

# Fully Integrating Remote Students into a Traditional Classroom using Live-Streaming and TeachBack

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**Abstract**—This paper proposes a simple method to add optional live-streaming to a highly interactive class in a way that reduces the number of students physically present in the classroom and doesn't hurt student performance. The effect of allowing live-streaming was analyzed by running an experiment where partway through the semester students in a flipped advanced level Computer Graphics class were given the option to attend the class remotely using a live-stream of the class with required use of a multi-featured audience response system (TeachBack). The results show that allowing remote attendance with TeachBack decreased the number of students attending physically from 93% to 75% of registered students and had no effect on unexcused absences. Students believed that their remote attendance was just as effective for their learning as attending classes face-to-face and analysis of the data confirmed their beliefs; they did however generally prefer being physically present in class. Our results suggest that appropriate use of live-streaming coupled with an Audience Response System can reduce some of the demand for large lecture halls by allowing a self-selected subset of students to attend some or all of the classes remotely. A large percentage of the students in the class felt that a live-streaming option should be added to most classes and this paper demonstrates that this goal is feasible and pedagogically justifiable.

**Index Terms**—computer-based instruction; online discussions; streaming media; learning management systems; personal response system; blended learning; distance learning; instructional change; flipped classroom; supplemental instruction; absenteeism

## I. INTRODUCTION

The traditional instructional model with an instructor and students meeting at the same time and same place in a classroom is still the dominant style of education, even though many institutions and researchers are actively exploring other models, such as distance education. In our view, the traditional model of instruction still provides the best teaching and learning environment due to the unbounded avenues of communication and interaction afforded by physical presence. However, the changing learning styles and needs of students and demanding schedules have forced the growth and adoption of remote instruction and distance education. The advancement of communication and information technology, as well, has contributed to the feasibility of distance education and enhancement of traditional classrooms by offering synchronous

and asynchronous facilities for communication, instruction, and distribution of learning materials.

In this experiment we set out to study the effects and feasibility of adding two features onto a flipped course pedagogy: (1) real-time video streaming of the class meetings and (2) web-based class-wide interactions. In the first part of the semester, students were required to be physically present and to use an audience response system to interact in class. This created a baseline for the course as a traditional flipped classroom. About halfway through the semester, students were given the option to either attend classes remotely or face-to-face, on a class-by-class basis.

The experiment was designed to facilitate a synchronous experience for the remote students similar to being in the classroom in person. Remote students could follow the in-class activities in real-time by watching the live-stream of the ongoing lecture in the classroom. The live video would guide the students on the content being covered, instructional activities being carried out and the various interactions happening between students and the instructor. We used the Echo360 Lecture Capture System to both archive a recording of the class for later on-demand viewing by students and to live-stream the lecture. This system is available in half a dozen large lecture halls at the University.

We used the audience response system TeachBack [1]–[3] to facilitate the interactions and other instructional activities between the instructor and the students, both face-to-face and remote. TeachBack is a web-based application that provides tools for use cases such as conducting individual and collaborative (formative) assessments, a way for instructors to collect and assess cognitive and affective feedback from students, and a way to more efficiently attend to student questions using a forum feature. The Echo-360 live-stream of the class provided a real-time access to the content and instructions happening in the classroom and TeachBack provided an interaction platform that allowed both remote and face-to-face students to participate equally well in all classroom activities.

As far as the existing practice of recording lectures for students' use, we do know that students are strongly in favor of having lecture recordings and that they find them useful to their learning in various ways [4], [5]. Some of the uses

include catching up on missed classes, reviewing complex concepts, revision for exams and assessments, as well as a general learning tool [6]–[8]. Furthermore, various research studies have shown that access to lecture recordings has little to no effect on class attendance [6], [7], [9]. Some studies reported lower class attendance when students had access to lecture recordings [10]–[12], however, the differences disappeared when demographic differences among students were considered. Moreover, in a study where access to lecture recordings was reported to result in lower class attendance, the effects on attendance had a negligible effect on student attainment [13].

Similar to the mixed literature results on effects on attendance, access to lecture recordings has also been shown to have little to no effect on student learning outcomes [14], [15], whereas studies by Phillips et al. [16] and Traphagan et al. [13] suggest that frequent access to recorded lectures leads to more positive results and learning behaviors. This review on the impact of lecture recordings sets a perspective on what to expect from the addition of the real-time synchronous and interactive lecture streaming as a remote alternative to face-to-face attendance.

The rest of the paper is organized as follows. Section II presents more detailed related work and background on the use of synchronous and asynchronous learning environments as well as discussing the various forms of distance learning environments. Section III covers the experimental design which describes the class, tools, and type of data collected. The major results are presented in Section IV and the conclusions in Section V.

## II. BACKGROUND AND RELATED WORK

Online instruction and learning are rapidly becoming alternatives and supplements to the traditional classroom instruction [17]. Students enroll in online courses and rely on online learning resources for a variety of reasons, including their desire for more flexibility. Asynchronous online environments offer anywhere and anytime learning; these include MOOCs, virtual classrooms, and learning from pre-recorded lecture videos. On the other hand, synchronous online environments offer anywhere learning but require students to tune in at specific class times. Studies show that students succeed in online learning environments when there are significant interactions and active participation [18], [19] which also results in greater student satisfaction and engagement [20], [21]. In this work we attempt to create an online learning environment with real-time interactions and active participation for remote students that is as close as possible to being physically present in the classroom.

Implementations of the real-time synchronous option for remote students similar to our approach are much less studied. Some researchers [22]–[26] have proposed or implemented lecture-streaming with real-time interaction among students and the instructor. However, most of the interactions are limited to the use of forums, text messaging and media sharing,

which are still inferior to the interactions possible in a face-to-face classroom. Our implementation offers a more fully interactive and synchronous classroom experience for remote students through the use of TeachBack in enabling the important social, teaching and cognitive elements of presence [27], [28] for online environments.

Most of the interactions and instructional activities in the class were mediated using TeachBack, and so there was very little difference in the classroom experience between remote and face-to-face students. This type of real-time hybrid class structure has the potential of significantly affecting learning and teaching experiences, learning outcomes, class attendance behaviors, and potentially reducing the need for large lecture halls. There is a clear need to study how the learning environment (physical classroom, virtual class, hybrid class, etc.) influences learning [29]–[32] and to understand why attendance in large lectures is decreasing and how to stop this trend [8], [33], [34].

## III. EXPERIMENTAL DESIGN

### A. The Class

The experiment was carried out during a flipped advanced level Computer Graphics course with enrollment open to undergraduate and graduate students. The course exposed students, through a hands-on introduction, to the science and practice of rendering three dimensional (3D) images using both resource intensive ray-tracing methods and real-time techniques using the GPU. The course was also intensive in mathematics and programming content and exercises. Students programmed the implementations of ray-tracing algorithms in Java and used it to create their own 3D scenes. They also created interactive web-based applications handling 3D graphics using WebGL and ThreeJS and they learned how to code programmable shaders using GLSL. The experiment was carried out during the fall semester of 2015 where 41 students completed the course. The course consisted of 26 highly interactive class meetings.

It is important to clarify that the particular selections of the course, the semester, and the corresponding student group were independent of the experiment design, and only coincided with the availability of the instructor and the resources to conduct the experiment. In our opinion, the experiment could effectively be performed during a different semester, course and group of students and we would expect to find similar results.

Typical class meetings started with pre-assigned readings in Nota Bene [35] where, as a graded homework, students were required to collaboratively add five comments or questions or to answer questions already asked by others in the readings. Nota Bene is a web-based annotation tool that allows users to annotate arbitrary PDF files online in a collaborative fashion. The tool is a product of active research and multiple development cycles from Massachusetts Institute of Technology (MIT) and it has been used in real classes since 2009. The instructor used students' responses in the readings as guidance for the short lecture demonstrations during class. The short lectures

included presentations from PowerPoint slides, websites and code samples. The goal was to make sure that students were familiar with all concepts from the readings and any raised misunderstandings were resolved before engaging students in active activities with the materials.

Since the class followed a flipped pedagogy, most of the class time was devoted to engaging students in hands-on tasks that re-enforced their understanding and mastery of the covered concepts. The course was programming intensive and thus a popular activity was coding demonstrations on implementing specific concepts where the instructor would write code snippets with students doing the same in their personal computers. Oftentimes, students would be asked to finish components of the code, and the instructor would select students to share and demonstrate their approaches. Another popular activity was formative assessment using the Questions and GroupWork tools offered in TeachBack. The Questions tool was devoted to assess simple concepts or programming questions where students would answer quickly and individually. GroupWork was used for more complex concepts and longer programming challenges where more time would be allocated for students to discuss their responses in small groups. During these formative assessments activities, the students who are remote and those in class would both participate equally. In GroupWork, student groups are generated randomly based on recorded attendance for the day and therefore the three students making a group could include students who are remote as well as those physically in class.

The Feedback tool in TeachBack was used to more quickly get an assessment of how students were doing during class with respect to the concepts just covered. For example, at various points during class the instructor would ask students to assess how they were doing and provide feedback. The instructor would then assess the percentage of students who reported being 'Bored', 'Confused', or 'Engaged' together with any accompanying comments. This was particularly important to the learning and teaching for the remote students. A particular emphasis was also given to the use and monitoring of the Forum where students would ask and answer questions about the concepts being covered in class. The use of the Forum was particularly important for the remote students as this was the only way to get personal attention from other students and the instructor.

### B. Echo360 Lecture Capture System

Echo360 was set to automatically record each of the class meetings, from start to end. The recordings are accessible through a web-based component of Echo360 where students and instructors can browse and playback recordings of lecture meetings after logging in. This practice has been a success and an important component of many courses at the university. Students appreciate the value and usefulness of the recordings, both as a supplement to face-to-face class attendance as well as an occasional replacement for when classes are missed.

Out of the 26 class meetings in the semester, the last 16 were also live streamed in real-time. Starting at the 11th

class meeting, students were informed about the new addition to the course and that they were freely allowed to attend the class remotely as long as they watch the live-streaming and participate fully in class activities and interactions using TeachBack.

### C. Data Collection

By adding the remote attendance part-way in the semester, we hoped to be able to compare and discover various measures of the learning and teaching experiences before and after the change. Most importantly, we hoped to learn about the feasibility of the practice from the students' and instructor's perspectives and how it affected, if at all, students' performance in the course. We also expected to learn how remote attendance would affect students' motivation, face-to-face class attendance and the use of resources such as the lecture recordings. We hoped that allowing students the option of attending class remotely could increase attendance as students who were sick or traveling (e.g. with their sports teams or at interviews) could still attend.

We collected data for analysis from four sources. From TeachBack, we gathered data on student attendance and performance on formative assessments using the Questions and GroupWork tools. For each Echo360 lecture recording, the system recorded all student interactions with the recording. We therefore had access to data such as whether a recording was watched live and for how long, and the number of times and duration that a student watched a particular recording on demand. At the end of the course a survey was given to students in order to gather their perspectives and evaluation of the course style and their learning experiences, especially with respect to remote attendance and assessment of the technical tools used to implement it. For overall performance in the course, we used students' grades in a final cumulative written exam which was administered at the end of the course and covered most of the materials taught in the course. We also used the overall course grade which included students' overall participation (in TeachBack and in pre-class reading assignments), three programming projects throughout the semester, and the final written exam.

## IV. RESULTS

### A. Effects on Absenteeism

For this analysis we compared the numbers of students who attended classes (remote or face-to-face) and those who were absent (didn't show up in-person or remotely). Contrary to our expectations, allowing remote attendance did not increase students' overall class attendance, but it did not decrease it either. We had hoped for a significant reduction on the average number of students who would miss classes (not attending in-person or remotely). Considering the first 10 classes without live-streaming (Part 1), and the last 16 classes with live-streaming (Part 2), the average number of absentees per day was approximately the same: there were 2.9 absentees during Part 1 and 2.875 absentees during Part 2. Since the class had 41 students, the average daily attendance was 93% which

includes students attending remotely and those physically in the classroom. Anecdotally, attendance in classes tends to decrease toward the end of the semester [11], so the fact that there was no decrease in the second half, could be a positive outcome.

TABLE I  
ABSENTEEISM, GROUPED BY NUMBER OF CLASSES MISSED BY STUDENTS DURING PARTS 1 AND 2 OF THE COURSE.

Missed Classes	Students (Part 1)	Students (Part 2)
0	23	17
1	11	12
2	5	8
3	0	2
4	2	0
6	0	2

Students only attend lectures if they perceive 'value' in doing so [8], especially in light of the availability of lecture recordings. Participation was 20% of the course grade, which may be part of the reason that attendance was so high throughout the semester. Table I shows the actual absenteeism during Parts 1 and 2 grouped by the number of classes missed by students.

We also analyzed the usage of lecture recordings by the students who were absent during those recorded classes. Over the duration of the semester there were a total of 72 class absences. However, 24 (or 33.3%) of the time these specific students would later watch the lecture recordings for the specific missed classes. This rate was approximately the same during classes before and after the introduction of live-streaming, 35.7% and 31.8% respectively.

### B. Student Use of Live-streaming

Attending classes remotely was embraced by students, with 75% of the class trying at least once and 18% attending remotely for at least 8 (or 50%) of the 16 live-streamed classes. Out of the 16 classes, Echo360 recorded a total of 121 significant live-streaming sessions from students. This averages to about 7.56 students live-streaming per day. This implies that, on average per class day, only about 75% of the registered students were physically present in the classroom, with 18% attending remotely and the remaining 7% being absent. Table II shows remote attendance counts grouped by the number of classes live-streamed by specific students.

Echo360 data was used to analyze students' commitment patterns when watching the live-stream of the class remotely. The duration for each class was 80 minutes and from each live-viewing session that was recorded in Echo360 we were able to calculate the percentage of the class duration that was watched live during each viewing session. A total of 121 live streaming sessions were recorded, and as seen in Fig. 1, 84 viewing sessions (about 69%) streamed at least 50% of the total class time, and 52 sessions (about 43%) streamed at least 90% of the total class time. The behavior demonstrated in Fig. 1

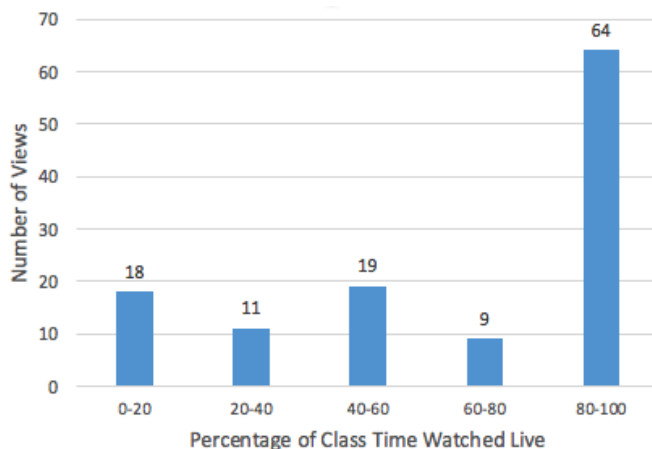


Fig. 1. Distribution of percentage of class time watched in live-streaming sessions.

shows that most remote students committed to streaming entire class sessions, which is satisfactory since remote attendance was supposed to replace face-to-face attendance which should normally last for entire class duration. However, there is a fair number of remote attendees who watched only part of the class sessions, perhaps due to oversleeping or having to leave early for another commitment.

### C. Effects on Learning Outcomes

We looked for correlations between remote attendance and each of final exam and overall course grades in order to study whether remote attendance had any effect on the learning outcomes of the students, especially for the students who heavily used the option. The final exam was a cumulative exam that covered most of concepts taught in the semester, it represents the best estimate on students' mastery of concepts. The overall course grade included scores from final exam, class participation (engagement in class activities on TeachBack and in pre-class reading assignments), programming assignments, and three major programming and design projects. Course grade represents a more rounded mastery of material and excellence in the course.

Linear regression was used to study correlations between levels of remote attendance and each of final exam grade and overall course grade. As seen in Table III, the regression analysis shows no statistically significant correlations with concepts mastery or overall performance in the course: sta-

TABLE II  
REMOTE ATTENDANCE, GROUPED BY NUMBER OF CLASSES LIVE-STREAMED BY SPECIFIC STUDENTS.

Classes	Students	Percentage of Class
0	10	25%
1	10	25%
2 - 5	14	32%
7 or More	7	18%

tistical significance was measured at ( $p < 0.05$ ) and the final exam and course grades have p-values of 0.459 and 0.343 respectively. There is, however, a very weak negative effect (as demonstrated by the negative coefficient values), but the  $R^2$  values of 0.0145 and 0.0236 imply the regression models are indeed very poor fits for the data. The hint of negative effect could imply that attending classes in-person is slightly superior to attending remotely.

Another regression analysis showed the negative impact that absenteeism has on course performance. This is demonstrated in Table IV. There is a strong negative correlation ( $R^2 = 0.3090$ ) between absenteeism and course grade, which is statistically significant with a p-value of 0.0002. It makes sense for absenteeism to have a more significant impact on course performance when a course is flipped with high levels of interactive learning activities. Even though absenteeism having a negative impact on course performance is an obvious result, the fact that there is no such negative impact for students who live-streamed demonstrates that remote attendance is an adequate substitute for physical presence in the classroom.

We performed further analysis by isolating the participation grade and its role in the course grade in order to get a better comparison between remote attendance and absenteeism with respect to their impacts on the learning outcomes. As mentioned earlier, class participation (measured as overall engagement in class activities on TeachBack and in pre-class assignments), counted as 20% of the course grade. And thus you would expect absenteeism to have a significant impact on course grade due to the missed class participation points from the days missed. From each student's course grade, we subtracted the student's earned participation grade, resulting in a modified course grade that only reflects mastery of concepts and skills. The regression analysis results reported in Table V, show the relationship between the modified course grade and each of remote attendance and absenteeism. The comparison shows a statistically ( $p = 0.00283$ ) strong negative correlation between absenteeism and learning outcomes as measured with the modified course grade. According to the regression model, a single absenteeism can result in missing approximately 2

out of 80 grade points. Comparing the modified course grade and remote attendance, on the other hand, shows no statistical correlation (p-value of 0.519 with a very low  $R^2$  value). This result provides further evidence to suggest that attending classes remotely is comparable to attending them in-person.

Next, we looked at the impact of remote class attendance on class participation. Table VI shows linear regression results comparing the relationship between participation grades with remote attendance, as well as with absenteeism. With a p-value of 0.441 the results show no statistical correlation between the participation grade and attending classes remotely. In other words, based on how this class was implemented, attending classes remotely did not result in poor class participation. And as expected, there is a statistically strong negative correlation between absenteeism and the class participation outcomes. Indeed, according to the regression model, missing one class can result in missing on average about 4.5 out of 100 class participation points.

#### D. Use of Lecture Recordings

Lecture recordings were a popular learning resource to students. Indeed, the use of lecture recording was very significant to both students who attended classes face-to-face and those who attended remotely. A total of 273 viewing sessions were recorded in Echo360, accounting for live viewings, views on demand, or both. As seen in Fig. 2, 162 sessions (about 59%) were views on demand where students watched lecture recordings at their own times for catching up on missed classes, personal studying or reviewing for exams and quizzes. 94 sessions (35%) were live-viewings only, when students attended class remotely. An interesting observation is from the remaining 17 sessions (6%) when students first watched the recording live and continued on to watch on demand. This could count as the times when remote students were late and missed an earlier part of a class meeting and they had to watch an earlier section of the lecture from the completed recording. If this is the case, the percentages of class time that remote students viewed live, as discussed in previous

TABLE III

LINEAR REGRESSION ANALYSIS: COURSE GRADE VS. REMOTE ATTENDANCE AND FINAL EXAM GRADE VS. REMOTE ATTENDANCE.

Item	$R^2$	P-Value	Coefficient
Course Grade	0.0145	0.459	-0.356
Final Exam	0.0236	0.343	-0.749

TABLE IV

LINEAR REGRESSION ANALYSIS: COURSE GRADE VS. ABSENTEEISM AND FINAL EXAM GRADE VS. ABSENTEEISM.

Item	$R^2$	P-Value	Coefficient
Course Grade	0.309	0.0002	-2.995
Final Exam	0.0581	0.1338	-2.135

TABLE V

LINEAR REGRESSION ANALYSIS: MODIFIED COURSE GRADE VS. ABSENTEEISM AND REMOTE ATTENDANCE.

Item	$R^2$	P-Value	Coefficient
Remote Attendance	0.011	0.519	-0.261
Absenteeism	0.211	0.00283	-2.081

TABLE VI

LINEAR REGRESSION ANALYSIS: CLASS PARTICIPATION GRADE VS. ABSENTEEISM AND REMOTE ATTENDANCE.

Item	$R^2$	P-Value	Coefficient
Remote Attendance	0.0156	0.441	-0.476
Absenteeism	0.435	0.0000036	-4.568

subsection, would be higher, albeit while still missing the class time participation in interactions and activities.

Fig. 3, shows the distribution, by the number of recording minutes watched, of students viewing patterns of lecture recordings. As seen in the figure, most of the time students would watch short sections of lecture recordings. Echo360 allows students to start viewing at any point in the lecture and provides the instructor with a heat map showing which parts were most watched. These tended to be the short-lecture sections of the class. Interestingly, there are some students who would watch more than 80 minutes (a recording is 80 minutes long, this means re-watching sections multiple times) of a recording in a single session.

### E. Students' Opinions

This subsection summarizes students' survey responses on remote attendance using synchronous lecture streaming with participatory interactions facilitated with TeachBack. Most of the students liked the approach; with 51.5% of the class feeling that most or all of the other classes at university should implement this approach as an option for students. Moreover, 36.4% of the class felt that only some classes should implement it, and 3% felt that the approach was not helpful. When asked to compare the effectiveness of the remote attendance option to physically attending classes, 50% of the class said that the remote attendance was not as effective or less effective. However, 30.6% of the class reported that the option was just as effective or more effective. 19.4% of the classes responded that they did not try remote attendance and that they didn't have an opinion on the comparison.

Students were particularly satisfied with how we implemented remote attendance. Research literature shows that students prefer face-to-face classroom learning over the asynchronous non-interactive online modes, and our work at-

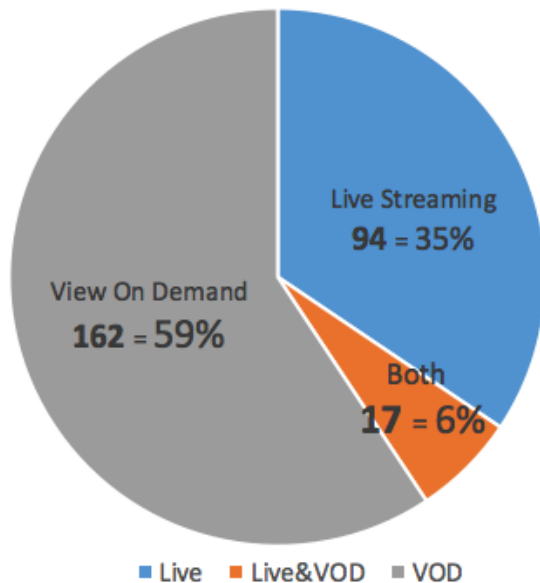


Fig. 2. Distribution between live streaming and view-on-demand in Echo360.

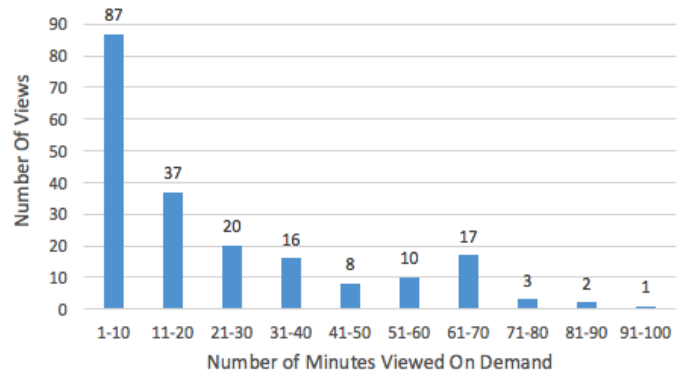


Fig. 3. Distribution of class recording minutes watched during view-on-demand sessions. Each class recording is 80 minutes long.

tempted to recreate the classroom experience though synchronous interactions and real-time participation in activities. According to findings by Farrington et al. [36], most students prefer the classroom as the primary learning space with online modes viewed primarily as a supplement to, or occasional replacement for, the face-to-face experience. In our experiment, however, 18% of our students chose the online mode over face-to-face more than half of the time.

On an effectiveness scale of 1-5 with 1 being 'not effective' and 5 being 'very effective', 87.2% of the students rated the effectiveness of TeachBack at 3 or above. On the effectiveness in using Echo360 to live-stream lecture meetings in the implementation, 79.4% of the class rated the system at 3 or above. These ratings show that students believed that the technical and pedagogical aspects of the implementation were practical and feasible in creating an effective alternative to attending classes face-to-face.

Looking at students' free response comments, the most popular advantage of the remote attendance option is convenience. Students liked the fact that they could attend the class from anywhere, including from home, during late commutes to school, and from out of town when they had to be away for various personal reasons. Attending class remotely was described by students as a valuable alternative when they have to miss class during sports trips or personal reasons like sickness, interviews or weddings.

Students were not fully satisfied with the video and audio quality of the lecture streaming, especially at times when it was hard to see projected screen texts and programming demonstrations. They thought that there was an inconvenient delay in getting responses to questions and group conversations when working online compared to face-to-face conversations in the classroom. Additionally, students thought that attending class remotely was prone to inferior concentration compared to being in class in-person. They also reported that video streaming depended on reliable internet connection; however, no one reported having an unreliable internet connection. These are all technical issues that can mostly be solved by better tuning on the Echo360 live-streaming parameters and reflect our relative inexperience in live-streaming a class for

the first time.

In terms of suggestions for improvements of the implementation, some students suggested that remote attendance is good when it is used as a backup option when it's absolutely necessary for students to physically miss classes, like when sick and during bad weather. Remote attendance would be less well-suited to seminar-style classes that are heavy on discussions. In GroupWork, many students felt that groups should be made up of students who are entirely remote or entirely in the classroom. Some students thought that remote attendance would be bad when students abuse it or get encouraged to miss classes, have poor class participation and distractions - factors that would put the students at the risk of poor performance, but we didn't see any of these phenomena.

## V. CONCLUSIONS

In this paper, we described an experiment exploring the effects of allowing remote attendance through a combination of live streaming and mandatory web-based individual and group activities during the class. The students were given the option to attend remotely in the second half of the semester. Our main research question was to determine the effects of allowing remote attendance on absenteeism, course grade, and in class participation.

We therefore collected data on which students attended remotely each day, how much each student used the web-based interaction tool each day, and the final course grades of the students, with and without the class participation component. We discovered that the remote attendance option was very popular. Three quarters of the students attended class remotely at least once, and 18% attended remotely at least half the time it was an option. We also discovered that remote attendance had very little impact on course grade, on absenteeism, or on class participation. Finally, the results of a survey at the end of the semester indicate that over half of the students felt this option should be available for most or all of their classes, and only 3% felt that it was not a helpful option.

This experiment has demonstrated that it is technologically feasible and pedagogically justifiable to add an alternative to class attendance using live lecture streaming with a web application facilitating class interaction and activities. Data analysis has shown that this approach does not negatively impact students' learning outcomes or increase class absenteeism. Indeed, the combination of live lecture streaming, lecture recording and the use of TeachBack has the potential to improve class attendance to nearly 100% with class involvement and participation in a synchronous or timely fashion. This approach provides more students with the convenience and flexibility of attending classes from anywhere while guaranteeing synchronous engagement with the rest of the class. It also allows students who would otherwise miss part or entire classes to still attend and participate remotely.

It is possible that the positive results obtained from this study may not generalize to other classes, other instructors, other educational levels, or other disciplines. This particular class made heavy use of active learning and it is not clear

if remote attendance would work as well in a traditional lecture style class as students could easily become distracted if they are not constantly required to interact with each other and respond to instructor's questions. The students in the class were highly motivated graduate students and upper-level undergraduates majoring in Computer Science at an elite university. It is possible that students in other majors or at less competitive universities might be less engaged in remote settings.

In the future, we plan on encouraging other faculty (at our institution and others) to try this approach, including the experimental design where the option is only available for the second half of the class. This should provide more data on the effectiveness of allowing remote attendance with mandatory web-based interaction. We expect that the remote-attendance option will be less effective in traditional lecture course, as compared to active-learning flipped-classrooms.

We also plan on making this option available to students for the entire semester and working on improving the technical aspects (sound and video quality) as well as adding more options to the mandatory web-based interaction tool. We expect that with these improvements, the remote-attendance option will be even more popular with students. We also suspect that many students will always prefer the in-class option because it provides the opportunity for face-to-face interaction with the instructor and their fellow students, and these interactions can be more socially rewarding.

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