Incorporating Active Learning Strategies and Instructor Presence into an Online Discrete Mathematics Class

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ABSTRACT

Online education offers an attractive alternative to face-to-face classes by providing flexibility to students and efficiencies for educational institutions. Leveraging online technology has the potential to help computer science departments offer a quality educational experience in the face of burgeoning enrollments. However, effective online course design is critical to student satisfaction and learning outcomes. In this paper, we describe the experience of converting a large face-to-face course in Discrete Mathematics to an online format. Particular care was taken to incorporate active learning strategies, such as clicker questions and interactive discussions, in order to enhance student engagement. We describe ways in which we cultivated an active instructor presence in the course through carefully designed pre-recorded videos, online video conferencing, and participation in Piazza, an online social learning platform.

In-class tests were specifically designed to provide a meaningful comparison of learning outcomes between a face-to-face and online offering of the course taught by the same instructor. The results indicate that there is no loss in student performance in the online course, even after accounting for demographic and academic differences between the students enrolled in the two courses. There is also no significant difference in performance for "at-risk" students. End-of-quarter student evaluations show a high level of student satisfaction with the online format, especially in regards to the opportunities to have questions answered and the positive presence of the instructor in the course.

KEYWORDS

Computing education, online instruction, active learning, quantile regression

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1 INTRODUCTION

Online courses have become increasingly popular in universities, with more than one in four students taking at least one online course in Fall 2014 [1]. Online education allows universities to use resources, such as classroom space, more efficiently. Universities with multiple campuses, in particular, can better meet the needs of students by allowing students at one campus to make use of open slots in courses offered by another campus.

Online education has the potential to offer significant benefits to students as well. The flexibility of an online class makes it easier for students to schedule their coursework around other commitments, and commuting students can save time in not traveling to campus for every class. Pedagogically, online instruction provides students the means to learn material at their own rate. Videos can be paused or replayed at points that are particularly difficult, as opposed to a face-to-face class where missing a small point can result in confusion for an extended period of time. In Computer Science courses, in particular, where class size has grown significantly in recent years, the opportunities for in-class interaction are diminished. By providing pre-recorded lecture content, an instructor is potentially freed up to interact more closely with the students in smaller discussion forums.

While online courses offer many advantages, there are a number of design challenges in planning an effective online course: how to structure the flow of the course so that students achieve the benefits of flexibility, but have enough structure to manage their time and stay on track; how to effectively organize the material so that students know what is expected of them by what time; how to foster a sense of community and connection in the class so that students feel that they are part of a shared experience; how to address student questions in a timely and effective way; how to foster an active and positive instructor presence.

In this paper, we describe our experience in creating an online class in Discrete Mathematics that addresses each of these challenges. We compare a face-to-face and online offering of the class taught by the same instructor in order to assess learning outcomes in the two different modes of instruction. Students in both courses were given four in-class tests to measure academic achievement. The test questions in the online and face-to-face tests were comparable so as to provide a meaningful comparison between the two groups. We find that there is no discernible difference in student performance even when accounting for students' academic preparation and demographic characteristics. Survey data from the students indicate that students had an overall positive experience with the online version of the class.

2 BACKGROUND

While online courses are often more convenient for educational institutions, faculty, and students, it is critical to ensure that students experience quality education in the online mode of instruction. Research results are mixed in comparing learning outcomes between online and face-to-face instruction, with some studies finding the face-to-face classes more effective, [2, 20, 25], and others finding online instruction comparable or even better than face-to-face, [3, 19, 21, 23]. Some studies suggest that online classes disproportionately affect less academically prepared students in a negative way [4, 13]. In addition, students often prefer to take courses face-to-face as opposed to online and, in particular, are hesitant to take difficult courses online [11].

Studies of online versus face-to-face classes specifically in the context of Computer Science education have also been mixed. Preston and Wilson [22] replaced face-to-face lectures with pre-recorded videos in one section of a CS1 course with no significant difference in performance between the two groups. Meanwhile another study in an upper-division database course showed that students in a face-to-face class performed better than a corresponding online class [20]. A study comparing groups of students who completed exercises in a data structures course online versus in class show now difference in performance between the two groups but a higher likelihood to drop the class among the online students [17]. These studies do not address specific course design questions aimed at making online classes more effective.

Meanwhile, active learning strategies have gained significant traction in recent years to enhance student engagement and learning in traditional face-to-face education. Freeman et al. [5] performed a comprehensive meta-analysis of active learning practices in STEM classes, showing that a variety of active learning strategies are effective in enhancing learning outcomes and minimizing failure rates. Haak et al. [9] show that a highly structured class, in addition to active learning strategies, can help the academic performance of disadvantaged students. More specifically, technology-based methods such as the use of clickers designed to increase student engagement in large classes can improve academic performance [18].

The success of active learning strategies is not limited to a face-to-face mode of instruction, as a growing body of accepted best practices in online education incorporate many features of active learning as well [8]. Other factors that make a difference in online course design include the structure of the course, high-quality interaction, and the presence of the instructor [14]. A recent study by Jaggars and Xu [12] that investigated the effect of different online course design features, found that high- quality interaction, including a positive and active presence of the instructor, was the single-most important factor in improved academic performance [11]. This empirical finding is in line with the educational theory that instructors need to form a personal connection with students in order to motivate them to succeed [10]. Our paper adds to this literature by showing how active learning strategies and instructor engagement can result in a successful online course. Course design features include:

- clicker questions embedded into pre-recorded online lectures
- interactive discussion by video conference
- active learning exercises built in to online discussions
- frequent on-camera presence of the instructor
- active use of Piazza, an online social learning platform.

3 COURSE DESIGN

ICS 6B and 6D are two quarter-long courses on Discrete Mathematics offered for computing-related majors. ICS 6B focuses on Boolean logic, proofs, and discrete structures (such as sets, relations, and functions) and is a recommended (not required) pre-requisite course for ICS 6D. ICS 6D covers induction and recursion, algorithmic number theory, and combinatorics. Students consider this course (ICS 6D) to be difficult, as the material is abstract and unlike the kind of mathematics they typically encountered in high school.

ICS 6D is required for most of the majors on campus related to computing, such as Computer Science, Computer Game Science, Computer Science and Engineering, and Software Engineering. Most students in ICS 6D are second-year students, with a significant number of first and third-year students in the course. The course is offered four times in the academic year, with two offerings during the Winter quarter to accommodate high demand. Over the last three years, every offering of ICS 6D had an enrollment of 300-400 students. This study compares two offerings of ICS 6D offered by the same instructor. The first offering was a traditional face-to-face version in Winter 2017 and the second was an online version in Winter 2019. Despite the two year gap between the offerings, the course content was the same.

3.1 Timing and Structure

Both the online and face-to-face versions of the class ran on a weekly cycle over a 10-week period. The face-to-face version of the class had three 50-minute lectures. The topics presented in one week (MWF lectures) were covered in a homework assignment due the following Wednesday. In the online version of the class, new material for the week was released at 8AM each Wednesday. Video lectures and reading activities were due the following Monday and the homework was due the following Wednesday. The choice to have lectures and reading due two days before the homework was designed to give the course more structure and force students to spread the workload across the week. Providing course structure is known to improve learning outcomes, especially among disadvantaged students [9].

3.2 Lectures

Each lecture in the face-to-face version of the class included 3-5 multiple choice clicker questions, for which students were given a small amount of participation credit. In the online class, the video lectures were presented as a Canvas "Quiz" for which students also received participation credit. Each lecture was divided into video segments that lasted 5-6 minutes on average, interleaved with multiple choice questions, often identical to the clicker questions given in the face-to-face version of the course. The total length of each video lecture was 20-40 minutes, in keeping with student preference for videos that are broken into shorter segments [6, 7].

In the experience of the instructor, students pay more attention to the explanation of a clicker question if they do not yet know whether they answered the question correctly. For this reason, the

instructor typically only reveals the correct solution to a clicker question after giving a conceptual explanation of the solution. In the online video lectures, we continued this practice by revealing the solution at the end of an explanation in the video.

Video lectures consisted of the instructor discussing course material while in screen-share mode using material typed in PowerPoint ahead of time and material written with a stylus as the lecture progressed. Camtasia was used to record and edit video lectures because it offers a rich set of tools for video editing. Preparation of the videos was by far the most time consuming aspect of developing the online version of the class. The instructor received a one-course teaching reduction to compensate for the time spent in this effort. In addition to the video lectures, each of the four major topics in the course was introduced with a professionally produced video featuring the instructor on camera with overlaid slides. Funding for the instructor course release as well as the video production were provided by an ILTI grant through the University of California [24].

3.3 Discussion Sections

3.3.1 Face-to-Face Course. The face-to-face version of the class was divided into discussion groups of approximately 100 students. Each group had two hours of discussion every week. The content of the discussion was based on student questions and sample problems prepared by the teaching assistants (TAs). Since no new material was presented and there were no graded activities in discussion, students viewed attendance as optional.

3.3.2 Online Course. While many online classes are completely asynchronous in format, the instructor felt that it was especially important for lower-division students to have a weekly time when they came together to engage with the class. The online version of the class was divided into discussion groups of roughly 130 students. Each discussion met synchronously online for 50 minutes on Monday after the video lectures and reading assignments were due. The discussions were led by the instructor, and took place through Zoom, a video conferencing platform. Zoom was chosen because the instructor's department provided free accounts to faculty. However, there are a number of other platforms that would likely have worked equally well. Prior to the discussion, students could request certain topics or specific problems to be covered in discussion. During the discussion, students' microphones were muted, but could ask questions through the chat box. Most often, the instructor would see the question and provide a verbal answer. At least one teaching assistant attended each discussion to answer questions in the chat-box that the instructor did not address in real time. The instructor appeared on camera and spoke to the students directly for a few minutes at the beginning and end of each discussion. For the remainder of the discussion time, the instructor shared her screen with the class and worked through problems with her tablet.

Each discussion included 2-3 interactive exercises in which the instructor would pose a question to the class. Students were encouraged to gather in groups for discussion to collaborate on these activities, but each student had to submit his or her response individually into Canvas (the learning management system). Student responses were graded generously based on participation. There was also some flexibility built into the grading scheme in that students could miss up to two weekly discussions and still receive full credit for discussion participation.

3.4 Reading

Both the online and the face-to-face version of the class used an interactive textbook replacement (zyBook) written by the instructor [26]. The zyBook system timestamps the activities of each student in his or her zyBook which allows and instructor to give credit for completed reading assignments by a particular deadline. The assigned zyBook sections were the same in the two courses. For the face-to-face version of the class, students were required to complete the participation activities in the zyBook before each lecture in order to receive credit for reading. The online class was structured so that each reading assignment and lecture was presented to the students in an ordered weekly "to-do" list through Canvas. The same set of activities were required for the online course, although there was no mechanism to enforce that students completed the activities in the required order.

3.5 Homework

A weekly homework assignment was due each Wednesday and covered material presented in lecture the previous week. The format and structure of the homework was similar for the two versions of the class. The homework included a few additional interactive activities from the zyBook, but mostly consisted of written problems submitted electronically. Many students find the problems for the written homework to be quite challenging as they are designed to push the students to put different ideas together or look at the concepts in a new way.

3.6 Piazza

Both the face-to-face and online version of the courses used Piazza as a platform to address student questions. In Piazza, students can post questions anonymously. Both instructors and students can respond to questions, and instructors have the capacity to endorse student answers. All of the course staff was responsible to respond to questions on Piazza.

3.7 Testing

In both courses, there were four 50-minute midterm exams administered on campus throughout the quarter and no final exam. The tests for the online and face-to-face courses had similar questions and structure (in order to provide a systematic basis for comparison). Students in the online course had the option to take any test at a remote testing center chosen from a list of eligible centers. Only a few of the 390 students in class took advantage of this option.

3.8 Course Staff

Both the face-to-face and the online course (and the online video content) were led by the same instructor, a full professor in Computer Science. For the face-to-face course, there were three TA's and three Readers, all of whom had 20 hour per week positions. Readers provided mostly behind-the-scenes assistance in grading homework and tests. The three TA's each held two hours of discussion and one hour of office hours each week. Since the instructor

led discussion for the online class, fewer TA's were required to staff the class. The online class had one TA, two 20 hour per week readers, and four 10 hour per week readers. The TA attended online discussions to help answer questions in the chat box and held several office hours per week.

3.9 Instructor Presence

Instructor engagement is a challenge in any class with 300+ students, whether the class is delivered online or face-to-face. However it can be particularly challenging to connect with students in an online format. Past research indicates that high quality instructor-student interaction is important to students [11] and leads to better learning outcomes [12].

There were several measures taken to ensure that the instructor had an active presence in the online class. First, since the instructor did not have to prepare and present three hours of lecture each week, she had the time to lead the online discussion sections, rather than using graduate TAs. For a few minutes at the beginning and end of each discussion, the instructor was on camera casually interacting with students as would happen at the beginning of a face-to-face class. The students would write comments or ask questions through the chat-box and the instructor would answer verbally on camera. Usually the conversation was related to the class, but sometimes the topic was about some other aspect of student life or an event happening on campus. Second, the students could also get one-on-one help through office hours. The instructor was available for two hours of office hours a week in the face-to-face class. In the online class, one hour of office hours was online over Zoom and the other was face-to-face. Third, the instructor checked Piazza at least once per day in both versions of the class. In the online class, the instructor provided significantly more contributions than any individual student or member of the class staff.

The material for each week started with a "Check-in" video, prepared the day before the material for the week was released. This was typically a short 2-3 minute video with the instructor on camera talking about the progress of the course, upcoming material, and performance on previous tests. These videos need to be created with each offering of the class to address the specific needs of that particular offering of the course. Sometimes the students will need a warning about a challenging aspect of the course coming up. Sometimes there will be a Piazza thread indicating a common misunderstanding about the material. Other times the students will need a pep-talk if the results on a recent test are not as high as expected. The point of the video is to respond to what is happening with the class at the moment and provide guidance as needed. This creates an online course tailored to the students who are currently taking the course and provides an individualized learning experience, key ingredients for a successful online course.

4 METHODS AND RESULTS

4.1 Student Demographics

Students who took ICS 6D in the Winter 2017 (n = 390) and Winter 2019 (n = 381) were included in this study. 81% of the students were enrolled in a computing-related major (CS students). 23% of the students were first year non-transfer students (Freshman), 31% were transfer students, 25% were female, 24% of students were designated as low income students, and 37% self-reported as first generation college students. 20% of the students self reported their ethnicity as Black, Latino, American Indian, Pacific Islander, Chicano or Philipino which we define as a group to be under-represented minorities (URM). 86% of the students passed ICS 6B –a recommended pre-requisite for ICS 6D–prior to taking ICS 6D. The summary statistics for the demographic characteristics are included in Table 1 separated by course type (i.e. face-to-face versus online). This study was approved by the institutions local Institutional Review Board (IRB #2018-4211) to study the educational effectiveness of incorporating active learning into an online course.

Table 1: Summary statistics for participants in the face-to-face and online course, given as percent for categorical variables and mean (standard deviation) for quantitative variables.

	Face-to-Face Winter 2017	Online Winter 2019
Low Income	25.64%	23.10%
First Generation	40.00%	34.65%
Female	19.49%	30.45%
URM	21.03%	19.16%
Transfer Student	35.13%	27.03%
Passed ICS 6B	91.54%	80.58%
CS Major	86.15%	76.38%
Freshman	22.56%	23.10%
GPAO	3.15 (0.82)	3.21 (0.80)
Score on Common Exams	81.81 (13.01)	82.82 (12.93)
	n = 390	n = 381

4.2 Course Performance

Since the tests for the two offerings had similar questions and structure, test performance on the four common exams is used as the basis for measuring learning outcomes in this study. Our main interest is to examine whether or not there is a difference in course performance for the face-to-face and online courses. As shown in Figure 1, we do not see a difference in the scores on the common exams for the face-to-face (Winter 2017) and online (Winter 2019) courses. If we compare students with similar grade point averages of other courses (GPAO) taken in the same term as ICS 6D, we do not see a difference in the face-to-face and online scores on common exams (Figure 2). Thus using GPAO as a measure of academic strength, the online mode of instruction did not have an adverse impact on lower-performing students (students with low GPAOs), as evidenced by the fact that the face-to-face line is similar to the online line at the left end of the graph.

4.3 Modeling Course Performance

To evaluate whether or not there is a difference in face-to-face and online course format, we would like to take into account other factors and demographic characteristics (GPAO, First Generation status, URM status, gender, and whether or not a student is computing-related major) that may affect course performance; in order to do

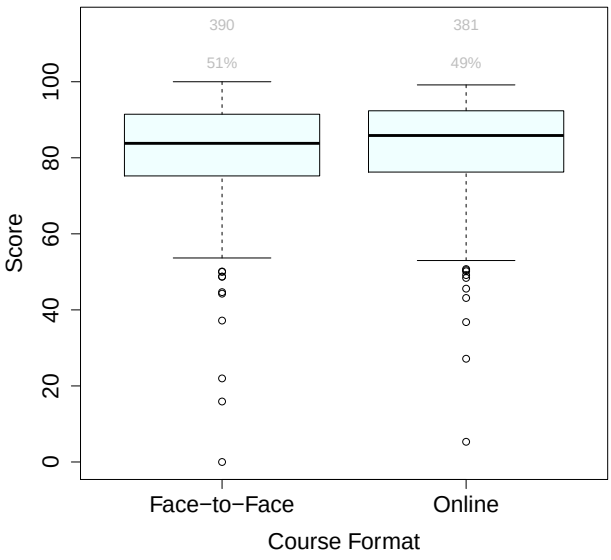

Figure 1: Boxplot of course performance (minimum, 25th percentile, median, 75th percentile, maximum, outliers denoted with circles). Course performance is measured by the (average) score of four common exams for the face-to-face (Winter 2017) and online (Winter 2019) courses.

Figure 2: Scatterplot of course performance versus GPA of other courses (GPAO) for face-to-face (Winter 2017) and online (Winter 2019) courses with fitted regression lines and confidence bands for the face-to-face (in red) and online (in blue) course.

this we use a quantile regression model Koenker [15]. To obtain the quantile specific regression parameters and respective confidence intervals we use the R package *quantreg* [16]. The estimated coefficients and respective 95% confidence intervals from the median regression model are presented in Table 2.

Each row of Table 2 shows the effect of a particular property on the typical (median) test performance in ICS 6D when controlling for the other covariates included in the table. Thus, after adjusting

Table 2: Quantile regression parameter estimates for $\tau = 0.50$ (median regression) and the 95% bootstrapped confidence intervals. Significance of the regression coefficients at the 0.05 level is denoted with an asterisk following the confidence intervals.

	Coefficients	95% Confidence Intervals
Intercept	54.90	(52.02, 57.93)*
Online	0.16	(-1.04, 1.07)
CS major	-0.87	(-2.07, 0.71)
Female	1.25	(0.08, 2.62)*
URM	-1.32	(-3.82, 0.16)
First Generation	-2.16	(-3.13, -0.83)*
GPAO	9.62	(8.35, 10.34)*

for GPAO (a proxy for student achievement) and demographic characteristics, the median score in the online class was 0.16% higher than the face-to-face class. We are 95% confident that the true difference in course performance for the online and face-to-face format is between -1.04% and 1.07%; based on the confidence interval we conclude that there is no significant difference in course performance for the online and face-to-face format.

As expected, when comparing students with similar demographic characteristics and course formats, but GPAOs that are one point higher than another group of students (i.e. comparing A students to B students or B students to C students), we see that scores are typically 9% higher. First generation (FG) students tend to perform worse than non-FG students, after controlling for other factors in the model. In contrast, females tend to perform slightly better than males on common exams after adjusting for the other covariates in the model. There was not a difference in course performance for CS majors and non-majors or for URM and non-URM students.

We also sought to determine whether the online format impacted performance of "at-risk" or "accelerated" students. To address this question we used a quantile regression model for $\tau = 0.25$ for the "at-risk" students and $\tau = 0.75$ for the "accelerated" students. For both models, we included covariates for academic achievement (GPAO) and demographic characteristics (whether or not the student was in a computing-related major, female, URM, or first generation college student). For both the "at-risk" and "accelerated" student models, we found there was no impact of the online course format compared to the face-to-face format ($\hat{\beta}_{online,\tau=0.25} = 0.07$ and $\hat{\beta}_{online,\tau=0.75} = 0.12$), which suggests that by incorporating active learning strategies and increasing instructor presence, there is no drawback to using the online format when measuring student performance for traditionally "at-risk" or "accelerated" populations of students.

4.4 Student Feedback

Evaluations were distributed to the students in each class at the end of the quarter. 77.5% of the students in the face-to-face class and 89.9% of the students in the online class completed the evaluation. The results in both classes demonstrated a high level of satisfaction with the course. In response to the question: "What overall evaluation would you give this course?", students gave an average score

of 8.22 out of 9 in the face-to-face class and 8.13 in the online class. The median score for both classes was 9.

In addition to the standard campus evaluation, a special survey was given to the students in the online class in order to assess the effectiveness of the online format. 315 out of the eligible 381 students participated in the survey. Table 3. shows the results to ten Likert-type survey items with seven possible responses, where 0 represents "strongly disagree" and 6 represents "strongly agree". The responses were overall very positive, especially in regards to whether the students felt they had an opportunity to have questions answered and whether the online tools helped them learn the course content. The relatively low standard deviations show a high degree of consistency in the ratings.

Table 3: Survey responses from the online class on a 0 to 6 scale.

Survey Item	Mean	SD
There were adequate opportunities to have questions answered.	5.42	1.00
The instructor/professor has a positive/active presence in the course.	5.58	0.94
I was satisfied with the level of interaction with the instructor.	4.89	1.80
The online videos supported my learning style.	5.08	1.36
The online tools helped me learn the content.	5.37	1.07
Online tools were well aligned with the course objectives.	5.13	1.55
This course presented information in ways that fit the way I learn.	5.08	1.37
I was able to grasp the concepts in this online course.	5.10	1.29
The quality of this online course was higher than other in-person courses at my university.	4.12	2.03
The format of this course allowed me the freedom to organize my time effectively.	4.98	1.49

There were also open-ended questions asking about what they liked the best and the least about the online format of the class. Many students expressed a high level of enthusiasm for the online format, citing in particular, the flexibility of the schedule. Some students also indicated that they liked being able to pause or replay portions of the video lecture when there was a point that required additional thought. Students also indicated that they appreciated the organization of the class overall and the online lectures in particular. For example, *"The lectures were split into short clips, which helped keep lessons concise. The quizzes after each clip and the explanations for the answers were very helpful."* Students also indicated that they did not feel a barrier to participation. For example, *"I found the professor's online discussions (done over Zoom) useful; we could interact with her but it was still technically online. Honestly, I participated in these discussions more than I do in my other in-person classes."*

On the negative side, many students indicated that they felt more inclined to procrastinate or miss assignments with the more flexible format. A number of students also said that they missed being able to ask questions during the lecture in order to clear up a question right away. Quite a few mentioned they felt more isolated, especially from their peers with the online format. Finally, some students simply stated that the face-to-face format is a better fit for their learning style.

5 LESSONS LEARNED

Incorporating active learning strategies to an online course resulted in comparable course performance of online students compared to students in the traditional face-to-face course. Our analysis showed that the two modes of teaching produced similar learning outcomes even after adjusting for academic preparation and other demographic factors. The high-structure course design was used to achieve an online format which provides students with enough structure to keep them on track in an online course–a common pitfall of online courses. In addition, interactive features were embedded into online tools, such as video lectures and online discussions, so that students stay engaged with the material. Although it is more challenging to connect with students in an online format, we overcame this by increasing instructor presence in the class by interacting with the students in discussion and providing short videos that are specific to a particular offering and cohort of students. These techniques resulted in a high level of satisfaction with the format of the online course in this study.

While some of the negative issues expressed by students may be inherent to an online course experience, there are others that can certainly be addressed. For example, students expressed that they would have liked to be able to connect with peers in order to form study/homework groups. In the future, the online format could be designed to help students find peers to collaborate with. We suggest that when departments decide to offer a course online, that they offer a combination of online and face-to-face offerings so (1) the quality of the course, under the new format, can be evaluated for educational effectiveness, (2) students can choose the course format that best fits their individual needs, and (3) data from both courses can be used to inform future decisions for new course development, be it online or face-to-face. Understanding the effect of particular online strategies on student engagement and ultimately learning outcomes is an important avenue for future study.

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