2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering Education for 130 Years
ASEE
Paper ID #39439

Best Practices in an Undergraduate Engineering Course from Analyzing a Decade of Data from In-Class, Hybrid, and Online Environments

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KEYWORDS: Hybrid learning, Online learning, Student engagement, Undergraduate Education

Abstract

The rise of online learning during the COVID-19 pandemic has presented new challenges in engineering education but has also provided a testing ground for alternate teaching techniques. Currently, no standardized approach for in-person, online, or hybrid learning is in place, and many new teaching methods have not been fully evaluated. Herein, we present research from a student perspective that outlines best teaching practices and strategies for each learning environment. The information analyzed to reach conclusions came from a course evaluation database spanning ten years, five instructors, three teaching environments, and over 600 students for an interdisciplinary undergraduate engineering Kinematics and Dynamics course. In all learning environments, students found example problems most effective for enhancing their learning. Before 2020, students valued the instructor's ability to present material effectively and effectively. From 2020-2022, students emphasized instructor accommodations, flexibility, availability, and clear course structure. Returning to in-person learning, students expressed that they wanted many teaching practices implemented during remote learning to remain in place. Additionally, students were more willing to provide specific suggestions about how to improve course structure. This analysis provides useful tips for teaching multidisciplinary courses and increasing student success, engagement, and development, specifically related to diversity and inclusion efforts.

Introduction

Most educators agree that student engagement increases academic performance, motivation, critical thinking, and graduation rates. One of the most famous definitions by Sousa,

who describes student engagement as the amount of attention, interest, curiosity, and positive emotional connections that students have when they are learning, willingness to participate, and pleasure in accomplishing their goals [1] . There are six ways students can be authentically engaged - intellectually, socially, culturally, physically, emotionally, and behaviorally. For undergraduate-level engineering courses, engagement requires effort from faculty and students [2] . Students expect faculty to provide active learning experiences, convey enthusiasm for the subject, and provide availability for student-faculty interactions. While students are expected to participate in class, complete assigned homework and projects, and engage with the instructor and peers. With a recent transition to hybrid and online learning, the theories behind engagement differ from what was used in a traditional classroom setting. Namely, three constructs are used to measure engagement in online learning scenarios - student-teacher interactions, transactional distance, and social presence [3].

The scope of this work is to evaluate the student perspective on in-person, hybrid, and fully online course offerings for an interdisciplinary course that is a required part of the ABET curriculum [4]. Herein, we present a decade of student perspective from both a quantitative and qualitative perspective. We have also organized and presented the course syllabus spanning ten years, 2011 to 2023, five instructors, three teaching environments, and 613 student responses for an interdisciplinary undergraduate engineering Kinematics and Dynamics course. We will also introduce future work, which includes further evaluations of the student perspective as well as new instructor perspective data that could further aid in optimizing the teaching of engineering courses.

Purpose

Student engagement varies greatly depending on the method of instruction. Different strategies have been proposed and used in the classroom to increase student engagement and improve performance despite the delivery method [5]. This work seeks to contribute to finding

answers to two questions: (1) Is there a difference in student engagement in a class depending on the method of delivery and (2) What are the best strategies to teach an introductory dynamics course depending on if the course is offered in person, online, or using a hybrid method of delivery?

Methods and Materials

Subject

The subjects of this study are 613 undergraduate students of an ABET-required, introductory dynamics course in offered to all students at a public university in the Pacific Northwest region of the United States of America and provided by the Department of Mechanical Engineering from 2011 to 2022. The course is designed as an introductory dynamics course for engineers in multiple departments ranging from Aeronautics and Astronautics to Mechanical Engineering. The course instructors range from graduate student instructors to tenured faculty. The students ranged from second to third-year students. About 81% of students were enrolled in the College of Engineering at the time that they took the course, with the remainder being enrolled in the College of Arts and Sciences. The university has a total enrollment of approximately 40,000 students a year. The College of Engineering has a total of 5,000 undergraduate students and 2,800 graduate students in 10 different departments.

There were 613 student evaluations used in the study from various terms during which the course was taught. The method of administration varied between in-person and online depending on the instructor and offering type. The offering type and class structure for each term and instructor was collected and is shown in Table 1. Courses that were offered in-person used in-person evaluations, while courses that were offered in the online or hybrid styles used online evaluations.

Table 1. Description of course offerings and grading scheme for an ABET Required Statistics and Dynamics Multidisciplinary Undergraduate Engineering Course reviewed in this work.

			Grading Scheme as a Percent of Overall Course Grade				
Instructor	Term, Year	Course Lecture Structure	Homework	Quizzes	Recitation/ Real Life Assignments	Midterm Exam (x2)	Final Exam
C	Spring, 2011	In-Person	10	0	0	30	30
C	Spring, 2013	In-Person	10	0	0	30	30
C	Winter, 2015	In-person	10	0	0	30	30
C	Spring, 2017	In-person	10	0	0	30	30
B	Winter, 2020	In-person ‡	10	0	0	30	30
B	Summer, 2020	Online ‡	25	0	0	25	25
C	Winter, 2021	Flipped classroom	40	0	0	20	20
A	Spring, 2021	Online ‡	15	15	20	15	20
D	Summer, 2021	Online ‡	60	0	10	10	10
B	Winter, 2022	In-person‡ h	30	10	15	15	15

‡Class structure included recordings; h Course offered as hybrid, meaning both online and in-person

The evaluations reviewed did not have any demographic information associated with it for the purposes of protecting student anonymity. Demographic data of the student's declared major information for both when students were taking the class and major upon graduation for 2351 students who took the course over 18 offerings was available and is shown in Figure 1.

Procedures

From the student evaluations, both quantitative ranking questions and qualitative free-response questions were analyzed. The quantitative ranking questions were examined for each offering of the course. The five evaluation questions with quantitative rankings are listed in Table 2. These questions remained the same for both online and in-person terms. They included both ranking questions and free-response questions to characterize student engagement in the course both qualitatively and quantitatively. The distributions of student responses to the ranking questions were analyzed to determine general trends in how engaged students were in the course. Analyzed independently, questions 1 and 3 provide insight into student engagement. To determine

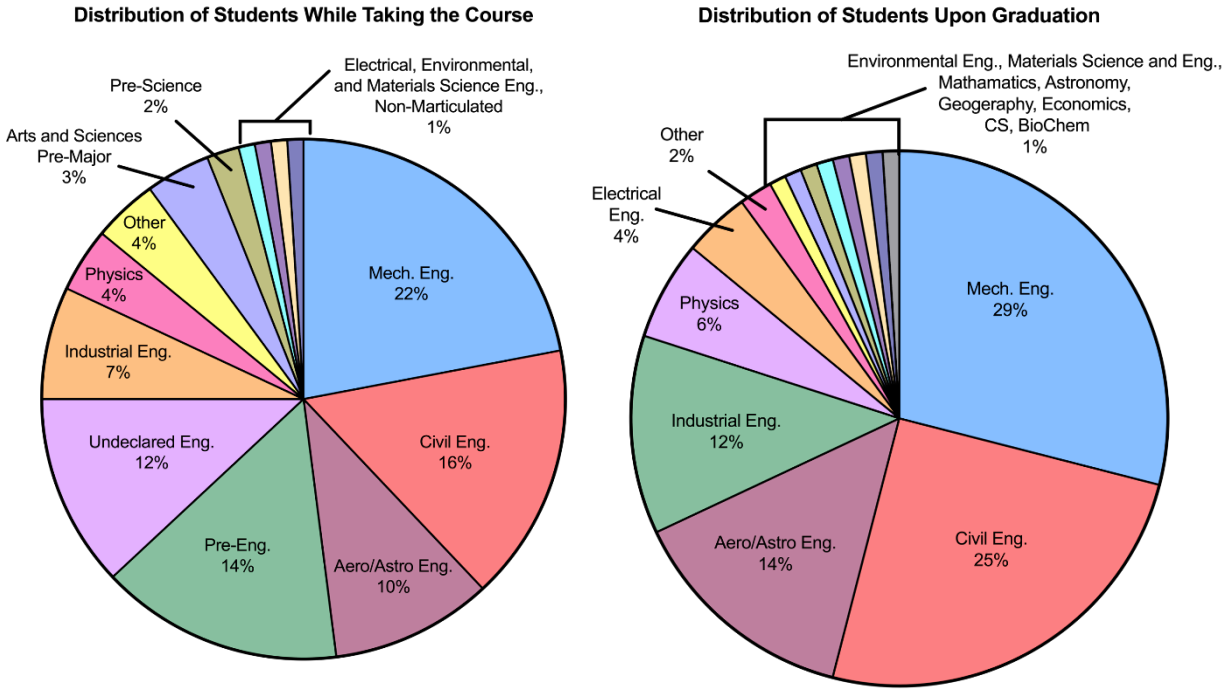

Figure 1. Students' major of study while taking the course and upon graduation from the university.

Table 2. Table of student evaluation ranking questions and scale analyzed in this study

	Evaluation Ranking Question		Ranking Scale
1.	The amount of effort you put into this course was ...	0	(Much Lower) - 7 (Much Higher)
2.	The amount of effort to succeed in this course was...	1	(Much Lower) - 7 (Much Higher)
3.	On average, how many hours per week have you spent on this course, including attending classes, doing readings, reviewing notes, writing papers and any other course related work?		Number of Hours
4.	From the total average hours above, how many do you consider were valuable in advancing your education?		Number of Hours

how efficient the course lectures and assignments were in teaching the students of the results for questions 1 and 3 were compared. The second and fourth questions, when evaluated alongside questions 1 and 3, indicate the students' engagement as well as how successful they perceived the course to be in teaching them.

In addition to the quantitative ranking questions in the student evaluations, three free-response questions on the end-of-term student evaluations were examined. These three questions are listed below:

- What aspects of this class contributed most to your learning?
- What aspects of this class detracted from your learning?
- What suggestions do you have for improving the class?

The recurring themes in these responses were used to infer students' preferences for what aspects of the class they found effective in maintaining engagement and teaching them the material. Note that all four in-person offerings by Instructor lack student comments, as the instructor at the time did not request this version of the evaluation. All comments from the in-person offering of the course are from Winter 2020. The remaining comments are from students who took the online and hybrid offerings of the course.

Results and Discussion

This section presents the results from curating a student evaluation database of 613 student responses. First, statistical analysis will be presented from questions that have quantitative answers. Second, detailed parsing and organizing of qualitative free-response questions for course aspects that contributed and detracted to their learning, as well as student suggestions, will be presented.

Evaluation Ranking Questions

Figure 2 shows the aggregate results of the ranking questions. A 1-way ANOVA test was used to determine if there was a statistically significant difference in the students' responses between the in-person and online offerings of the course. The results show a significant change in student responses for the in-person vs. online offerings except for question 3. The course evalua-

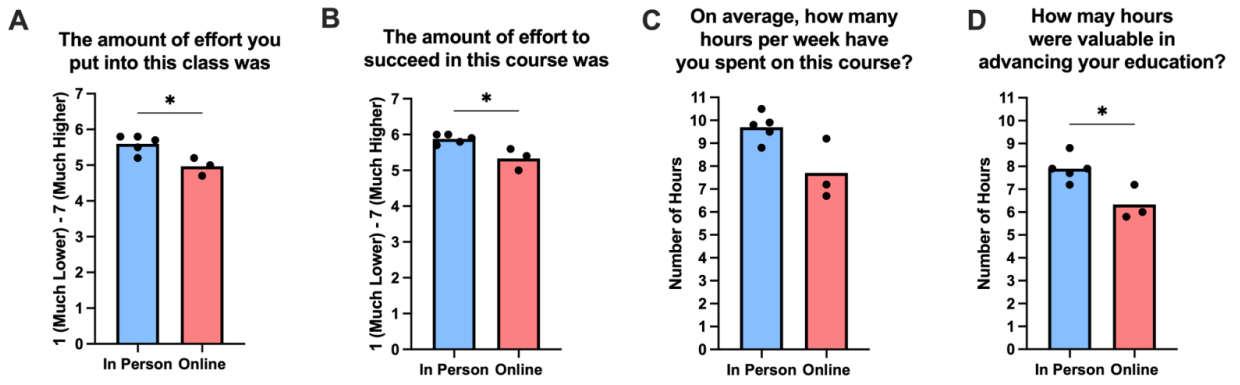

Figure 2. Distribution of student responses to ranking questions. The * indicates a significant variation in the student responses between the in-person and online offerings of the course

tion results from the hybrid offering of the course were not included as it was only offered once, and thus did not provide enough data for insightful comparative statistical analysis.

The differences in Figure 2A and Figure 2B suggest that students felt that they put more effort into the in-person course compared to the online offering of the course and that this additional effort was necessary to succeed in the course. Figure 2D shows that students found more hours spent on the course were valuable to them in the in-person courses compared to the online course. Despite this, students from both offerings said about 81% of total hours spent on the course were valuable to them. This implies that while students spent more absolute time on the course during the in-person offerings, the relative amount of valuable time that they spent on the class did not change significantly between offering types.

In general, students in the in-person offerings of the course put more time and effort into the course than students who took the course when it was offered in the online or hybrid setting. Surprisingly, the percentage of valuable hours was about the same in both settings. This indicates that students still found the online offerings to be of similar value to the in-person offerings of the course. The implications of these quantitative results from the ranking questions will be examined

more closely by combining these results with the student comments taken from the free response questions in the following section.

Student Free Response Questions

To determine why students answered the ranking questions the way they did, the free response question responses for each course offering were examined to determine what worked well for students in each offering and what did not help their engagement and learning.

Aspects that Contributed to Student Learning

The following are some highlighted quotes from the student responses to the first free response question from each course offering type. From the in-person offering:

- “Recitations since ... we got to work through problems”
- “Illustrations, notes being … color coded”
- “Lecture notes were clear and organized”
- “Doing practice problems in class and hearing our professor's explanation of them helped”

From the online offerings of the course:

- “doing the hw and example problems in class”
- “the polls during class help keep me focused on lecture…”
- “practice quizzes because it ... gives other problems to practice with”
- “The professor is also very accessible by email.”

From the hybrid offering of the course:

- “The examples in class (especially the way it was taught in steps...) was very helpful to help me … apply class examples to homework”
- “extensions on homework allowed me to rewatch lectures”
- “The professor's enthusiasm and care for the class”
- “I could also tell that [Instructor B] and the TAs really cared about how much we learned and how the class was for us”

Students' responses from all course offering types to the first question of what contributed most to students' learning indicated that working on examples step-by-step helped students learn how to solve problems more efficiently. One difference is that the responses of students in the in-person offering focused on in-class activities such as example problems and lecture note organization. Conversely, in the online and hybrid offering, students found aspects such as in-class polling to be helpful for maintaining engagement in class and increasing learning. Additionally, flexibility in assignment deadlines allowed them more time to digest and engage with the material, thus increasing their learning.

Students in the responses for the online offerings also frequently mentioned that the professor's availability to provide help, their attitude, and demonstration of general care for the class greatly affected how they performed in the course. Students felt that they benefited from professors taking actions that showed that they cared, such as being available throughout the day to answer questions, providing homework extensions, and allowing some assignments to be dropped. This aspect was not mentioned at all in the responses from the in-person offering. One potential reason that students found the tangible demonstration of care important in the online offerings is that it gave students a way to connect to the instructor and teaching assistants even when everything was entirely online. The responses from the evaluations of the hybrid offering had many similar themes as from the online offerings demonstrating that students have continued to care about instructor investment and demonstration of care despite the return to mostly in-person teaching.

Interestingly, comments from the online and hybrid offerings of the course as well as the variety of assignments as indicated in Table 1 indicate that students have more assignments to work on during these offerings. This contrasts with student responses to the ranking questions, where their responses indicated that they spent more time on the course during the in-person

offerings. One potential issue that this inconsistency could indicate is that the current student evaluation question does not accurately measure how much time students perceive they spend on the course. Another possible issue is that assignments decreased in length when the course was taught online. However, this issue cannot be confirmed without a more in-depth look at the syllabi.

Aspects that Detracted from Student Learning

The following are highlighted quotes from student comments to the second free response question for each course offering. For the in-person offering:

- "There were a lot of derivations and it made it easy to get lost with what we needed to know vs what was just part of the derivation"
- "... engagement with students in the lecture hall was late in the quarter…"
- "... most of the TA's could not provide alternate explanations…"
- "Lecture was poorly paced…"

For the online offerings:

- "... the lab sections were pretty much useless since they had basically no student participation…"
- "... classmates are too afraid to actively participate in discussions…"
- "... we spent too much time deriving and going over equations in class…"
- "... not much communication between … classmates did detract a little from my learning…"
- "I wasn't very motivated to go to the lab sections because they weren't mandatory…"

For the hybrid offering:

- "The online environment for the beginning of the quarter"
- "... recitation was not recorded, unable to hear the TAs thoughts as they went through the examples if i couldn't make it to the live section"
- "... lectures were sometimes confusing… derivations were rushed…"
- "Having the class being hybrid … caused a lack of motivation…"
- "... I did not realize some of the derivations were just derivations so maybe specify that…"

In-person, online, and hybrid course offerings all suffered from some similar aspects that detracted from student learning, including (1) the pacing and length of equation derivations and (2) low engagement with students. This is consistent with the student's responses to the first free response question, where students tended to find that example problems and in-class polls that increased engagement during the lectures contributed to their learning. An interesting trend that appears in the comments from the online and hybrid offerings of the course was that students found that low participation in online recitations detracted from their learning. Furthermore, students reported lack of motivation to attend recitation when offered online. This lack of online recitation attendance is a contributing factor to the decreased participation in online recitations. The trend of decreased student motivation for online versus in-person recitation was found in the hybrid course offering as well. Students in the hybrid offering reported that motivation to attend class was lower due to an option to attend lectures completely online.

Student Suggestions for Improving the Course

The following are highlighted quotes from student comments to the third free response question on the evaluations from each offering type. From the in-person offering:

- "I found the derivations … helpful, but only as long as if, …[Instructor B] went back over each piece of the eqn and explained where it came from/what it caused"
- "I would suggest trying to interact with the students more…"
- "Real life examples and how we could use the ideas from class to solve it"
- "... more grade weight on quiz section or hw…"
- "Even more examples during class"

From the online offerings:

- "Practice tests would be helpful…"
- "... more big picture overviews in the notes…"
- "... have in-depth prelecture videos that build upon the textbook content…"

- "... example problems in lecture where students are given a few minutes to look at it in groups before the professor goes over the answer…"
- "Required lab sections"

For the hybrid offering:

- "More poll EV's to help with engagement"
- "... quiz sections can be a little more group working involved…"
- "Possibly consider flipped approach…"
- "... videos of example problem solutions on the course page…"
- "I would prefer some experiments over merely doing example questions…"

For all three offering types, students expressed interest in having more practice material. For the in-person offering, this request came in the form of students asking for more example problems in class and problems related to real-life applications. Students in the online and hybrid offerings had more varied requests, such as asking for time to review the problems with classmates, more big-picture overviews of concepts to frame in-class discussion, and the inclusion of additional example problem videos on the course website.

One potential reason that student requests became more varied is that when schooling moved to be entirely online, instructors tried various techniques to increase engagement and learning. This can specifically be seen in Table 1 where the offerings taught entirely online (Spring 2020 through Summer 2021) have a larger variety of graded assignments including quizzes, participation in recitation sections, and real-life assignments where students need to find and document objects in their everyday lives that demonstrate a dynamics concept. These 'real-life' assignments explored alternative ways to engage with students when face-to-face interactions were not possible. In addition, some students requested a flipped classroom approach during the online offerings of the course. This desire to switch to a flipped classroom approach is consistent with student feedback to the first free response question since this naturally creates more time to do

example problems during lecture by moving the explanation of key concepts to pre-lecture videos.

Students in the online and hybrid offerings of the course also show more awareness of the importance of instructors engaging with students in class in their responses during online and hybrid offerings of the course. This can be seen in the quotes where students mention the need for methods to increase engagement, such as in-class polls, required participation in lab/recitation sections, and giving space for students to discuss example problems before working through the solution. Students also showed an interest in other methods of content delivery, including example problems specifically on real-life applications of the material and providing additional video tutorials of practice problems for review on the course web pages.

Conclusions and Future Work

Herein, we dissected the student perspective on in-person, hybrid, and fully online course offerings by analyzing a database containing 613 quantitative and qualitative responses for a required ABET curriculum interdisciplinary kinematics and dynamics course. Three key conclusions were reached. First, professors need to close the transactional distance gap created by online learning to increase engagement. They can do this through various techniques such as in-class polling, deadline flexibility, and accessibility via email or online video and chat systems. This engagement from the instructor is very important to maintain student engagement in all course modalities, especially in online offerings. Second, in online courses, participation from peers is also critical to student engagement and learning. Students lost motivation to participate in or even attend recitations when their peers did not also participate. The lack of participation made it difficult for students to practice the problems with their peers, which they stated helped them engage with and digest the material more effectively. Third, students want more real-life application problems and examples over derivations in any course offering. The real-life

application and example problems made the concepts more tangible and better prepared them for understanding homework and exams.

Extensive future work is underway that includes evaluating student engagement strategies from the instructor's perspective, which could offer insights into which of these techniques are feasible for instructors to implement. Additional future work could inform suggestions for greater systemic change, such as guidance on designing courses to suit students' needs best and improve the student experience.

Acknowledgments

The authors would like to thank Prof. Molly Mollica and Prof. Steve (I.Y.) Shen for insightful discussions. Dr. Elizabeth Rasmussen was funded for a portion of this work by a National Research Council (NRC) postdoctoral fellowship distributed by NIST.

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