Challenges with Online Teaching and Learnings for the Post-Pandemic Classroom

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Abstract

At the start of 2020, safety concerns stemming from the COVID-19 pandemic caused educational institutions around the world to rapidly transition to emergency remote learning (ERL). This has caused educators to rethink their course delivery strategies and re-examine their assumptions about what constitutes a good education. Although the research community has widely reported on remote learning—including its benefits, its challenges, and suggestions for the future—institutions have recently begun resuming in-person activities, which begs the question, what has changed? While previous work has compared remote learning during the pandemic to pre-ERL in-person learning, we expand on the findings of the community by examining student feedback obtained during post-ERL in-person learning. We begin by discussing the main challenges we faced during the year of online teaching, then present an analysis of survey data gathered for both remote and (post-ERL) in-person learning during the pandemic. Insights on synchronous and asynchronous learning are presented, including the benefits and drawbacks that are unique to each. We show that while students generally preferred synchronous learning over asynchronous, many of the key benefits of synchronous learning are only attainable in a physical setting. We discuss the reasons for this, as well as the reasons why students overwhelmingly desired an asynchronous learning option to augment their synchronous learning activities. Unlike many previous studies which solely rely on quantitative survey data, we draw our conclusions using a combination of quantitative data and written feedback from students, the latter of which allows us to better understand students' reasons for adopting certain learning strategies and preferences. Alongside these insights, we identify opportunities for improving student satisfaction and share actions we took to better support our students.

I. Introduction

The COVID-19 pandemic has greatly impacted higher education, with students and teachers being forced to adapt to emergency remote learning (ERL, or "online learning" for convenience) for over a year. As shown in Figure 1, the Fall 2020 (Sept. – Dec. 2020) and Winter 2021 (Jan. – Apr. 2021) semesters were entirely online at our university. During this time, teaching modalities varied across faculties and instructors, and generally fell into one of three categories: (1) synchronous, where instructors and students were present at the same time (face-to-face but online), (2) asynchronous, where lectures were recorded and posted for students to view on their own time, and (3) a hybrid of the previous. In-person learning resumed for the Fall 2021 (Sept. – Dec. 2021) semester, again with variation in teaching modalities. For example, some instructors returned to their pre-ERL methods, while others attempted to "modernize", i.e., employ technology.

Figure 1. Learning environments for the three semesters of interest.

During the ERL period, members of the research community have reported on the disruptions their classrooms faced [1, 2, 3] and the strategies they adopted to improve the effectiveness of online learning [4, 5, 6]. A popular research avenue has been to investigate the impacts of ERL in the context of laboratory and project work—aspects of engineering education which have traditionally involved hands-on experiences unique to the in-person setting. In [1], the authors explain that a key issue arising when conducting labs online is the lack of access to conventional laboratory equipment, and therefore the reliance on simulation. Interestingly, the authors in [5] show that lab simulations can provide students with a novel "opportunity structure", offering them more ownership over the lab procedures and allowing them to explore phenomena in ways that would not be feasible in-person. This sentiment is echoed in [4], where the authors state that the flexibility associated with online experimentation demands greater self-guidance abilities from students. The authors in [5] remark that they could see simulations as valuable pre-lab or post-lab activities going forward, but that the research community lacks a clear understanding of how labs conducted entirely online affect engagement and learning. This issue is partially addressed by the work in [7], which investigates attitudes and behaviours across two groups of students: those taking a lab course on-site, and those taking it online at the same time. The authors show, using quantitative survey data, that although the online students felt they did not learn as much as their in-person counterparts, their self-efficacy was comparable to that of the on-site students. Similar issues are investigated in the context of a capstone design course in [2]. The authors show that students' project scopes and teamwork processes underwent significant adaptations in response to the rapid transition to online learning; nevertheless, the students demonstrated resilience and reported learning experiences on par with previous years. However, this resilience took a toll on their mental health.

These studies show that the research community has accepted that online teaching can usually be made effective, even for coursework with a strong emphasis on interactive components. They also show that online learning takes a toll on the students, with engagement, quality of learning, and mental health all being important factors to monitor. Although these studies have shown costs associated with the transition to online learning, little work has investigated to what extent the transition in the other direction (i.e., resuming in-person learning) carries costs as well. This online-to-in-person transition has been highly anticipated (with some thinking that going "back to normal" will have strictly positive outcomes), but has yet to receive much attention in the literature since educational institutions have only resumed in-person activities recently (if at all). This new transition direction warrants careful study, since it can help researchers better understand the needs of today's students, including the challenges they face and the educational resources and support systems they now expect to be available. Furthermore, critically examining *what worked better* online can help advance the community's understanding of what

constitutes a successful learning environment. In summary, this avenue of study would be valuable for understanding the future of education in the post-pandemic world.

In the quest to address this research challenge, this paper reflects on our experience teaching an introductory computer networks course, titled Computer Networks I, from the Fall 2020 semester through the Fall 2021 semester. The course is typically taken by electrical and computer engineering students in their third or fourth year of studies, and it covers layered network architectures with an emphasis on the TCP/IP protocol suite. Since it is an upper-year course, all the students who have taken it in the past two years have experienced at least one full year of in-person studies. Through a combination of quantitative survey data and written responses from students, the main contribution of this work is to expand upon the findings of the community by analyzing the costs and benefits students experienced for both online and (post-ERL) in-person learning, the latter of which has been impossible to study until recently. We explore students' perspectives on both labs and lectures in detail, and provide insights into their attitudes, concerns and satisfaction levels.

The rest of this paper is organized as follows. Section II discusses the challenges we faced with online teaching and the remedies we employed to address them. Our key takeaways from the online experience are presented in Section III, with an emphasis on what we have learned about the post-pandemic classroom. These learnings are supported by observations made upon the return to in-person learning in the Fall 2021 semester, and an analysis of student surveys conducted in the Winter 2021 and Fall 2021 semesters. We conclude with a summary and a discussion of future work in Section IV.

II. Challenges with Online Teaching

As mentioned in Section I, the Fall 2020 and Winter 2021 semesters were entirely online at our university. Unlike most upper-year engineering courses, our computer networks course is relatively light on mathematics, and instead focuses on protocols, algorithms, and systems-level thinking. Lectures and tutorials are dedicated to teaching the relevant concepts and problem-solving skills, while laboratory sessions are centered on hands-on design and analysis. Students are paired for the labs and are required to complete two large socket programming projects in the C language. In this section, we discuss the key challenges that we faced in the online delivery of our course. We analyze these challenges, explain the actions we took to address them, and draw connections to the literature.

The first challenge we faced on the teaching side was determining how to deliver lecture content remotely. In the Fall 2020 semester, about 30% of the students in our department were international students partaking in remote learning from their homeland. Due to different time zones, this meant that no single lecture time would be reasonable for everyone's schedules. To best approximate the classroom environment, we chose to hold synchronous lectures, where instructors and students were present in a virtual space simultaneously via the Zoom platform. The lectures were recorded and made available for offline viewing for those who were unable to

attend in real-time. The importance of this challenge was that it constrained us to make all lecture content accessible in an asynchronous fashion, to accommodate everyone (e.g., posting recordings of lectures). Although this was generally viewed as a good decision (even a necessity), it was not without flaws. First, it created a fairness issue, since it partitioned students into two distinct groups: those who had access to a synchronous classroom environment and those who did not have access to this learning resource. Second, it raised concerns about student engagement. Do students learn as well in a synchronous environment when they know recordings will be available? Do they even bother attending the synchronous lectures at all? If they choose not to attend synchronous lectures, are they sufficiently disciplined to engage in gradual learning, or do they tend to cram before tests?

Student engagement and participation are of utmost importance, since *learning* the content of a course is fundamentally a different process than just viewing it. It is a concern that online learning environments (especially asynchronous ones) may blur this distinction, especially since the technology students use for online learning (e.g., a laptop) is often associated with entertainment in their day-to-day lives. This situation is likely exacerbated by the fact that a typical engineering workload consists of 5 or 6 courses per semester; keeping up with such a large amount of educational content is not a task to be taken lightly. As we will see in Section III, many of our students expressed a preference for the discipline associated with in-person lectures, e.g., having a dedicated time slot where a classroom environment keeps them focused on a subject for an hour. In contrast, when engaging in online learning they felt distracted by other tasks more easily, tempted to try viewing lecture recordings at 2x speed, or tempted to participate in social media activities. This discussion illustrates some ways in which the education medium can affect the learning experience. This begs the question, what assumptions about learning and teaching hold for physical spaces, but not necessarily online or hybrid ones? Although a variety of researchers have studied similar questions in the past [8, 9, 10, 11, 12], this line of investigation has taken on new significance since the advent of ERL. Addressing this question is beyond the scope of the current work, but we draw attention to it because we believe it is tightly coupled to the challenges educators faced with online teaching during the pandemic. For example, the authors in [1] remark that online education focusses more on content than on how educators communicate that content to students. However, the preceding discussion suggests that for an effective learning experience, content needs to be intentionally matched to the medium through which it is communicated. The authors in [13] recognize this and comment that the lack of social presence in digital spaces results in decreased student interaction, motivation and engagement—we will revisit this comment in Section III. In summary, we believe this idea that the education medium affects the way students digest content is useful to keep in mind when investigating how teaching modalities affect student engagement and participation.

We consider a student to be engaged when they integrate the course material into their way of thinking—this might occur when the student develops curiosity about the material or has practiced applying it. While we could try our best to foster curiosity in students, we could exert considerably more control over when they practiced applying material. This became especially

relevant when, about halfway through our first online semester, we noticed that synchronous lecture attendance had dropped by a considerable amount—only about half the class was attending. While we were not opposed to students relying on the lecture recordings if that suited them best, we became concerned by the thought of a large portion of the class using the recordings to cram for tests. To mitigate this risk and encourage gradual learning, we chose to dedicate a small percentage of students' final marks to lecture quizzes, and to support the students in different time zones, we chose to impose a time limit of 24 hours for each quiz. The quizzes were neither difficult nor lengthy; the objective was simply to incentivize students to keep up with the material and apply what they were learning, similarly to the low-stakes quizzes idea discussed in [6]. In the following paragraphs, we will discuss the issues of engagement and participation in more detail and will revisit this topic with an analysis of survey data in Section III.

The online environment greatly isolated students; as such, fostering a welcoming environment for student participation was more important and challenging than ever before. Synchronous lectures were our starting point for addressing this issue since they gave students a chance to ask questions. However, this virtual environment could not replicate all the valuable social benefits of a classroom, e.g., the one-on-one student-teacher interactions that often occurred before and after in-person classes. To compensate for this, we ensured that our teaching team had a strong virtual presence on Piazza, a platform for discussion between students and instructors. As an illustration of how Piazza participation changed throughout the pandemic period, we summarize activity indicators in Table 1. The number of posts refers to the questions asked by students, while the number of contributions is the total number of posts, responses and edits. Table 1 shows that the number of posts and contributions exploded during the first semester online, with a 221% increase in the number of contributions relative to the previous year (in-person). This peak was sustained throughout the pandemic response, and even with the return to in-person learning (Fall 2021), the contributions were still up by 135% relative to the previous in-person course offering. There could be various reasons for why Piazza participation skyrocketed during the pandemic, which we will now address. First, students were no longer able to make impromptu visits to the teaching team's offices. Even when we told students members of the teaching team were willing to arrange one-on-one meetings via Zoom, less than 1% of the students chose to utilize this offering. Together, these two points suggest that students felt more comfortable communicating with the teaching team asynchronously (e.g., via Piazza posts or emails) than synchronously (e.g., via Zoom), when they were not able to do so physically. Another factor that could explain the increase in Piazza participation is that some students did not have the opportunity to ask questions synchronously (or chose not to use it), e.g., those in different time zones. A unique consideration for the Fall 2020 semester is that students had to adapt to virtual learning platforms, which spawned new administrative questions, such as what the lab sessions would look like and how lecture recordings could be accessed. Another possible explanation for the Piazza trends may be the notion of positive feedback. That is, as more students asked questions and received quick and satisfactory responses, then more students may have felt it was worthwhile to participate. Finally, it may be the case that students were more inclined to discuss their questions with their peers prior to going online, while after going online

students were more inclined to ask their questions directly to the teaching team. Further study is required to determine what the exact reasons were for the increase in Piazza participation since, as shown by this discussion, there are many possible explanations related to the social factors of the learning environment.

Table 1. Piazza Participation

Semester	Online?	Number of Posts	Number of Contributions
Fall 2019	No	131	401
Fall 2020	Yes	385	1287
Winter 2021	Yes	295	1046
Fall 2021	No	257	944

Besides creating challenges for student interactions, the online environment also demanded adjustments to administrative processes and coordination among the teaching team. For example, near the beginning of each online semester we were contacted by several students who wished to move to a different lab section to better suit their time zone and/or course schedule. Students who were not able to find a lab partner within a reasonable time were randomly paired with another available student. We periodically monitored the group compositions and tried to pair students with a new partner if we saw that their existing one had dropped the course. However, this random pairing resulted in groups where the partners were in disparate time zones, which made it difficult for them to collaborate on the lab projects in real-time. We opted to handle such scenarios on a case-by-case basis since they were an infrequent occurrence, but they could have been eliminated entirely through time-zone-aware group formation. Another administrative process that demanded adjustment was dealing with missing assignments and/or labs, which were awarded a mark of 0 by default. Since students were facing many new challenges both inside and outside of the classroom, we wished to provide reasonable accommodations to support their learning, and so were almost always willing to extend deadlines on a case-by-case basis. This way, most students kept on track, and we did not disproportionately penalize those who needed assistance. Part of what made this strategy possible was that our labs were software-based and therefore did not require access to any scarce resources, e.g., equipment that might be needed in an electromagnetics lab. This way, groups requesting a make-up opportunity could simply be asked to attend the next upcoming virtual lab session, or meet one-on-one with a teaching assistant (TA) virtually. From our point of view, the organization of the labs improved after going online because it spurred a modernization in the teaching team's coordination. Instead of relying on oral instructions, written instructions were provided. All information pertaining to labs was consolidated into an online spreadsheet for the teaching team, containing lab schedules, students' marks, and a record of approved accommodations. This modernization would have benefitted the teaching team pre-pandemic, and it is interesting that we only deemed it necessary once we could no longer be in each other's physical presence. Prior to the pandemic, the only time the teaching team met physically (except labs) was to mark exams. The approach

to exam marking changed after going online in the Fall 2020 semester: to distribute the workload of marking the midterm, each TA was assigned a single question and was given flexibility to complete the marking at their own pace. The result was that the marking dragged on for several weeks, and it was inconsistent due to ambiguities that the TAs encountered with the marking rubric. Due to students' complaints, half of the questions had to be re-marked. While the inconsistent marking could have been avoided by the TAs communicating more openly with the instructor, the entire experience motivated a fresh approach to marking the final exam. The day after the final exam, each TA was again assigned a single question, but this time they also joined a virtual meeting with the instructor. This allowed the TAs to immediately discuss points of confusion, resulting in greater marking confidence and consistency. Furthermore, this meeting was framed around the goal of finishing the marking by the end of the day, and surely enough all the exams were marked in approximately six hours. This approach for marking the final exam closely resembled the one that was employed in-person pre-pandemic.

III. Learnings for the Post-Pandemic Classroom

Having described the key challenges faced during the year of online learning, we now reflect on the experience of returning to the in-person classroom in the Fall 2021 semester. While the year of online learning had its fair share of challenges, it also motivated a modernization of our approach to in-person learning for the Fall 2021 semester. We focused our efforts on synchronous lectures but also provided lecture recordings which could be viewed asynchronously. We continued using lecture quizzes with a 24-hour time limit to encourage gradual learning. Labs were conducted in physical spaces, but we remained flexible and offered virtual options for students who were sick or approved for an extension. As mentioned in Section II, Piazza participation was sustained far above the pre-pandemic levels. Communication among the teaching team took place almost exclusively online, and the coordination for labs continued using an online spreadsheet. Nevertheless, this semester had its own unique set of difficulties, which challenged our assumption that in-person learning would be a return to something familiar. Late return students (i.e., those who missed the first one to three weeks of classes due to pandemic-related restrictions) constituted 10% of our class, making an asynchronous learning option a necessity in our eyes. Furthermore, even the students who chose to attend synchronous lectures insisted strongly on an asynchronous learning option. We also received far more requests for accommodation (i.e., petitions) than any previous semester. Although we were able to resolve these difficulties effectively, there is a lot to dig into when we consider the implications for the post-pandemic classroom. In this section, we analyze feedback from student surveys and report on our learnings.

A central question for this section is, did students have a better learning experience upon returning to in-person classes in the Fall 2021 semester? More generally, do students prefer virtual learning environments to physical ones? As we will see, the answer no doubt depends on who you ask; nevertheless, students' preferences and the reasons behind them exhibit interesting trends. Our survey in the Winter 2021 semester (online) was issued Jan. 27th, 2021 (approximately the 15th week of lectures since online learning began) and elicited a response

from 73 out of 135 students and our survey for the Fall 2021 semester (in-person) was issued Dec. 8th, 2021 (approximately the 12th week of lectures after in-person learning resumed) and elicited a response from 46 out of 134 students. Information about the questions and response options for the surveys can be found in Appendix A: Surveys. In short, we surveyed students on their experiences with synchronous and asynchronous learning (in general), and asked some questions specific to their experience in our course.

We begin with an analysis of how students rated the effectiveness of synchronous and asynchronous learning; data from both surveys are summarized in Table 2.

Table 2. Effectiveness of Teaching Modalities

	Synchronous	**Asynchronous**	**Synchronous with Recordings**
Winter 2021 (online)	7.1/10	7.0/10	N/A
Fall 2021 (in-person)	7.9/10	6.7/10	9.6/10

Table 2 shows that the effectiveness of synchronous lectures increased by 0.8 points upon returning to in-person classes; we can therefore conclude that students preferred in-person synchronous lectures over online synchronous lectures. Furthermore, by comparing the synchronous numbers to the asynchronous ones, we can conclude that on average, students preferred synchronous lectures to asynchronous ones in both semesters. The extent to which they preferred synchronous lectures was almost negligible for the Winter 2021 semester (0.1), however, synchronous lectures led asynchronous lectures by 1.2 points in the Fall 2021 semester, which is significant.

We take great interest in the fact that synchronous lectures with recordings available were almost *unanimously* agreed upon as *completely effective* by the respondents to the Fall 2021 survey. Although we did not ask students to rate this hybrid learning modality in the Winter 2021 survey, this data point still provides valuable insight about the Fall 2021 semester. In particular, the relatively lower numbers for synchronous and asynchronous lectures *must* mean that these teaching modalities are complementary, i.e., each one has something that the other lacks, with respect to students' learning preferences and needs. For example, a student who rates asynchronous and synchronous lecture effectiveness low and high, respectively, may think asynchronous lectures are not a proper substitute for an active classroom environment. On the other hand, someone may have the opposite preferences if the flexibility that comes with asynchronous lectures improves their quality of life, e.g., someone who is trying to balance schoolwork with other activities. To investigate this closer, we treated the asynchronous and synchronous lecture effectiveness ratings as discrete random variables and visualized their joint probability mass function (PMF), as shown in Figure 2 and Figure 3.
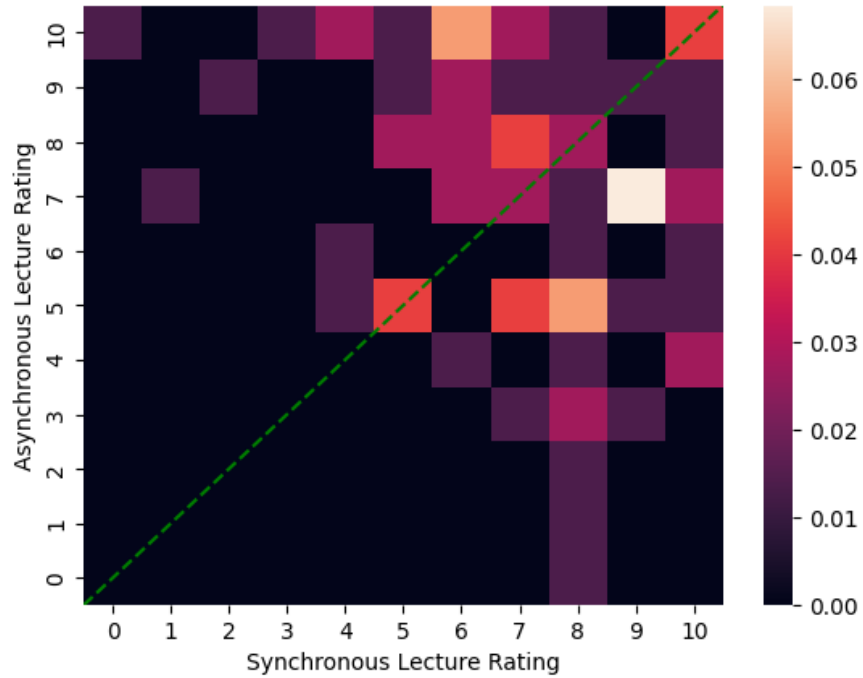
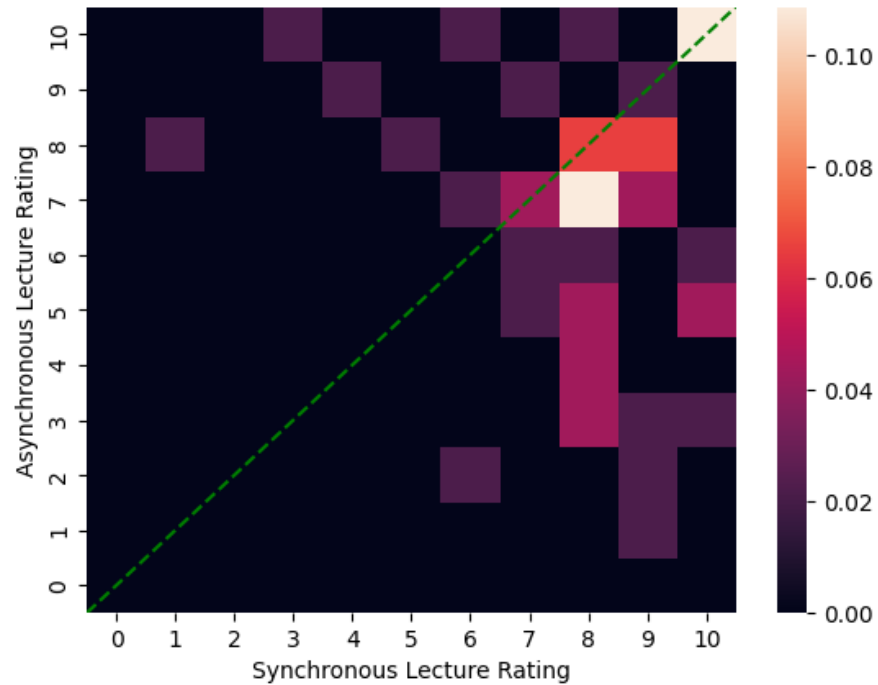Figure 2. Winter 2021 (online) lecture effectiveness rating joint PMF.

Figure 3. Fall 2021 (in-person) lecture effectiveness rating joint PMF.

In Figure 2 and Figure 3, most ratings fall in the upper-right triangle of the grid, meaning that students found at least one of the teaching modalities to be mostly effective. Ratings falling along the diagonal (i.e., the green $y = x$ line) represent students who found both teaching modalities to be equally effective. Ratings above the diagonal indicate students who found

asynchronous lectures more effective than synchronous ones, while the opposite is true for ratings below the diagonal. The probability mass on, above, and below the diagonal are summarized in Table 3; analyzing this table will help us understand what the heatmaps signify.

Table 3. Probability Mass On, Above, and Below the Diagonal

	On Diagonal	**Above Diagonal**	**Below Diagonal**
Winter 2021 (online)	0.15	0.41	0.44
Fall 2021 (in-person)	0.24	0.17	0.59

Table 3 shows that the Winter 2021 survey results were much more polarized than the Fall 2021 ones. The results from the Winter 2021 survey suggest that students tended to prefer one teaching modality over the other but were approximately equally divided about which one they preferred. The ratings in this semester also exhibited a large variance, and a Pearson Correlation Coefficient of -0.25. The Fall 2021 survey results also exhibited a negative correlation coefficient, but with a smaller magnitude of -0.13. The fact that the ratings for synchronous and asynchronous lectures are negatively correlated means that, on average, students who liked one teaching modality tended to dislike the other one; the extent to which this is the case is captured by the magnitude of the correlation coefficient. This is a deeper story than what is immediately apparent from the averages in Table 2. Furthermore, students' ratings shifted drastically in the Fall 2021 semester, with a strong indication that synchronous lectures were more effective than asynchronous ones, and a secondary indication that they were equally effective. It is interesting that the proportion of students who found asynchronous lectures more effective than synchronous ones decreased by 24%. For additional context, we will now analyze students' estimates of their average synchronous (in-person) lecture attendance for our course in the Fall 2021 semester, the results of which are shown in Figure 4.
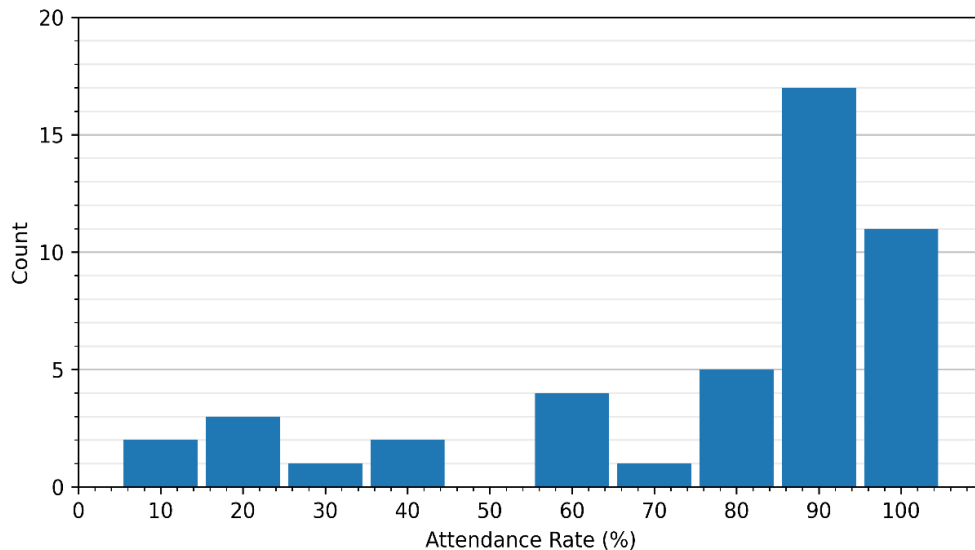

Figure 4. Histogram of synchronous lecture attendance rates for ECE361 (Fall 2021, in-person).

The data in Figure 4 reveals an average attendance rate of 77%, with a median of 90% (left-skewed); these indicators of central tendency are unsurprising upon inspecting Figure 4. However, we do find it surprising that the synchronous lecture attendance rates were so high, given that we made recordings available (not to mention that students *wanted* them). Unfortunately, we did not collect granular attendance data in the Winter 2021 survey, although 78% of respondents indicated (in a binary fashion) that they attended the online synchronous lectures. To help make sense of the quantitative data for lecture effectiveness and attendance rates, we will now dive deeper into the Fall 2021 survey results by analyzing students' written responses.

We begin by looking at the top reasons students chose to attend in-person synchronous lectures. The most frequent reason was the interaction with the instructor and their peers: participating in lecture discussions, being able to get quick response to their questions, and even gauging whether their peers were also struggling with the same material are a few to name. One student who gave asynchronous lectures a 5/10 rating and synchronous ones a 10/10 rating explained this as follows: "*I like the interaction with [the] professor and ability to ask questions in real time and gauge if my peers are also struggling with the material*". The social elements highlighted by this student appeared in other students' responses, e.g., "*I went to class because it was easier to hear questions from students and participate more in person*", and "*in person lectures are often easier to understand when the professor is visible and other students are there*". Together, these three quotes speak to how the social environment of the classroom plays a direct role in engagement, corroborating the statement from [13] discussed in Section II. Remarkably, gauging whether peers are struggling, hearing questions from students, and visually experiencing the presence of the professor and other students are all phenomena that are *independent* of the material *and* of the learner's own participation. These sources of sensory information would therefore appear to be ancillary to the learning at hand and are certainly lost when a classroom is virtualized using current technology. To this end, the warning from [14] rings true: "*technological changes in our modes of communication…change [a culture's] cognitive habits, its social relations, its notions of community*". The second most frequent reason that students chose to attend in-person lectures was that it improved their ability to keep on track with the course. As one student stated, "*If everything were all online, I would delay watching videos and would not keep up with the course*". This sentiment is echoed by others, e.g., "*in-person lectures build up a better routine*", and "*if there are only recorded lectures I sometimes neglect watching them on a regular basis which causes them to pile up*". These quotes speak to how discipline and gradual learning are aided by the physical classroom; perhaps this is because physical learning environments are what most students have acclimated to throughout their lives. The third most frequent reason for attending in-person lectures was that the physical learning environment presented students with fewer distractions. In the words of our students, "*in-person forces me to use the allocated lecture time to focus on a single class rather than trying to finish 3 things at the same time*", and "*In-person is [a] much more effective way of learning and it helps me focus*". The first quote touches on a point mentioned earlier: the devices students use to conduct online learning have most likely *not* been associated with serious activities for most of their lives, but rather entertainment. On this basis alone, it is no surprise that students should have difficulties

remaining focused, especially with close to 40 hours of class per week (not to mention social factors, etc.). In summary, many of the advantages of synchronous lectures would appear to be unique to the in-person setting, which helps explain why the question of asynchronous vs. synchronous lectures was so divided in the Winter 2021 semester, but firmly on the side of synchronous in the Fall 2021 semester.

Despite the benefits associated with in-person synchronous lectures, there was almost unanimous demand for lecture recordings in the Fall 2021 semester, even though synchronous lecture attendance was high. We now discuss some of the reasons for this, which overlap with the reasons why some students preferred asynchronous lectures over synchronous ones. Perhaps unsurprisingly, the most common reason why students wanted access to asynchronous lectures was that they would not have to worry about falling behind if they missed a lecture. The age-old method for dealing with such circumstances would be asking a peer for notes, but recordings offer benefits such as being able to learn from the same source as everyone else. As explained by our students, "*the lecture recordings made me feel less worried when I was not able to attend lectures due to illness*", and "*[it] was a tough time managing work and staying up to date with things. Which is also why I benefited a lot from the recordings*". The first student mentioned illness, which has been a top priority for our university due to the pandemic (anyone experiencing symptoms was required to isolate at home). As such, students who fell sick were put at a significant disadvantage unless their classes offered lecture recordings. The second quote touches on a different issue, which is that students' circumstances outside of school can vary drastically, and synchronous education can prove very difficult for people who need to balance a lot of commitments, e.g., students working part-time jobs, student athletes, etc. The flexibility associated with asynchronous lectures can enable these students to optimize across all their commitments and achieve more balanced lifestyles. Other students had assignment deadlines coinciding with lectures and chose to skip the synchronous lectures to focus on their assignments, since they could view the material asynchronously later. The next most common reason why students wanted asynchronous lectures was that they could review difficult material. Student comments such as "*I use recording solely for refreshing my memory of lecture's content or catching up something that is complicated*" shows that asynchronous lectures provide a gateway to more practice and repetition for those who need it. Other reasons why students wanted access to asynchronous lectures included being able to get through them faster (e.g., fast-forwarding parts that make sense, and watching more slowly for difficult parts) and being able to pay better attention in class. For the latter, students mentioned that the availability of the recordings shifted their focus away from scrambling to take notes during synchronous lectures, and towards listening to the lectures and digesting the material in real-time. In summary, asynchronous lectures were able to benefit many students in ways that synchronous lectures could not. Most of our respondents saw these benefits as additional learning resources, rather than a replacement for synchronous lectures. Those who viewed asynchronous lectures as their primary learning resource tended to be students with overwhelming extracurricular commitments, or students who found recordings a more efficient learning medium.

We have analyzed the impact that both asynchronous and synchronous lectures had on our students' engagement, discipline, and learning processes. Before moving on, it is worth discussing some feedback provided by students that is not directly related to lectures. Group work is typical in engineering courses and is often a mixture of technical problem solving and written communication. For example, as mentioned in Section I, students in our course were required to work in pairs for the programming labs. One student's feedback from the Fall 2021 semester indicated that they found it much easier to work on team programming projects *in-person*, and that in the previous online semesters, they struggled to work effectively with remote teammates. Since much professional software development these days occurs remotely, this could suggest some gaps in the software foundations at our university, particularly where software intersects project management. Also related to the programming labs, we received feedback that it was easier to obtain in-person lab support before the pandemic. This could simply mean that our course lacks in-person lab help relative to other courses with a lab component, but it also reminds us that (like with lectures) learning preferences and needs vary across students for project work. Although we endeavoured to make Piazza a beneficial learning resource (see Table 1), we recognize that it is not a *replacement* for in-person help—the medium is different, and therefore so is the content. That is to say, writing messages on Piazza demands a different type of discourse than having the same discussions verbally, not to mention that composing written messages takes students far more time. Since the medium and content are different, so is the collection of students who will feel supported by it. A final piece of feedback worth discussing is that, like the "Zoom fatigue" associated with online learning [15], our students reported a "switching fatigue" associated with the return to in-person learning. One student described this switching fatigue as a "readjustment" which caused their Fall 2021 semester to be a less effective experience than their previous semesters in-person, even though they felt the learning resources in the Fall 2021 semester were objectively better. As of this writing, the Winter 2022 semester is currently online at our university, which requires students to switch their learning techniques yet again, relative to the previous (Fall 2021) semester. Given the uncertain future of the pandemic, and its tendency to come in waves, we believe it is important for educators to be aware of the negative impacts to students' well-being associated with switching learning environments. That is not to say that learning environments should remain constant until the pandemic is under control; rather, we argue that educational institutions need to prioritize building supportive learning environments and communities for students [3]. In this regard, the work from [16] may be relevant, which suggests placing peer mentors in learning spaces to nurture the social aspects of learning; learning analytics [17, 12] may also be a useful tool to help understand and optimize learning environments, although it is not without concerns [18]. The following concludes this section by discussing actions taken to support our students better and identifying opportunities for improvement.

First, a drastic increase in term work petitions, particularly for the programming labs, was observed during the Fall 2021 semester. At the same time, our grading of the programming labs revealed a similar increase in misunderstandings of C programming concepts. These also occurred occasionally in previous semesters, but not to the same extent as the Fall 2021 one, raising the question, *why*? To make the first point more concrete, there were a total of 7

programming lab petitions in the Winter 2021 semester (each from a unique student), while there were 28 in the Fall 2021 semester (from 24 different students). Students' reasons for requesting accommodations were overwhelmingly related to health, e.g., feeling sick and therefore not able to finish their code on time/not able to attend in-person lab assessments. Lab petitions usually resulted in an extension on the order of a week, after which time each student would meet with a TA virtually for assessment. Although this technique began during the fully online period, it continued to be useful in-person for handling exceptional cases. Such cases typically ended with the student successfully completing their programming project. Even though these students required time beyond the deadlines, they were still able and willing to put in the work needed to achieve success. This begs the question: what does this tell us about how academic culture is evolving? On the one hand, one could argue that these practices are teaching the next generation of students that deadlines do not have consequences. This is especially relevant now that many companies have opted to let their employees work from home without rigid schedules—provided that they get their work done on time. This shift in industry might suggest that time management is more important now than ever, since people are being given more flexibility in how they manage their time. On the other hand, such flexibility and support are likely to benefit students' mental health (an issue discussed in [2]) and it would not be fair to punish them for circumstances beyond their control (such as getting sick). While the increase in petitions would not appear to be indicative of academic matters, it is difficult to say the same about the C programming issues we observed. In the Fall 2021 semester, we ran into far more students than ever before who lacked a proper understanding of memory allocation concepts and good C practices, e.g., fixing compiler warnings and avoiding undefined behaviour. There were certainly some excellent students, but we felt that the students' programming skills were lacking compared to previous years, on average. Most students in our course were in their third year, meaning that their second year was fully online. During their second year, they were required to take an important programming course which aims to develop systems programming skills in C++ and instill good software development practices. It is possible that this course was less effective when it was fully online, but further research is required to get to the root cause of this issue. To address these shortcomings for the future, we added sections to our lab handouts that caution students on the most common programming errors we observed previously.

Finally, one of the students stated that their in-person experience in the Fall 2021 semester was worse than their in-person experience pre-pandemic because they worried that being on campus may have been an unnecessary risk to their family's health (especially with the rise of COVID-19 cases as we approached our exam season in December 2021). This student reported that only 2 of their courses, besides ours, offered lecture recordings; recalling that a typical engineering course load can be 5 or 6 courses per semester, this means it was *necessary* for this student to be on campus for about half of their lectures. Additionally, midterms and final exams were only offered in-person for all courses. This was partially due to academic integrity concerns associated with online exams (an issue which [6] explores in detail). Although this student's worry was a single voice among our respondents, it draws attention to the fact that our university's decision to return to in-person classes, without requiring teachers to implement an asynchronous learning option, has forced some students to put themselves in uncomfortable

situations health-wise. Because of this, it is our opinion that lecture recordings should be provided for all courses—at least during pandemics. Optional asynchronous learning has many benefits and few drawbacks that cannot be remedied, as was discussed throughout this paper.

IV. Conclusions and Future Work

In this paper, we reflected on our experiences teaching an upper-year engineering course online and in-person during the COVID-19 pandemic. In Section II, we described the four main challenges we faced during the transition to online learning, along with the solutions we employed. The first challenge was determining how to deliver lecture content remotely, and to address this, synchronous lectures *and* recordings were offered to students. However, recordings raised concerns about whether students would be sufficiently disciplined to participate in the gradual learning process that is essential to engineering subjects, or whether they would just cram before exams. To address this second challenge, a small mark percentage was dedicated to straightforward quizzes based on each lecture, which were available for 24 hours. These quizzes incentivized keeping up with the course material and gave the students a way to immediately solidify their learnings. The third challenge was that online learning isolated students and required new mechanisms to prevent them from becoming passive observers. Offering online synchronous lectures gave students a chance to ask and answer questions in real-time. We also observed massive growth in students' usage of Piazza—an online Q&A platform used in the course. Finally, moving online motivated a revamp of the processes used for coordinating labs and marking exams. Throughout this discussion, questions were raised about how online environments affect students' engagement, participation, and overall learning.

Section III explored these questions in more detail, by analyzing survey results from the Winter 2021 (online) and Fall 2021 (in-person) semesters. We found synchronous lecture attendance rates to be similar across the two semesters, although students found in-person synchronous lectures more effective than online synchronous ones. In both semesters, students found synchronous lectures more effective than asynchronous ones. A statistical analysis of lecture ratings revealed that when students were constrained to an online environment, their opinions on whether synchronous or asynchronous lectures were more effective were polarized. However, students were united about synchronous lectures being more effective than asynchronous ones when in-person learning resumed. Despite this fact, they expressed nearly unanimous interest in having the *option* to attend lectures asynchronously. This motivated a deep dive into students' written responses from the Fall 2021 survey, which culminated in a study of the unique benefits associated with each teaching modality, and how they complement each other. On the one hand, students chose to attend in-person synchronous lectures because of (1) the interactions with the professor and their peers, (2) it helped them keep on track, and (3) they faced fewer distractions than when they watched recordings. While the first reason could also apply to online synchronous lectures, the second and third are only fully attainable in a physical learning setting. On the other hand, students found asynchronous lectures beneficial because (1) they did not have to worry about falling behind if they missed a lecture, (2) they enabled them to balance

extracurricular commitments better, and (3) they provided an alternative way to review difficult concepts. Following this analysis, we studied some miscellaneous student feedback and were reminded that variation in students' learning styles requires educators to offer various mediums to support them through, especially where project work is concerned. Finally, actions taken to remedy challenges and to better support students upon the return to in-person learning were discussed.

There are several avenues to consider for future work. For example, continuing to monitor student feedback as the pandemic response evolves, and comparing the new and old data. Such work could further our understanding of the support systems students require to be successful online, in-person, and after a switch between these two learning environments. Another avenue of investigation could be to study how academic culture has evolved throughout the pandemic, and what implications this has for the next generation of graduates' capabilities. What support systems might they need? Compared to previous classes, are they more passionate about learning, or less? Given that professional environments have also changed during the pandemic, we can ask: has academia evolved in a similar direction? Is it adequately preparing students for the future of professional life?

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Appendix A: Surveys

Table 4 and Table 5 provide samples of the questions and response options used in the Winter 2021 and Fall 2021 surveys, respectively.

Table 4. Relevant Questions from Winter 2021 Survey

Question Type	*Response Options*	*Item*
Rating Scale	0 (very ineffective) to 10 (very effective)	Do you find Asynchronous lectures effective? Please choose from scale of 0-10 with 10 being the most effective.
		Do you find Synchronous lectures effective? Please choose from scale of 0-10 with 10 being the most effective.
Multiple Choice	Yes, no	Do you attend the live lectures for ECE361?

Table 5. Relevant Questions Added for the Fall 2021 Survey

Question Type	*Response Options*	*Item*
Rating Scale	1 (very ineffective) to 10 (very effective)	How effective do you find in-person (synchronous) course offerings that provide recordings of the lectures?
Multiple Choice	0, 1, 2, 3, 4, 5	How many of your current in-person (synchronous) courses offer a recording of the lectures, excluding ECE361?
Rating Scale	0 (never) to 10 (all the lectures)	Please indicate what percentage of the in-person lectures in ECE361 you attended (10 = 100% of the time, 9 = 90% of the time, etc.).
Written Response	N/A	(Optional) If desired, please elaborate on the factors that affected your decision about whether to attend lectures in-person. (e.g., if you often attended in-person despite the fact that lecture recordings were available, why was that?).
		(Optional) What can we do to improve and support your education (learning)?
		(Optional) Is there anything you learned from online delivery of courses during last year that is assisting you in learning now? What have you learned that might improve the educational experience going forward?