90, 163	0.282	3.74 ± 1.02, 232	0.238	3.86 ± 0.93, 300	**0.007**
T3	3.47 ± 1.03, 174	3.55 ± 0.99, 140	0.492	3.69 ± 0.97, 166	**0.042**	3.75 ± 0.93, 245	**0.005**
(c) I could do almost all the work in this class if I didn't give up							
T1	4.22 ± 0.79, 320	4.33 ± 0.70, 197	0.106	4.27 ± 0.79, 251	0.499	4.20 ± 0.73, 358	0.724
T2	3.87 ± 1.10, 248	4.12 ± 0.87, 163	**0.013**	4.00 ± 1.01, 232	0.168	4.09 ± 0.98, 300	**0.014**
T3	3.80 ± 1.01, 174	3.98 ± 0.89, 140	0.109	3.84 ± 1.12, 166	**0.014**	3.98 ± 0.98, 245	0.079

Table 3. Comparison of the student motivation across the years using the 2019 pre-pandemic cohort as the baseline. Mean and standard deviation are calculated. N represents sample size. The bolded values indicate $p<0.05$.

Research question 2. Student learning outcomes of engineering skills across the pandemic

During the remote learning implementation in 2020 and 2021, the instruction team assessed the students to evaluate whether the learning outcomes of engineering skills were compromised due to the adaptation of course format and contents. Figure 2 illustrated six expected student learning outcomes including the ability to design and fabricate a device, ability to use CAD, ability to implement design process, ability to program a microcontroller, understanding of Gantt chart and time management, and ability to work on an interdisciplinary project. Survey data was taken at the beginning of the course (T1), the end of the first term (T2), and the end of the second term (T3). Data for the ability to program a microcontroller at T2 was not collected as programming had only been taught during the second term.

Within each year, students increased every skill significantly at T2 and T3 in comparison to T1. It is noted that 2020 to 2021 cohort (during the pandemic) had a significantly higher mean of the ability to use CAD in comparison to the 2019 cohort, $p < 0.05$, at T2 and T3 respectively, possibly due the extensive use of computers during the pandemic (some students could only perform CAD tasks due to remote learning). We also observed a decrease in the students' ability in fabrication in comparison to 2019, possibly as an after-effect of the remote learning adoption in high schools, especially for the 2022 cohort where $p < 0.05$, at both T1 and T3 respectively. This may be due to the lack of hands-on activities in high schools during the pandemic, and therefore the post-pandemic students were less prepared in hands-on skills in comparison to pre-pandemic students.

For the remaining learning outcomes, no substantial differences in student ratings were found at T2 and T3 respectively across the years. Overall, the course was able to provide a similar educational experience for the students in terms of learning outcomes throughout the pandemic in comparison to the pre-pandemic era, despite the adaptation of a new project and course format changes implemented during the pandemic.

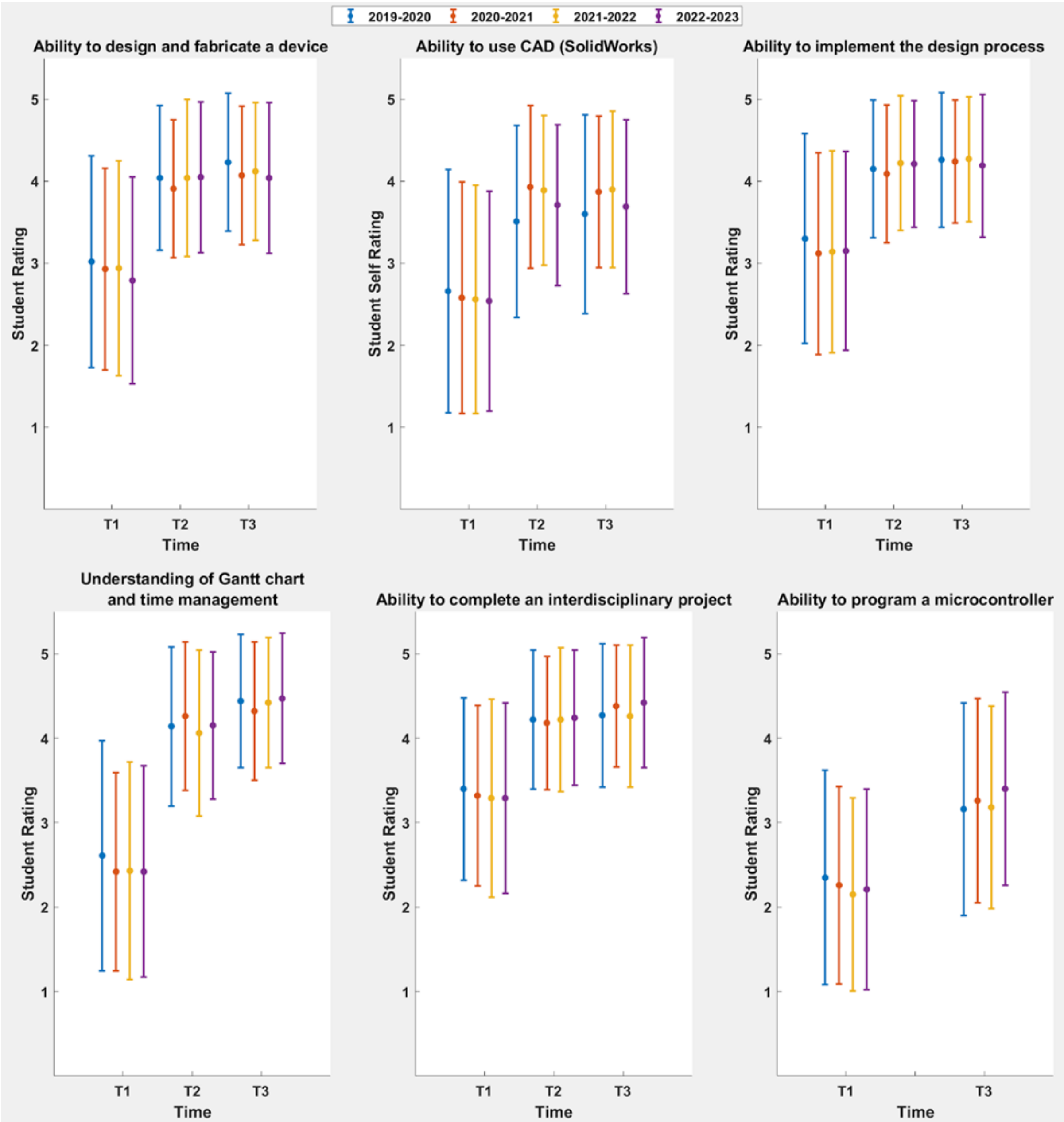

Figure 2. Comparison of student perceived learning outcomes of engineering skills across the four pre-, during and post-pandemic cohorts, 2019 – 2022.

Research question 3, Preferred course resources and features across the pandemic

The importance of course resources were assessed among each cohort of students at the end of each term (T2 and T3) respectively. No substantial differences were observed for lecture files and the use of office hours comparing the pandemic and post-pandemic cohorts with the 2019 pre-pandemic cohort as a baseline.

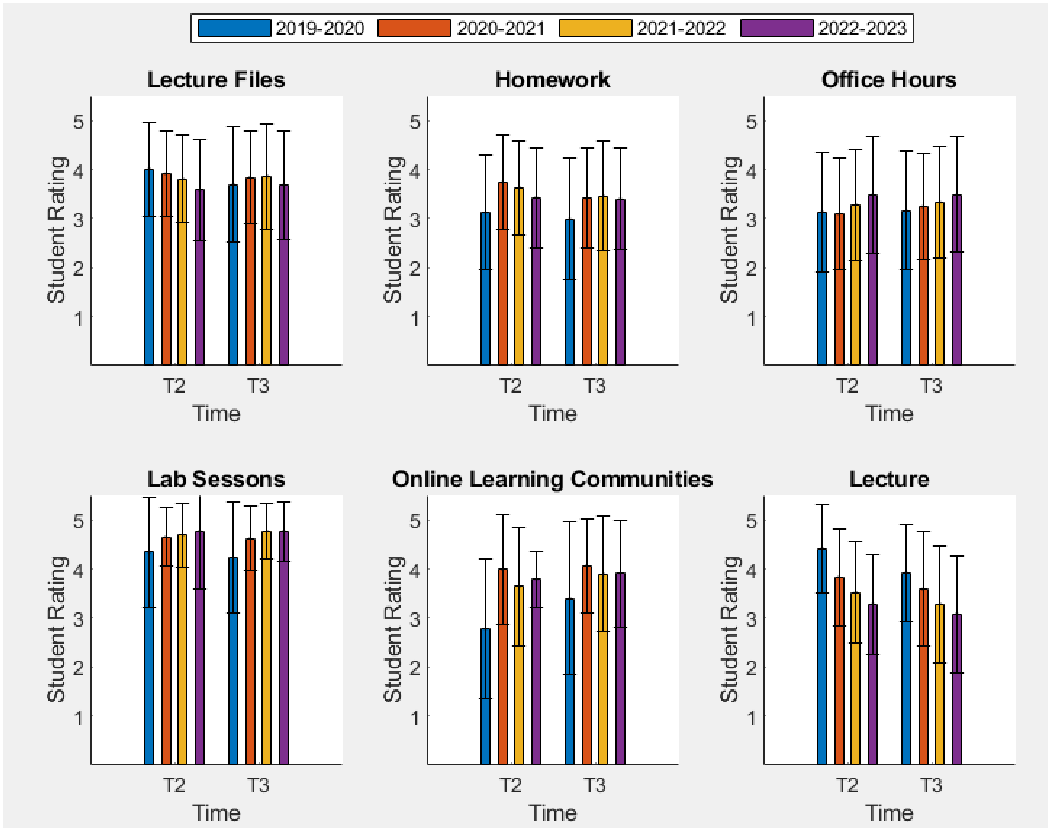

Figure 3. Comparison of course resources and features that are important to students across the four pre-, during and post-pandemic cohorts, 2019 – 2022.

However, homework assignments, lab sessions, the use of online communities and lectures all had a significant difference in preference, $p<0.05$. Students found the homework to be more relevant in assisting their learning during the pandemic, and also rated hands-on learning during lab sessions as a more important resource in comparison to the 2019 cohort.

Since the implementation of the course, we have used an online community platform for student engagement due the large size of the class. In 2020, we changed the online community platform from Facebook to Discord. The prior social media platform seemed to be less popular among the current college students. The Discord platform was substantially more used by students to seek help from each other and from the instruction team during and post pandemic in comparison to the Facebook platform used in 2019, ($p<0.001$). However, there was a decrease in using the online platform in 2021 and 2022 as the teaching mode had gradually transitioned back to in-person learning. Surprisingly, students from 2020-2022 consistently rated lectures to be much less effective in comparison to other resources, at T2 and T3 respectively, in comparison to the 2019 cohort ($p<0.01$).

This observation aligns with lecture attendance that was surveyed across the years as shown in Table 4. Students attended lectures much less frequently from 2020 to 2022. The lecture attendance was the lowest for the 2022 cohort although the lectures were changed back to in-person teaching. The 2019 pre-pandemic course lecture used a traditional instruction mode that students did not have access to lecture recordings unless they were enrolled in an online section. Starting in 2020, the lecture recordings over Zoom were provided to all students as an additional education resource under remote learning. This change may have explained the decrease in lecture attendance. We conclude that for such a project-based learning course, traditional in-person lecture may not be the most suitable teaching modality. During the post-pandemic era, students may prefer a combination of remote learning with lecture recordings for a course which may be more lab based.

	Lecture Attendance, Mean ± S.D.			
Survey Time	**2019 - 2020**	**2020 - 2021**	**2021 - 2022**	**2022 - 2023**
T2 (end of first term)	4.42 ± 0.90	3.84 ± 1.22	3.58 ± 1.38	3.10 ± 1.43
T3 (end of second term)	4.31 ± 1.21	3.59 ± 1.32	3.22 ± 1.55	2.92 ± 1.46

Table 4. The percentage of lecture attendance surveyed across the years on a scale from 1-5. 1 is attending less than 40% of the lecture. 2 is attending between 40-59% of the lectures. 3 is attending between 60-79% of the lecture. 4 is attending between 80-99% of the lecture. 5 is attending 100% of the lecture.

Conclusion

This paper reports on a multidisciplinary lower-division experiential learning course offered to all engineering majors for elective units. Due to the Covid-19 pandemic, the course adapted to remote learning, hybrid learning and back to in-person learning from the 2020-2021 to 2022-2023 academic year. Certain course features were adapted correspondingly such as implementing a new project, the use of a new social media community platform, training students remotely on skills through pre-assembled training kits, etc. Student motivation, the development of engineering skills as student learning outcomes, and the importance of course features and resources were assessed across the pre-, during and post-pandemic years (2019-2022). The survey results were compared within each academic year. In addition, the 2019-2020 pre-pandemic academic year was used as a baseline for comparison across the pandemic to evaluate changes in student learning.

First, student motivation exhibited an increase during and post-pandemic in comparison to the pre-pandemic cohort at the end of each term. Next, student learning outcomes of developing engineering skills increased in each academic year at the end of the course despite the changes implemented during the pandemic. The pre-pandemic students were observed to be stronger in fabrication while the students enrolled during the pandemic displayed strength in CAD. Also, students found different course features to be more important during the pandemic in comparison to the pre-pandemic cohort. Furthermore, students found lecture-based teaching modality for an experiential learning course to be less effective post-pandemic, but lab-based learning to be much more useful to their learning. In summary, this experiential learning course successfully maintained student motivation and provided a similar educational experience in comparison to pre-pandemic time despite the challenges of pandemic adaptation. Future work will further examine the study of student motivation change by inviting students to participate in focus group interviews to assess faculty-student interactions and course enjoyment.

References

[1] B. Geisinger and D. Raman, "Why They Leave: Understanding Student Attrition from Engineering Majors", International Journal of Engineering Education, vol. 29, pp. 914–925, 2013.

[2] L. J. Shuman, C. Delaney, H. Wolfe, and A. Scalise, "Engineering Attrition: Student Characteristics And Educational Initiatives", 1999 Annual Conference Proceedings, 1999.

[3] Seymour, E., & Hewitt, N. M. (1997). Talking about leaving: Why undergraduates leave the sciences. Boulder, CO: Westview Press.

[4] G. Tembrevilla, A. Phillion, and M. Zeadin, "Experiential learning in engineering education: A systematic literature review", Journal of Engineering Education, vol. 113, no. 1, pp. 195–218, 2023. doi: https://doi.org/10.1002/jee.20575

[5] Y. Kong, "The role of experiential learning on students' motivation and classroom engagement", Frontiers in Psychology, vol. 12, 2021. doi: https://doi.org/10.3389/fpsyg.2021.771272

[6] M. Gadola and D. Chindamo, "Experiential learning in engineering education: The Role of Student Design Competitions and a case study", International Journal of Mechanical Engineering Education, vol. 47, no. 1, pp. 3–22, 2017. doi: https://doi.org/10.1177/0306419017749580

[7] H. Nguyen, Liang Li Wu, G. N. Washington, Kyu Yon Lim, and C. Fischer, "Collaboration Patterns and Design Practices in First-Year Project-Based Engineering", 2020 ASEE Virtual Annual Conference, June 2020. doi: https://doi.org/10.18260/1-2--34298.

[8] H. Nguyen, L. Wu, C. Fischer, G. Washington, and M. Warschauer, "Increasing Success in College: Examining the Impact of a Project-Based Introductory Engineering Course", Journal of Engineering Education, vol. 109, no. 3, pp. 384–401, 2020. doi: https://doi.org/10.1002/jee.20319.

[9] S. Jacques, S. Bissey, and A. Martin, "Multidisciplinary Project Based Learning within a collaborative framework: A case study on urban drone conception", International Journal of Emerging Technologies in Learning (iJET), vol. 11, no. 12, p. 36, 2016. doi: https://doi.org/10.3991/ijet.v11i12.5996

[10] M. McCormick, J. Parham-Mocello, and D. Heer, "Improving Multidisciplinary Understanding Through Interdisciplinary Project-based Learning in a First-Year Orientation Course", in 2020 IEEE Frontiers in Education Conference (FIE), 2020, pp. 1–9.

[11] V. J. Bhute et al., "Effectiveness of a large-scale implementation of hybrid labs for Experiential Learning at Imperial College London", Education for Chemical Engineers, vol. 39, pp. 58–66, 2022.

[12] L. L. Wu, C. Fischer, F. Rodriguez, G. N. Washington, and M. Warschauer, "Project-based engineering learning in college: associations with self-efficacy, effort regulation, interest, skills, and performance", SN Social Sciences, vol. 1, no. 12, pp. 287, 2021. doi: https://doi.org/10.1007/s43545-021-00286-4.

[13] A. M. Maatuk, E. K. Elberkawi, S. Aljawarneh, H. Rashaideh, and H. Alharbi, "The COVID-19 pandemic and e-learning: Challenges and opportunities from the perspective of students and instructors", Journal of Computing in Higher Education, vol. 34, no. 1, pp. 21–38, 2021. doi: https://doi.org/10.1007/s12528-021-09274-2

[14] A. Shekh-Abed and N. Barakat, "Changes of project based learning effectiveness due to the COVID-19 pandemic", 2022 ASEE Annual Conference & Exposition Proceedings, Oct. 2022. doi: https://doi.org/10.18260/1-2--40402

[15] K. S. Gutierrez et al., "Undergraduate Engineering and education students reflect on their interdisciplinary teamwork experiences following transition to virtual instruction caused by COVID-19", Education Sciences, vol. 12, no. 9, p. 623, 2022. doi: https://doi.org/10.3390/educsci12090623

[16] C. N. Chang, G. K. Saw, and L. Malagon-Palacios, "Challenges of Remote Learning and Mentoring among Engineering Students and Faculty during the COVID-19 Pandemic", 2022 ASEE Annual Conference & Exposition Proceedings, Oct. 2022.

[17] L. L. Wu et al., "Rapidly Converting a Project-Based Engineering Experience for Remote Learning: Successes and Limitations of Using Experimental Kits and a Multiplayer Online Game", Advances in Engineering Education, vol. 8, no. 4, 2020.

[18] V. M. Ray, B. Sorge, K. R. Hughes, K. Rose, and C. Rownd, "Post-Pandemic Faculty Motivation: Causes for Burnout Offset by Motivation or Hygiene Factors", 2023 ASEE Annual Conference & Exposition, June 2023.

[19] C. Fleaher, G. Kirk, P. Pisacane, D. Suwanakeree, B. McCoy, and A. Hill, "Project-based Learning in a Persistent COVID-19 Environment Project Based Learning in a COVID Environment: A New Normal in Engineering Education", 2021 ASEE Virtual Annual Conference, July 2021.

[20] J. Tsenn, "The Effects of COVID-19 on Mechanical Engineering Senior Capstone Design Student Self-efficacy and Projects", 2021 ASEE Virtual Annual Conference, July 2021.

[21] L. L. Wu, C. Fischer, F. Rodriguez, and G. N. Washington, "Evaluation of Online Learning in a First-year Engineering Design Course," 2018 ASEE Annual Conference, June 2018. doi: https://doi.org/10.18260/1-2--30453.