A Comparison of Students' Academic Achievement and Perceptions in Hyflex and Non-Hyflex Engineering Courses

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1. Introduction and Literature review on the HyFlex instructional model

Due to the COVID-19 pandemic, more universities are exploring the use of technology-rich pedagogies like Hybrid Flexible (HyFlex). HyFlex is defined by California State Polytechnic University, Pomona in 2021-2022 as an instructional mode in which students have the option to participate in-person in the classroom, synchronously online (via Zoom), or asynchronously online (watching recordings of class). This modality utilizes technology to breakdown instructional barriers for vulnerable populations of students, provide additional study aids for students, and allows students to interact even when they are sick or faced with an emergency. The role of technology in HyFlex has been shown to be a best practice in other fields, but this paper explores the feasibility of HyFlex in the engineering disciplines.

Given that HyFlex is a relatively new approach to teaching, there is a small but growing set of literature on its efficacy. Initial research indicates that HyFlex neither greatly helped nor hindered students' learning [1], but rather provides flexibility with managing school, work, and homelife [2]. This format also has potential benefits for retaining students who face challenges with in-person attendance. Studies suggest that students are reasonably satisfied with HyFlex classrooms [3] and valued their options of choosing the mode of instruction for each session. Graduate business students reported appreciating that they could still be engaged with the instructor and peers even when remote [4]. Miller et al. [1] found that HyFlex programs could increase understanding and participation, and can help students feel behaviorally, cognitively, and emotionally engaged.

Another possible benefit of the HyFlex instructional model is that it requires instructors to create recordings of each class session, essentially generating a small video library for that semester. Recent research by the authors indicates online video libraries are valued by students because they can review information from their instructor or a trusted instructor, and video libraries increased student confidence [5]. Similarly, students treated HyFlex recordings as supplemental videos for review and reported increased confidence as a result [1]. Past studies have shown that recorded lectures can result in a select group of students failing to participate – however, when this group was excluded from analysis, student performance was not negatively impacted by the availability of taped lectures [6]. Additionally, English language learners perceived the availability of such videos as enhancing their academic performance [5].

Informed by existing studies, the goal of this research was to explore the HyFlex model's impact on both students and instructors in upper division engineering courses. A comparison of one HyFlex section and one face-to-face lecture section was conducted for three engineering courses, whose instructors volunteered to participate in comparison and more in-depth look at their HyFlex section would be compared to Non-HyFlex section. Various factors were considered in the analysis of HyFlex: Student success, engagement, social-emotional experiences of both students and faculty, and access to materials particularly for vulnerable and underserved students.

2. About the engineering courses

The engineering courses that participated were "Mechanical Engineering (ME) 4150: Heat Transfer" in Fall 2021, and "Civil Engineering (CE) 3211: Water Resource Engineering" and "Engineering Technology ETM 3301: Instrumentation and Controls" in Spring 2022. ETM 3301 was a lecture and lab combination, and the lab was a corequisite taken at a different time of the day or week. ME 4150 and CE 3211 were lecture courses with no lab component.

Due to the sequencing of classes designed by departments, some of the students in the classes were familiar with each other and the instructor prior to registering for the course (which might affect the student and instructor experience in the course). For example, ME 4150 is a course in a sequence of courses that students must complete in the correct order for the major. In contrast, CE 3211 was not in a sequence of courses that students complete together. The instructor felt that this class had very few students who knew each other or the instructor prior to registering for the course, and the course likely had the fewest number of students who were familiar with each other. Like ME 4150, ETM 3300 had many students who knew each other prior to registering. The students stayed together in their cohort, which was third out of four in a sequence of courses for the major.

3. How the courses were run as HyFlex and Non-HyFlex sections

The university announced it would initiate a HyFlex pilot project in the 2021-2022 academic year when the university transitioned back to in-person instruction. Faculty volunteered to teach HyFlex in Fall 2021 and Spring 2022 as part of a larger study of 18 Hyflex sections from other non-engineering disciplines.

The university's implementation of HyFlex required faculty to teach to a live audience on campus, stream live via Zoom simultaneously, and provide a recording of the lecture to students after class through the university's LMS (Canvas). Students chose whichever modality they preferred and could vary the modality between class sessions. Quizzes and exams were to be taken in-person or online. Some HyFlex faculty chose to slightly modify the definition of HyFlex and required or strongly encouraged students to attend certain days (e.g., exam days or certain lab days).

As part of the evaluation of the HyFlex pilot project, one HyFlex section and one face-to-face lecture section was conducted for each of three engineering courses: ME 4150 in Fall 2021, and CE 3211 and ETM 3301 in Spring 2022. Both sections of each course were taught back-to-back by the same instructor to minimize time-of-day and instructor bias.

HyFlex and non-HyFlex sections of each course were run similarly, as shown in Table 1. Each of the three instructors provided homework assignments, quizzes, and exams, that were designed to be as similar as possible across their two sections. In ETM 3300, students in both sections completed quizzes and exams online. In CE 3211, HyFlex students had the option to take exams either online or in-person, however, the instructor *encouraged* students to complete the midterm exams online. Students in the non-HyFlex section completed the midterm exams in person. That

instructor required all students to complete the final exam in the classroom to ensure academic integrity. In ME 4150, *non-HyFlex* students completed quizzes and the final exam in person in the classroom. Students in the HyFlex section were allowed to complete quizzes and the final exam live online via Zoom or in the classroom, and they could alter the mode between each assessment (e.g., a student could take Quiz 2 in the classroom, then take Quiz 3 online). HyFlex students who completed a quiz or exam online were required to have their webcams and microphones turned on to mitigate the risk of cheating. Additionally, all students were required to write a short integrity statement at the beginning of the exam stating they will follow the rules. The instructor kept track of which mode the HyFlex students used for each quiz and the final exam.

The instructors were instructed to teach in-person in a special classroom, stream their class sessions live via Zoom, and provide videos of their class sessions after class. Instructors made recordings of the lecture available on their class websites as a supplemental resource and to allow students who were unable to attend class to stay current with the class material. Indeed, several students contracted COVID-19 and had other serious personal matters during the semester but were able to continue learning from the recorded videos. Table 1 summarizes the key differences between the HyFlex and non-HyFlex sections.

Table 1: Comparison of HyFlex and non-HyFlex sections' pedagogy, enrollment, and participation in surveys and focus groups

	HyFlex ME 4150	Non-HyFlex ME 4150	HyFlex CE 3211	Non-HyFlex CE 3211	HyFlex ETM 3300	Non-HyFlex ETM 3300
Taught live in classroom	Yes	Yes	Yes	Yes	Yes	Yes
Streamed live via Zoom	Yes	No	Yes	No	Yes	No
Recording available [a]	Yes	Yes	Yes	Yes	Yes	Yes
Location for taking quizzes and final exam	In-person or online	In-person only	In-person or online[b]	In-person only	Online	Online
Students enrolled in the section	37	37	45	44	29	36
Students completing the survey	32	30	39	34	7	7
Students participating in focus groups	19	10	0	0	1	0

[a] Instructors provided either the HyFlex or non-HyFlex class recording to both sections. In ME 4150, the non-HyFlex sections were recorded and posted for non-HyFlex students. In CE 3211, recordings of HyFlex sections were made available to non-HyFlex sections.
[b] Although quizzes may be taken online, students were required to take the final exam in person.

4. Study Method

Data was collected to assess whether the HyFlex modality might impact student achievement (e.g., final exam and course grades) and student and instructor experience. Three instructors and 149 students completed surveys. Some students who completed the survey also answered additional questions in interviews (n=40), providing more detailed information about their experience.

Instructors tried to encourage students to participate in the study. In ME 4150, the instructor gave a small amount of extra credit to students who participated in the surveys and focus groups (e.g., students could earn +1.5% of their overall course grade for completion of surveys and +1% for participation in focus groups). In CE 3211, the instructor made the survey an assignment, so students were asked to submit proof of completion and they then received full credit for the assignment. The ETM 3300 instructor did not report offering extra credit or making the survey an assignment.

One member of the assessment team also attended HyFlex sessions to better understand the student experience. One session of ME 4150 was observed in Fall 2021. This was done to provide additional context to the surveys and focus group data. (Multiple sessions of other HyFlex sections were also observed, but not included in this report).

Class materials such as syllabi were analyzed to confirm that HyFlex and non-HyFlex sections were treated as similarly as possible and to determine what instructions and guidance students were given about HyFlex.

5. Findings – Quasi-experimental comparison of HyFlex and face-to-face sections

The impact of HyFlex on academic performance, attendance, and student and faculty perceptions (e.g., satisfaction, procrastination) are provided next along with other themes. As previously mentioned, the main instructional difference between HyFlex and non-Hyflex sections was that instructors told HyFlex students they have the option of not attending class in person. Both HyFlex and non-HyFlex sections had access to the video recordings of class. See Table 1 above for additional details of the six sections.

Academic performance: Grades

Students did not perform significantly worse in HyFlex sections. In fact, Grades were similar in the HyFlex and non-HyFlex sections, according to t-tests and other analyses. Results for each of the three courses are summarized in Table 2.

In ME 4150, both sections had identical average course grades assigned at the end of the term of C+ (calculated to be 2.9 on a scale from 0.0 to 4.0). Also, both sections had a similar DFW rate (HyFlex = 17%, non-HyFlex = 19%), "A" letter grades (HyFlex = 30%, non-HyFlex = 22%), and average final exam grades (HyFlex = 71% or C-, non-HyFlex = 67% or D+, out of 100%). Interestingly, the ME 4150 instructor taught four sections of that course prior to the pandemic with DFW rates ranging from 14% to 21%, which are in line with the DFW rates obtained during the HyFlex study.

In CE 3211, the HyFlex section earned similar grades compared to the non-HyFlex section. Specifically, t-tests indicated that although the average course grades were slightly lower for the HyFlex section (2.8 out of 4.0) compared to the non-HyFlex section (3.0 out of 4.0), the difference was not statistically significantly different. Additionally, students earned identical rates of "A" grades in the course (13% in each section). The instructor provided other assessment opportunities, such as assignments, quizzes, projects, midterm exam, and the final exam. HyFlex students tended to perform similarly well on the various assessments compared to non-HyFlex

students, with the exception of quizzes where HyFlex students scored on average 6% worse (HyFlex = 81%, non-HyFlex = 87%), which was statistically significant ($p < 0.05$).

In ETM 3300, the HyFlex and non-HyFlex sections had identical average course grades (3.6 out of 4.0). Compared to the non-HyFlex section, the HyFlex section appeared to have a slightly lower DF rate (HyFlex = 3%, non-HyFlex = 9%) and slightly lower "A" grade rate (HyFlex = 66%, non-HyFlex = 72%), but these differences were not statistically significantly different.

Table 2: Student performance data for each section.

Course Section	Average Course Grade [a]	DF Rate [b]	Fraction of students receiving an A	Average Final Exam Score
ME 4150				
HyFlex (n = 36)	2.9	19%	30%	71%
Non-HyFlex (n = 36)	2.9	17%	22%	67%
CE 3211				
HyFlex (n = 45)	2.8	4%	13%	67%
Non-HyFlex (n = 42)	3.0	2%	13%	72%
ETM 3300				
HyFlex (n = 29)	3.6	3%	66%	N/A
Non-HyFlex (n = 35)	3.6	9%	72%	N/A

[a] Grading Scale: A=4.0, A-=3.7, B+=3.3, B=3.0, B-=2.7, C+=2.3, C=2.0, C-=1.7, D+=1.3, D=1.0, D-=0.7, F=0

[b] The DF rate is the percentage of students who earned a D or F in the course. A DFW rate is the percentage of students who withdrew or earned letter grades of D or F for the course. There were so few withdrawals that they were not included in these analyses, and it was unclear if the withdrawals were due to illness or academic problems.

Attendance in-person

In the interviews, instructors said that many students attended in person at the beginning of the semester (especially the first day of class), but over time attendance in person decreased. By the end of the semester, more students tended to participate on Zoom and some relied on asynchronous videos when they needed more time to study and appreciated being able to participate from home. (However, most students said they relied on the recordings as a supplemental aid not as a substitute for class).

The CE 3211 and ETM 3300 instructors wondered whether students' choice to attend class synchronously online was affected by the fact that early in Spring 2022, high case rates of COVID led to remote instruction for the first three weeks of class. It is possible that students became accustomed and confident in an online format for their courses, and then maybe students chose to stay in that mode.

The instructor for ME 4150 reported that most HyFlex students attended in-person regularly early in the Fall semester. Within weeks, about one-quarter of the students regularly attended in-person and approximately two-thirds attended synchronously by Zoom. The remaining small proportion (~10%) of students relied on the asynchronous mode (video recordings) at various times in the semester. In contrast, most of the non-HyFlex students attended in-person and used

the video recordings on days when they had to miss class. The instructor stated that although most of his students tended to pick a mode and stick to it, it was not consistently the same students who attended in person. Students had emergencies and illnesses that affected their mode choice. The instructor explained that students who normally attended in person caught COVID and were forced to stay home for a few weeks during the semester. The instructor and students credited HyFlex for enabling them to pass the course and not fall behind.

Procrastination

Students were asked to rate their level of procrastination in their course compared to other courses. Table 3 shows there were similar levels of student procrastination between HyFlex and non-HyFlex sections, and t-tests revealed the differences were not statistically significant. Additionally, a few students mentioned in surveys and focus groups that they had to fight a tendency to procrastinate, but procrastination did not appear to be a severe problem for them.

Table 3: Comparison of students' self-reported procrastination tendencies in each section
"I procrastinated more than usual in this class" on a scale of strongly agree (5) to strongly disagree (1)

	Mean Score (out of 5.0) [a]
ME 4150	
HyFlex (n = 32)	2.6
Non-HyFlex (n = 30)	2.4
CE 3211	
HyFlex (n = 33)	2.2
Non-HyFlex (n = 30)	2.5
ETM 3300	
HyFlex (n = 7)	2.7
Non-HyFlex (n = 2)	2.0

[a] t-tests indicated that the differences between HyFlex and non-HyFlex students were not statistically significant.

Across the three courses, HyFlex students were particularly satisfied with the modality's flexibility. They appreciated being able to join class live through Zoom and being able to watch videos later. During the semester, there were students who had COVID or felt sick and uncomfortable coming to class, and they expressed their gratitude for being able to learn from home. Instructors and students noted that the students would have fallen behind in the course if they had no synchronous or asynchronous options.

Satisfaction

Table 4 shows that HyFlex students felt satisfied with their HyFlex course, as shown in Table 4. They also strongly agreed that the HyFlex mode helped them be confident, be grateful for the flexibility, understand course material, stay home when sick, and succeed in the course.

Table 4: Comparison of satisfaction with HyFlex mode between all HyFlex students and students in each HyFlex sections.
"You have experienced a HyFlex course that had three different instructional options for class. Please indicate your agreement with the statement on a scale from not all (1) to strongly agree (5). Compared to an entirely in-person version of this class, I feel more...satisfied with a HyFlex class."

	Level of satisfaction [a]
ME 4150 HyFlex students (n=32)	4.4
CE 3211 HyFlex students (n=33)	4.2
ETM 3300 HyFlex students (HyFlex, n=7)	4.7

[a] Weighted average, with 5 indicating the highest level of satisfaction.

Instructor skill

All the instructors were skilled and experienced with the course and online classes. The instructor with the most experience in designing and running asynchronous classes and classes in different modes seemed to be particularly ready and well-suited for teaching HyFlex in a smooth-running way. HyFlex students liked the skillful way that the ME 4150 instructor delivered the synchronous and in-person lectures and handled questions; for example, if a question was asked in-person, he was very adept at repeating it back for those attending on Zoom. He solicited questions well too. Students explained that this instructor was better than other instructors at organizing and managing the class, especially in all three modalities, and many students felt that their learning was enhanced by the HyFlex format. This instructor mentioned that he learned quickly that he needed to use his own technology. The non-HyFlex students expressed appreciation for the instructor's skill, the course structure, and the asynchronous videos (both HyFlex and non-HyFlex students had access to videos) as well.

Problems to solve for HyFlex modality

Faculty Workload: HyFlex faculty reported several problems requiring solutions. The first issue was an increased workload. It can be a great deal of extra work to set up a HyFlex course, which was similar to preparing for a new course according to some faculty. One instructor said it was a lot of work to administer the HyFlex course, especially when they had multiple courses running in separate modalities. The instructor noted that it was like teaching two separate classes even though the content was the same. The instructional mode made the courses almost independent of each other as technology issues had to be addressed especially when group work and class discussions were considered. In contrast, for another instructor it was minimal work to run a HyFlex course after the initial planning, training, and technology was implemented. These instructors tended to have extensive experience teaching with online components, microphones, laptops, and recordings of class, prior to teaching a HyFlex course. Also, they also gave students the message to attend the course and not rely on videos as a substitute for class. The most successful instructors set expectations for attendance early in the class with both the syllabus and in their course introduction on the first day of class.

Exams and cheating: A second problem was how to ensure exams and assessment activities were equitable. This was an important issue. Instructors grappled with how to administer exams or other assessments in-person and/or synchronously online. They knew they would not be able to write different assessments that are equitable and commensurate for students. University wide, instructors have addressed this issue differently to uphold academic integrity. Some instructors require students to attend in person on exam days, some allow students to take the test

synchronously online with camera and microphone enabled, others allow online testing for all students. Regardless of delivery, all instructors do not allow students to test asynchronously. Little difference has been shown on student performance on exams based on testing protocol.

Class technology: A third problem was the classroom technology. Some faculty members struggled to have the built-in tracking camera follow them as they walked around the front of the classroom. Additionally, the built-in microphones often produced an audio quality that was insufficient for students engaged in the synchronous online or asynchronous modalities. Faculty shared that the built-in microphones were very sensitive and picked up the slightest sounds which could have disrupted lectures for students attending synchronously or watching a lecture recording.

One instructor (the ME 4150 instructor) mentioned that he decided against using the new technology provided by the university. The tracking camera was not necessary for him to use, since he primarily taught using PowerPoint and a writing pad on his laptop. The content was streamed to students through Zoom and projected to students in the classroom simultaneously. The laptop webcam allowed the students attending through Zoom to see the instructor's face, and the instructor stood in place throughout the class session to stay within frame. The instructor also did not use the built-in classroom microphones since they had relatively poor audio quality compared to his personal lapel microphone. Because students on Zoom and in the classroom could not hear each other well, the instructor verbally repeated questions from students before answering. All lectures were recorded using Zoom and made available to students within 24 hours on the class website. The instructor for the other two deep dive sections used the provided technology.

The CE 3211 and ETM 3300 instructors used the classroom technologies installed for the HyFlex pilot project. Students in both courses mentioned that it was difficult for students to see, while watching class online. The cameras in the HyFlex classroom were angled poorly, and the camera provided poor quality video images. Addressing such technical issues interrupted and took the instructor's time away from the class. Additionally, students struggled with group work because in-class and intra-group discussions are challenging with students participating in multiple mode

Engagement and equivalent class experience: A fourth problem experienced by some of the HyFlex instructors is how to ensure students are engaged and participating in class, getting equivalent experiences online and in-person. At least one commented that the students attending synchronously (on Zoom) tended not to talk much or ask questions, but at least the students attended. Fortunately, the instructors rarely had issues of "ghosting" (i.e., students missing class in person or Zoom, and not replying to emails), which can be problem in asynchronous classes in general. One instructor used the student assistant provided by the university to facilitate groups discussions on zoom with those students attending synchronously, however, asynchronous students missed the class discussion entirely. Discussions in this matter inhibited students from interacting across delivery methods.

Department committee process: While this HyFlex classes were well-designed and well-run in this pilot study, one important message is that the HyFlex mode might work well only with

certain faculty, students, and courses. For example, faculty who are trained and skilled in such instructional technology and have prior experience teaching the course might be a good fit for HyFlex, while other faculty might need additional support (e.g., training in HyFlex technology). HyFlex has also been shown ineffective for first year students. Having a goal and purpose for offering a course in the HyFlex modality is imperative to the success of the course. For departments that offer multiple sections of a course, it might be worthwhile to offer a limited number of sections in the HyFlex format if an instructor is comfortable teaching in that style and ask one instructor to teach all the HyFlex sections to avoid preparing for multiple delivery methods. It would also be impactful for departments to consider courses that are typically taken together in a semester to develop a plan that allows students to take advantage of the HyFlex modality.

6. Conclusion

The HyFlex modality allows students to participate in courses face to face, synchronously, or asynchronously. These three upper division engineering courses showed little difference in student performance across modalities. The technology in the classroom allowed learning to meet the needs of students who struggle with other demands. While the modality needs to be continually refined, it was a way to offer flexibility to students in lecture style classes, further research into lower division and laboratory classes is needed to entirely refine the modality. HyFlex is best when the technology is strong, instructors are well trained and supported by the university, and the instruction and course structure is well planned. A complete vision centered on outcomes for students and support for faculty is needed to ensure that HyFlex is as effective as possible.

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