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Student experience using synchronous and asynchronous instruction in mathematics classes

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ABSTRACT

This paper aims to study the effects that asynchronous and synchronous instructional methods have on student perceptions and attitudes towards online education. We analyze both qualitative and quantitative survey responses from 496 students in three large (greater than 200 enrolled students) first-year calculus classes at the University of Guelph. The survey results show significant differences among the three online instructional formats in students' attitudes toward asking questions, the similarity of each instructional modality to face-to-face delivery, technology issues encountered, students' perceived ability to keep up with course content, how collaborative the course felt, and student preferences for mode of delivery. There were no significant differences reported in relation to time-management skills or communication with instructors. Qualitative analysis of student comments also revealed perceived strengths and weaknesses of each mode of instruction. The results are used to make suggestions for improving student experience in online, post-secondary mathematical teaching.

Keywords: asynchronous delivery, synchronous delivery, distance education, online learning, undergraduate mathematics

INTRODUCTION

While the issue of post-secondary mathematics teaching is already complicated (Baldwin & Squires, 2019), the subject area is particularly vulnerable to the disruptions that COVID-19 has caused (Kuhfeld & Tarasawa, 2020). Amidst the throes of the COVID-19 pandemic, access to online learning became absolutely essential to the continued functioning of higher education (Westoll, 2020). In the online setting, courses may consist of synchronous and asynchronous components. Asynchronous learning refers to the instructional methods that are time-delayed such that instructors and students do not engage with the course materials at the same time, usually in the interest of making course materials accessible to students at their own pace (van der Keylen et al., 2020). In an asynchronous setting, the vast majority of communication from student-to-instructor and student-to-student involves emails, instant messages, video messages, audio messages, and discussion forums. In contrast, synchronous learning refers to the educational materials and learning experiences that students engage with in real-time. Pre-COVID-19 frameworks for the delivery of post-secondary mathematical instructional exist in the form of "distance education" (DE) courses, which are intentionally designed to be offered remotely, such that students and instructor may be both physically and temporally separated (Anderson & Rivera-Vargas, 2020). At the University of Guelph, DE courses are offered through methods of online instruction, and contain both synchronous and asynchronous course components. In light of these considerations, a need to develop and refine online educational resources through the integration of synchronous and asynchronous course components has emerged.

In addition to the challenge of transitioning teaching to an online setting, mathematical preparedness has been a longstanding issue in post-secondary education (Baldwin & Squires, 2019). While numerous studies have compared different online learning formats (Chen & Shaw, 2006; Makransky et al., 2019; Shahabadi & Uplane, 2015; Strang, 2011; Walker, 2021; Yamagata-Lynch, 2014) across different disciplines, the literature currently lacks pedagogical research focused specifically on the delivery of undergraduate mathematics via online learning, particularly as it relates to synchronous versus asynchronous teaching modalities. Teaching mathematics at the university level comes with unique challenges, and such challenges may be amplified through the limitations of online learning. In the online setting, the social supports offered by the formal and informal learning conversations, which would otherwise take place in the in-person course environment, may be limited by course design factors (Bedenlier et al., 2020).

In the particular context of a mathematics course, an exclusively asynchronous lecture format denies students the opportunity to ask questions as the material is being taught, and perhaps even more problematically, as practice problems are being worked through. Moreover, offering lectures in an exclusively asynchronous context may inhibit students from discussing and clarifying

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concepts amongst themselves, and may deprive students of the opportunity to observe and consider the oftentimes enlightening questions of their peers. Ryan and Deci (2000) offered that student who had access to synchronous settings reported more peer feedback than their counterparts who studied in an asynchronous setting. Of particular note in the field of post-graduate mathematics teachings were the findings of Nsa et al. (2012) and Ogbonna et al. (2019), who found that students acquire practical skills (e.g., mathematical problem-solving) better when they are taught in a synchronous online setting, as compared to an asynchronous online setting.

One of the most informative aspects of online education is the student's own subjective evaluation of the learning experience. This study was designed to investigate how students perceive their online learning in large first-year level mathematics classes at the University of Guelph, a large research university in Canada. This paper will compare the students' perception of the advantages of the synchronous and asynchronous teaching modalities, with the goal of developing an online teaching methodology that performs to a standard comparable to in-person methods. Specifically, this paper will investigate student attitudes towards questions, the similarity to face-to-face learning, technology issues, student self-regulation, and interactivity in three large first year online mathematics classes (calculus) at the University of Guelph.

The goal of this study was to first assess the effectiveness of different online instructional course designs across three undergraduate calculus classes. Each course consisted of a different mixture of synchronous and asynchronous components, ultimately producing three distinct online course designs. The second goal of this study was to examine student preference for the synchronous versus asynchronous course components across these three course designs. The research questions to be addressed were, as follows:

1. **Student attitudes towards questions:** Are students more comfortable asking questions in asynchronous or synchronous learning environments?
2. **Similarity to face-to-face learning:** Do students feel that they get the same or similar learning experience in an online instructional setting as they do with traditional face-to-face classes?
3. **Technology issues:** Do students experience issues with technology more often in synchronous or asynchronous learning environments?
4. **Student self-regulation**
   a. **Ability to keep up with course material:** Does the modality of certain course components, particularly in the synchronous versus asynchronous format, impact a student's ability to stay on schedule with the course syllabus?
   b. **Time-management abilities:** Do time-management skills differ between students in asynchronous and synchronous learning environments?
5. **Interactivity**
   a. **Student-student collaboration:** Is the level of interaction and collaboration among students significantly different between asynchronous and synchronous course components?
   b. **Student-teacher communication:** Is the level of interaction and communication between students and teachers significantly different between asynchronous and synchronous course components?
6. **Learning method preferences**
   a. **Face-to-face preferences:** Do students prefer face-to-face learning over their current mode of asynchronous or synchronous instruction?
   b. **Asynchronous/synchronous preferences:** Do students prefer particular elements of synchronous learning to their asynchronous counterparts, or vice versa?

LITERATURE REVIEW

Online Learning

The present literature defines "online learning" as a mode that is essentially carried out in virtual learning environments, through the internet and with active use of digital devices (Anderson & Rivera-Vargas, 2020; Bates, 2019; Lee, 2019). Its emergence and consolidation must be understood not only as an evolution of traditional DE, but also as a modality capable of dealing with the new formative demands of a technologically infused world (Lee, 2019) and a networked and connected society (Selwyn, 2019).

Online learning has quickly become one of the essential ways for both teachers and students to share and acquire available resources for research and learning (Arkorful & Abaidoo, 2015). Panigrahi et al. (2018) outline the benefits of online learning as increasing access to education and training while improving the cost-effectiveness of education. Online learning is typically offered in an asynchronous or synchronous format. Synchronous delivery emulates in-person learning with video conferencing and real-time collaboration through the internet, while asynchronous delivery involves a separation by time and distance (Al-Areibi et al., 2022). In other words, course content is available for students to access regardless of their time-zone or location in asynchronous learning. Asynchronous delivery has the ability to reach a greater number of students at the same time, while maintaining uniformity of content (Panigrahi et al., 2018). In emergency situations (such as the recent COVID-19 pandemic), it is important to design effective online courses that can successfully take over in-person learning. This is not only critical to support students during a pandemic, but also for future situations, where students are unable to attend in-person classes for various reasons (Al-Areibi et al., 2022). The need to bridge the gap in the quality of post-secondary mathematical instruction between in-class and online settings is well-documented, Lopez et al. (2021) concluded that many post-secondary mathematics faculty members "felt that online instruction could not produce learning outcomes equivalent to in-person instruction" after the COVID-19 pandemic forced instruction into the online environment. David et al. (2019) found that the primary concern of online statistics instructors was that students stay connected and advocated for the use of novel technologies as a means of improving student-instructor engagement.

Many studies can be found in the literature extolling the virtues of certain synchronous and asynchronous online course components (Beldarrain, 2006; Bernard et al., 2004; Cavanaugh et al., 2004; Giancola et al., 2009; Jaques & Salmon, 2012), but only a limited number of these studies have compared different online education methods, especially from students' point of view. Johnson's (2008) comparison study focused only on text-based discussions and concludes that both asynchronous and synchronous forms of online discussion contribute to students' cognitive and affective outcomes. Blau et al. (2017) suggest that the virtues of synchronous online learning as it facilitates the use of natural language, the opportunity for immediate feedback, and the encouragement of real-time interpersonal dialogue. Hrastinski (2008) discovered that asynchronous communication increases a person's ability to process information, while students participating in synchronous communication felt more psychologically aroused and motivated. Fabriz et al. (2021) observed that students who studied in "mostly synchronous" settings enjoyed more feedback and participation in peer-focused activities than students in "mostly asynchronous" instructional environments. Their research also concluded that students in mostly synchronous settings described a sense of greater overall satisfaction with their online learning experience as compared to students in the mostly asynchronous setting. In particular, students in a mostly synchronous setting enjoyed a greater facilitation of their needs for relatedness and support under SDT framework. A study conducted by the Department of Dental Medicine of Lutheran Medical Center compared three learning formats for first-year dental residents, including face-to-face, synchronous, and asynchronous methods (Kunin et al. 2014). The results show that technology had a significant impact on the efficacy of the delivery methods, and overall, the asynchronous learning format was the most effective way to teach a postgraduate course. Indeed, the issue of ensuring the instructional integrity of online education is not a novel one. Recent research by Jensen et al. (2022) indicates that students' performance was worse in an asynchronous online course as compared to the equivalent in-person experience. However, it must be noted that most of the existing literature regarding online learning has been situated in the context of students who have chosen this medium for themselves (Al-Areibi et al., 2022). The impacts and disruption of the COVID-19 pandemic, particularly on the area of mathematical instruction, have materialized in recent years. Kuhfeld and Tarasawa (2020) described "COVID-19 slide" in which students demonstrated patterns of academic setbacks characteristic of summer breaks throughout the extended COVID-19-precipitated school closures. In particular, they suggested that students returned to the Fall 2020 semester with less than 50% of the mathematics-specific learning gains that would be anticipated in a typical school year.

Perhaps one of the most influential pieces of literature produced on the topic of online learning is the community of inquiry (COI) theoretical framework (Garrison et al., 2000). COI framework is a deeply researched methodology intended for the development of online learning experiences. Under COI paradigm, a successful education experience comprises the successful integration of social, teaching, and cognitive presences. The term social presence refers to the participant's capacity to project their individual personality into COI (Garrison, 2009). Teaching presence encompasses instructional design, course discussion, and facilitation of discussion in the interest of realizing personally impactful learning outcomes (Garrison et al., 2001). The term cognitive presence qualifies the extent to which participants are able to develop and validate understanding through the use of engaging discourse and meaningful learning activities. The mechanism of cognitive presence is of particular import as it is essential to the integration of new and existing ideas in the development of a novel critical thinking process. Cognitive presence is achieved through discussion, the acquisition of meaningful feedback, and reflection (Garrison et al., 2001). COI cognitive presence framework gives credence to the well-known pedagogical technique of "learning by teaching" (Martin, 1985), which purports to deepen a student's learning experience by allowing them to collaborate with their peers. While COI framework has been comprehensively researched to assess the performance of asynchronous teaching methodologies, there is a lack of literature exploring the particular issue of the roles of social and teaching presence in synchronous and asynchronous mathematical instructional methods. In particular, there is an insufficiency of established research explaining the disparities in performance and student satisfaction between the synchronous and asynchronous instructional modalities as it relates to mathematics teaching. Another study done as part of the Alabama ACCESS Distance Learning Program looked at comparisons between online (asynchronous) and interactive videoconferencing (synchronous) (Roblyer et al., 2007). Students in asynchronous courses were more likely to rate their courses as more difficult and time consuming compared to traditional classes.

As the prevalence of online learning rises, it is increasingly important to understand the experience of student learning in an online setting. Online mathematics education requires unique considerations from the instructional perspective. For first-year students enrolled in university programs involving higher mathematics, the transition from secondary school to post-secondary school can be a major challenge (Rach & Heize, 2016). In many universities across Canada, first-year students often find themselves taking mathematics courses in very large classes. According to Muller (2009), this causes students to feel overwhelmed with information. Muller (2009) also describes that this makes it harder for students to find the necessary support to help them make the transition to university mathematics, and many students never receive the guidance to develop their independence in learning mathematics. The challenge was only magnified as teaching and learning were moved to online environments during the COVID-19 pandemic. This paper seeks to investigate the advantages and disadvantages of using synchronous and asynchronous course components, so as to produce prescriptive guidelines for the instruction and course design of online, post-secondary mathematics courses.

Clickers

Clickers are a student response, web-based system. Instructors can use clickers to poll students, ask discussion prompts, present lecture material and track attendance. Students can respond to clickers questions and prompts using the devices they already own.

Each student's ability to learn and interact with educators is influenced by their personality, family backgrounds, mental processes, learning styles, priorities, maturity levels, and academic ambitions (Tucker, 2021). Social constructivist theories suggest that learning is effective when students feel they are part of a community of positively interacting peers who learn from and with each other (Lin et al., 2021). Through peer discussion in the classroom, students have the opportunity to jointly use their interpersonal and intrapersonal thinking skills to improve collective and individual learning (Lin et al., 2021). Effective classroom discussion provides important opportunities for students to practice social and emotional skills, including communicating effectively and disagreeing respectfully. Discussions in the form of peer instruction give students an avenue to discuss and defend their ideas relating to the topic at hand while questioning the accuracy of their thought processes. In addition to an enhanced understanding of academic concepts, increased opportunities for in-class peer discussions can promote healthy communication, improvement of social and teamwork skills, and encourage class participation. Students also develop stronger connections with their peers, which allow them to share more resources with each other and provide support (Lin et al., 2021).

METHODOLOGY

Measuring the student experience means identifying essential experiences on campus. Collecting this kind of data has long been a challenge. While students' daily experiences are influenced by many factors, both within and outside school, we assessed students in-school experiences by asking students in the moment what they thought about their classes. Student surveys have become one of the largest and most frequently used data source for quality assessment in higher education (Williams, 2014). Measuring a student's experience is an opportunity for instructors not just to assess and analyze but also to demonstrate that they care about each student as an individual.

Having already secured approval from the Research Ethics Board at the University of Guelph, we conducted an online survey available to approximately 800 students in three calculus courses Fall 2020 and 496 students participated in this survey. The online survey involves gathering both qualitative and quantitative data to answer the research questions (Creswell, 2012). According to Creswell (2012), the mixed-method approach helps researchers to gain a more complete picture of the research issue as compared to any standalone quantitative or qualitative study because it integrates the benefits of both approaches. The survey questions verified for validity and reliability before using them. Levels of satisfaction were self-reported by students using responses to end-of-semester survey questions. Our survey included open-ended responses, checklists, and summative rating scales. This study was conducted in the researcher's own classroom and based on qualitative and quantitative analysis of a closed and open questionnaire. The survey questions addressed undergraduate students' perceptions of learning and learning experience in a calculus course taught with a synchronous versus asynchronous delivery. This data helped capture student opinions rather than basing our results on grades.

Participants

The participants of the study were 496 first-year students in three large mathematics classes at the University of Guelph. All students enrolled in the classes were invited to participate in this research project. The study was approved by the research ethics board prior to the distribution of the surveys. There were no known risks to the students. Data were collected using an online survey designed by the authors for the study. Announcements were set on the course website to all students at the three first-year calculus classes describing the study, inviting their participation, and providing a link to the survey. The survey instrument included demographic questions (gender, and academic area/department) and items addressing perceptions and experiences during their calculus class. The surveys were brief, requiring less than ten minutes each to complete. The survey consisted of Likert scale style questions (1=strongly disagree to 5=strongly agree), as well as open-ended response questions. The survey was open for students to complete in the last three weeks of the Fall 2020 semester. All information was kept confidential, and the investigator had access to the information only after all final grades were submitted to the registrar's office. No compensation or incentives were offered to the subjects, nor did the subjects incur any costs in participating.

Course Structures

Three large (greater than 200 enrolled students) first-year mathematics courses were investigated in this study. Each course was delivered in an online format. The format and scope of teaching for each course are described below and presented in summary in **Table 1**.

Business mathematics (MATH*1030) introduces single-variable calculus with an emphasis on mathematical modelling related to business and economics. During the Fall of 2020, MATH*1030 was delivered online through primarily asynchronous methods. The instructor recorded all of the lectures prior to the beginning of the semester and the students could access these lectures at their own pace. It should be noted, however, that synchronously held virtual office hours were provided by teaching assistants and the course instructor. These office hours gave students the opportunity to ask clarifying questions and work through practice problems with immediate feedback available. Questions were also answered by the instructor via email and an online discussion forum. Students were assessed only via bi-weekly online quizzes.

Table 1. A summary of learning modalities across three different course designs

Instructional element	MATH*1030	MATH*1080DE	MATH*1200
Lectures	Asynchronous: Link to an existing online video	Asynchronous: Link to an existing online video	Synchronous
Office hours	Synchronous	Synchronous	Synchronous
Student-student discussion	Asynchronous: Online discussion forum	Synchronous: Virtual coffee breaks	Synchronous: Devoted question period in-lecture
Student-instructor discussion	Asynchronous: Online discussion forum	Synchronous: Virtual coffee breaks	Synchronous: Devoted question period in-lecture
Student-instructor correspondence	Asynchronous: Email	Asynchronous: Email	Asynchronous: Email
Participatory lecture activities	None	None	Synchronous: Fill in blank lecture notes, & clicker response questions

Elements of calculus I (MATH*1080DE) teach the principles of single-variable calculus with an emphasis on mathematical modelling in the biological sciences. MATH*1080DE was delivered as a DE course. DE courses are designed to be implemented in the case, where teacher and learner are separated by distance, and oftentimes also separated by time (Anderson & Rivera-Vargas, 2020). At the University of Guelph, DE courses are offered using methods of online instruction. These differ from the course layout of MATH*1200 and MATH*1030, which were *designed* to be offered in-person, and then were moved online as a consequence of the pandemic. Explicitly, DE courses integrate elements of course design that are intended to be delivered in a setting that facilitates physical and oftentimes temporal distance between the student and instructor. DE courses may feature synchronous and asynchronous course components. The course ran through the Fall semester of 2020. Students were provided with a course textbook from which they could learn each of the concepts to be covered in the course. In addition, the instructor also created PowerPoint slides for each unit of the course to supplement the textbook. While lectures were not recorded by the instructor of the course, links to existing online videos related to the course content were provided. Virtual office hours were offered in a synchronous format. The instructor specified a list of practice questions that students should complete (these were not assessed for marks). Online virtual office hours were provided by the instructor and teaching assistants from 9:00 am-11:00 pm daily, which gave students the opportunity to rectify issues in their understanding by working through problems and receiving instantaneous feedback to their questions. Questions were also answered by the instructor via email. The instructor ran five virtual coffee breaks, where the students could interact with the instructor and each other socially. Students were assessed only via weekly or bi-weekly online quizzes.

Calculus I (MATH*1200) is yet another single-variable calculus course offered at the University of Guelph, though it is intended primarily for students who expect to pursue further studies in mathematics and its applications. MATH*1200 was delivered online, where lectures were synchronously held over Zoom at regularly scheduled hours. To encourage student engagement during lecture, students had partially completed lecture notes with fill-in-the-blanks, which were to be completed during the lecture. Additionally, an online classroom response system ("clickers") was used during lectures to actively engage students in problem-solving and to give an opportunity for feedback on student progress. A large fraction of the lecture was also devoted to answering student questions. Online virtual office hours were provided by the instructor and teaching assistants four days a week. The instructor also answered many of the students' questions via email. Students were assessed via low-stakes, unlimited-attempt online homework, online timed bi-weekly tests, and a final exam. Students were then given the opportunity to give comments on what they felt were the biggest advantages and disadvantages of the instructional method utilized by their course.

Data Analysis

A total of 496 students participated in an online survey out of 2,689 students enrolled in three large first-year mathematics classes. The data were analyzed in the statistical software R. The survey consisted of 18 questions pertaining to different aspects of the courses using a Likert scale (most questions using 1=strongly disagree, 5=strongly agree, and a few questions using 1=no, 3=yes), as well as two open-ended written-response questions. The mean and standard deviation of student survey ratings for each factor were calculated. Differences in groups were analyzed using the Kruskal-Wallis (KW) test since this test was selected because it does not require the groups to be normally distributed and is more stable to outliers. If the results were considered significant, a post-hoc Dunn's test with a Bonferroni correction for the p-values was used to determine which of the three groups differed significantly. A p-value of <0.05 was considered statistically significant. Open ended student responses were grouped based on key topics and themes.

Table 2 shows mean student rating for each factor based on Likert scale.

Table 3 shows mean student ratings for each factor rated from 1=no to 3=yes.

RESULTS

Factors That Were Significantly Different

The factors that were found to be significantly different among the three learning groups were student attitudes toward questions, the similarity to face-to-face learning, technology issues, ability to keep up with course material, student-student collaboration, face-to-face preferences, and asynchronous/synchronous preferences. We explore each of these factors below.

Table 2. Mean student rating for each factor rated from 1=strongly disagree to 5=strongly agree

Factors (1=strongly disagree, 5=strongly agree)	MATH*1030	MATH*1080DE	MATH*1200
1. Student attitudes towards questions	Mean=3.23 & SD=1.10	Mean=3.22 & SD=1.09	Mean=3.57 & SD=1.23
2. Similarity to face-to-face learning	Mean=2.83 & SD=1.31	Mean=2.41 & SD=1.13	Mean=3.06 & SD=1.19
3. Technology issues	Mean=1.87 & SD=1.06	Mean=2.01 & SD=1.04	Mean=2.52 & SD=1.15
4a. Ability to keep up with course material	Mean=3.29 & SD=1.30	Mean=3.22 & SD=1.28	Mean=3.74 & SD=1.19
4b. Time management abilities	Mean=3.82 & SD=1.08	Mean=3.76 & SD=1.33	Mean=3.93 & SD=1.07
5a. Student-student collaboration	Mean=2.57 & SD =1.17	Mean=2.22 & SD =1.08	Mean=3.64 & SD=1.08
5b. Student-teacher communication challenges	Mean=1.81 & SD=0.83	Mean=1.82 & SD=0.90	Mean=2.09 & SD=1.16

Table 3. Mean student ratings for each factor rated from 1=no to 3=yes

Factors (1=no, 3=yes)	MATH*1030	MATH*1080DE	MATH*1200
6a. Face-to-face preference	Mean=2.33 & SD=0.79	Mean=2.24 & SD=0.80	Mean=2.72 & SD=0.55
6b. Asynchronous/synchronous preferences	Mean=1.96 & SD=0.81	Mean=1.98 & SD=0.83	Mean=1.44 & SD=0.70

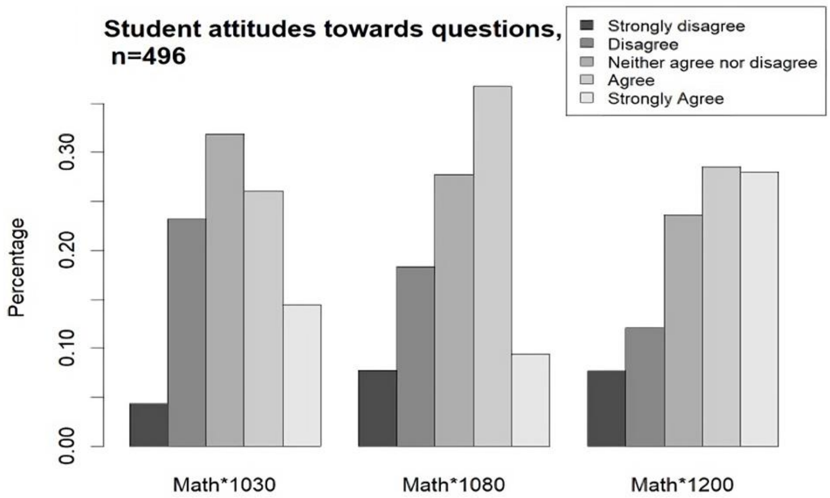

Figure 1. Histogram of student survey percentages for question "synchronous learning in my mathematics class encourages me to ask questions in real-time" for MATH*1200 students, & "by using asynchronous or DE learning in my mathematics class I feel comfortable asking questions in real-time" for MATH*1080DE & MATH*1030 students (Source: Authors' own elaboration)

Student attitudes toward questions

To measure student attitudes towards questions, students were asked how comfortable they felt asking questions in class (from 1=strongly disagree to 5=strongly agree). A total of 496 students answered this question of the survey (182 from MATH*1200, 245 from MATH*1080DE, and 69 from MATH*1030).

The results of KW test indicated that there were statistically significant differences among the three learning groups (H=12.268, df=2, p=0.002168). Next, the post-hoc Dunn's test results indicated that the synchronously-lectured group (MATH*1200) differed from the group instructed by links to existing online videos (MATH*1080DE) (p=0.002787). Students from the MATH*1080DE group tended to rate their responses slightly lower (18% disagree and 8% strongly disagree) to the question "I feel comfortable asking questions in real-time", whereas students in the MATH*1200 group rated their responses higher (29% agree and 28% strongly agree), indicating that students in lecture delivered by synchronous instruction are generally more comfortable asking questions in real-time (see **Figure 1**).

Similarity to face-to-face learning

Similarity to face-to-face learning was measured by asking students how similar their experience of online learning was to traditional face-to-face instruction (from 1=Strongly Disagree to 5=Strongly Agree). A total of 496 students answered this question of the survey (181 from MATH*1200, 246 from MATH*1080DE, and 69 from MATH*1030).

The results of KW test indicated that there were statistically significant differences among the three learning groups (H=30.62, df=2, p=2.243e-07). Next, the post-hoc Dunn's test results indicated that the synchronously-lectured (MATH*1200) group differed from the group instructed by links to existing online videos (MATH*1080DE) (p=1.23e-07). Students in MATH*1200 rated their responses higher (29% agree and 10% strongly agree), while students in MATH*1080DE rated their responses lower (36% disagree and 23% strongly disagree) to feeling like they had a traditional classroom experience recreated with online learning (see **Figure 2**). Overall, students in synchronously-held lectures (MATH*1200) felt that they had a learning experience resembling a traditional in-person classroom experience more than students in the group that experienced an asynchronous lecture format.

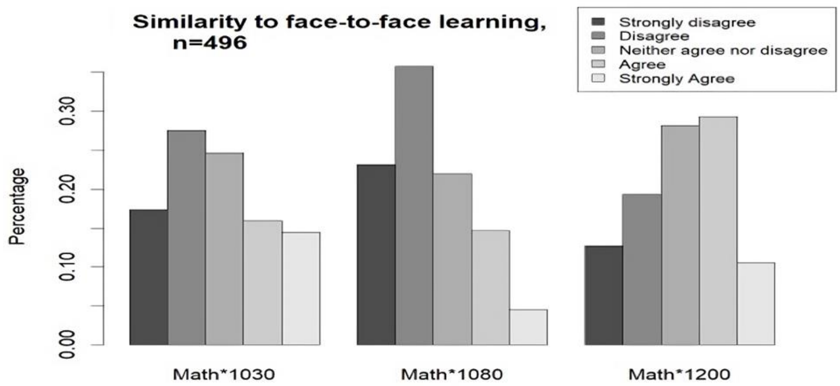

Figure 2. Histogram of student survey percentages for question "using synchronous learning in my mathematics class recreated traditional classroom experience successfully" to MATH*1200 student & "I have a traditional classroom experience when using asynchronous learning or DE in my mathematics class" for MATH*1030 & MATH*1080DE students (Source: Authors' own elaboration)

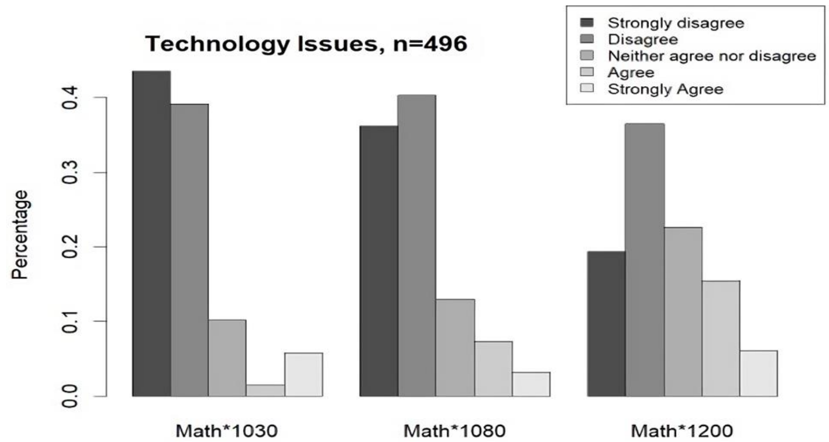

Figure 3. Histogram of student survey percentages for question "I have many issues with technology-based nature of synchronous learning" for MATH*1200 students & "I have many issues with technology-based nature of asynchronous or DE learning" for MATH*1030 & MATH*1080DE students (Source: Authors' own elaboration)

Technology issues

Students were asked about technology-related issues experienced in their online learning (from 1=strongly disagree to 5=strongly agree). A total of 496 students answered this question of the survey (181 from MATH*1200, 246 from MATH*1080DE, and 69 from MATH*1030).

The results of KW test indicated that there were statistically significant differences among the three learning groups (H=31.681, df=2, p=1.32e-07). Next, the post-hoc Dunn's test results indicated that the synchronously lectured group (MATH*1200) differed from both the group instructed by links to existing online videos (MATH*1080DE) (p=3.29e-06), and the group lectured asynchronously (MATH*1030) (p=1.805e-05). In both pairwise comparisons, students in MATH*1200 tended to rate their responses higher (15% agree and 6% strongly agree) when asked if they had many technology-based issues. Students in the MATH*1080DE group rated their responses significantly lower (40% disagree and 36% strongly disagree), as did students in the MATH*1030 group (39% disagree and 43% strongly disagree) for having any technology-based issues (see **Figure 3**). Overall, students in synchronously held lectures reported more issues with technology.

Students self-regulation

Ability to keep up with course material: Students were asked if they felt they were able to easily stay on top of their course material in their online classes (from 1=strongly disagree to 5=strongly agree). A total of 495 students answered this question of the survey (180 from MATH*1200, 246 from MATH*1080DE, and 69 from MATH*1030).

The results of KW test indicated that there were statistically significant differences among the three learning groups (H=19.275, df=2, p=6.524e-05). Next, the post-hoc Dunn's test results indicated that the synchronously-lectured group (MATH*1200) differed from the group instructed by links to existing online videos (MATH*1080DE) (p=5.124e-05) and the MATH*1030 group (p=3.402e-02). In both pairwise comparisons, students in the MATH*1200 group tended to rate their responses higher (34% agree and 32% strongly agree) when asked if they were able to stay on top of course material. With reference to being able to stay on top of the course material, students in the MATH*1200 group rated their responses lower (21% disagree and 12% strongly disagree) as did students in the MATH*1030 group (23% disagree and 10% strongly disagree) (see **Figure 4**). In general, students in synchronously

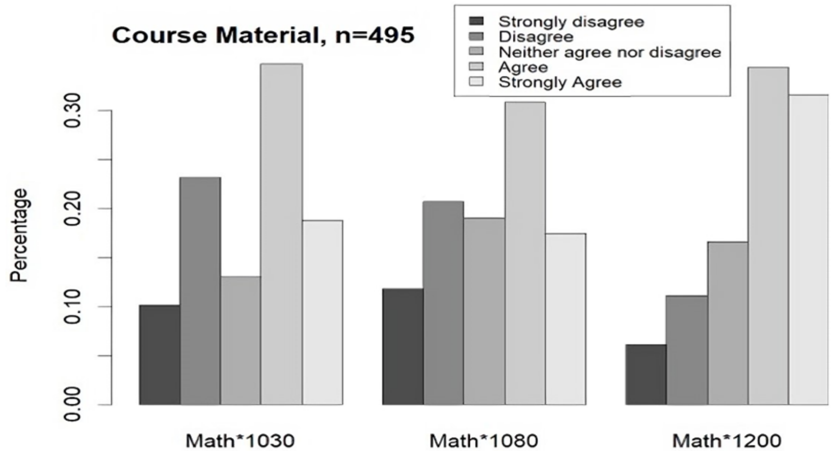

Figure 4. Histogram of student survey percentages for question “using synchronous learning in my mathematics class helps me to stay on top of course material” for MATH*1200 students & “using asynchronous or DE learning in my mathematics class helps me to stay on top of material” for MATH*1030 & MATH*1080DE students (Source: Authors’ own elaboration)

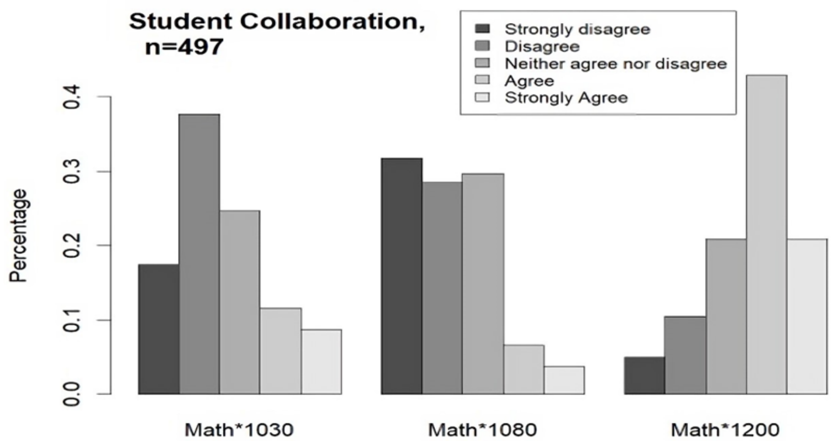

Figure 5. Histogram of student survey percentages for questions “I feel a sense of collaboration, in my synchronous mathematics class” MATH*1200 students & “by using asynchronous or DE learning in my mathematics class I feel a sense of collaboration during lectures” for MATH*1030 & MATH*1080DE students (Source: Authors’ own elaboration)

held formal learning environments (e.g., lectures) felt that they could stay on top of course material better than students in asynchronous learning environments.

Interactivity

Student-student collaboration: Students were to rate their sense of collaboration among their classmates in their online classes (from 1=strongly disagree to 5=strongly agree). A total of 497 students answered this question of the survey (182 from MATH*1200, 246 from MATH*1080DE, and 69 from MATH*1030).

The results of KW test indicated that there were statistically significant differences among the three learning groups ($H=135.63$, $df=2$, $p < 2.2e-16$). Next, the post-hoc Dunn’s test results indicated that the MATH*1200 group differed from the MATH*1080DE group ($p=2.88e-30$) and the MATH*1030group ($p=3.13e-09$). In both pairwise comparisons, students in MATH*1200 rated their responses much higher (43% agree and 21% strongly agree) to feeling a sense of collaboration while students in MATH*1030 rated their responses much lower (41% disagree and 17% strongly disagree) to feeling a sense of collaboration, as did students in the MATH*1080DE group (28% disagree and 32% strongly disagree) (see **Figure 5**). Based on these results, students in the MATH*1200 group felt the most sense of collaboration amongst their peers, while students in the MATH*1080DE group felt the least sense of collaboration.

Learning method preferences

Face-to-face preferences: Students were asked if they prefer face-to-face classes over their current mode of online learning (from 1=no, 3=yes). A total of 483 students answered this question of the survey (178 from MATH*1200, 238 from MATH*1080DE, and 67 from MATH*1030).

The results of KW test indicated that there were statistically significant differences among the three learning groups ($H=45.875$, $df=2$, $p=1.092e-10$). Next, the post-hoc Dunn’s test results indicated that the MATH*1200 group differed from the MATH*1080DE group ($p=7.78e-11$) and the MATH*1030 group ($p=5.76e-04$). In both pairwise comparisons, students in the synchronously-lectured group (MATH*1200) tended to rate their responses higher (78% Yes) more frequently when asked if they preferred face-to-face

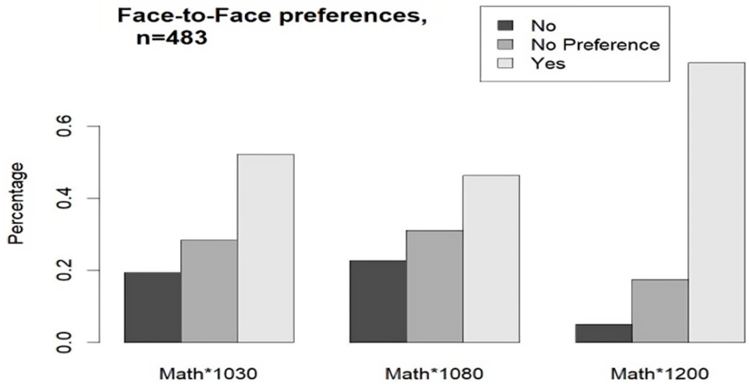

Figure 6. Histogram of student survey percentages for questions “do you prefer face-to-face classes in mathematics instead of synchronous delivery?” for MATH*1200 students & “do you prefer face-to-face classes in mathematics instead of asynchronous or DE delivery?” for MATH*1080DE & MATH*1030 students (Source: Authors’ own elaboration)

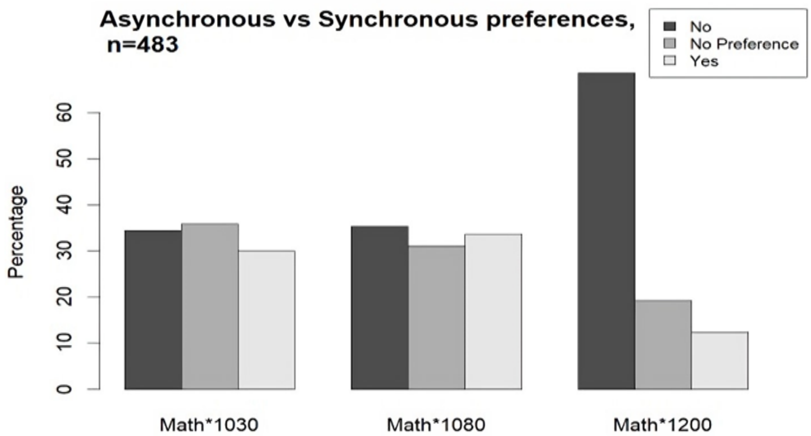

Figure 7. Histogram of student survey percentages for questions “do you prefer asynchronous classes in mathematics instead of synchronous classes?” asked to students in MATH*1200 group, & “do you prefer synchronous classes in mathematics instead of asynchronous or DE classes?” asked to students in MATH*1030 & MATH*1200 groups (Source: Authors’ own elaboration)

classes over synchronous classes. Students in the group instructed by links to existing online videos (MATH*1080DE) rated their responses lower (23% No) and students in the asynchronously-lectured group (MATH*1030) (19% No) rated their responses lower more frequently compared to students in the synchronously-lectured group (see **Figure 6**). In general, many students in all three classes said they preferred face-to-face classes, but students in synchronous instructional environments prefer face-to-face classes significantly more.

Asynchronous/synchronous preferences: Students in MATH*1200 were asked if they preferred to be instructed by links to existing online videos (as in MATH*1080DE) or to receive asynchronous, pre-recorded lectures by their course instructor (as in MATH*1030), while students in the MATH*1080DE and MATH*1030 groups were asked if they preferred synchronously-held lectures over their current mode of learning (from 1=No, 3=Yes). A total of 483 students answered this question of the survey (178 from MATH*1200, 238 from MATH*1080DE, and 67 from MATH*1030).

The results of KW test indicated that there were statistically significant differences among the three learning groups ($H=50.215$, $df=2$, $p=1.247e-11$). Next, the post-hoc Dunn’s test results indicated that the synchronously-lectured (MATH*1200) group differed from the group instructed by links to existing online videos (MATH*1080DE, $p=3.25e-11$) and the asynchronously-lectured (MATH*1030) group ($p=1.74e-05$). In both pairwise comparisons, students in the synchronously-lectured group tended to rate their responses lower (69% No) more frequently when asked if they preferred the opposite style of learning. Students in the MATH*1030 group rated their responses higher (30% Yes), as well as students in the MATH*1080DE group (34% Yes) to preferring the opposite mode of learning (see **Figure 7**). Based on these results, synchronous learning environments are generally more preferred by students in asynchronous lecture settings.

Factors that Were Not Significantly Different

The factors that were not found to be significantly different among the three groups were time-management abilities, and student-teacher communication challenges.

Students self-regulation

Time-management abilities: Students’ ability to effectively manage their time was measured using a question about how effectively the course teaching method helped in managing their time for readings and coursework (from 1=strongly disagree to

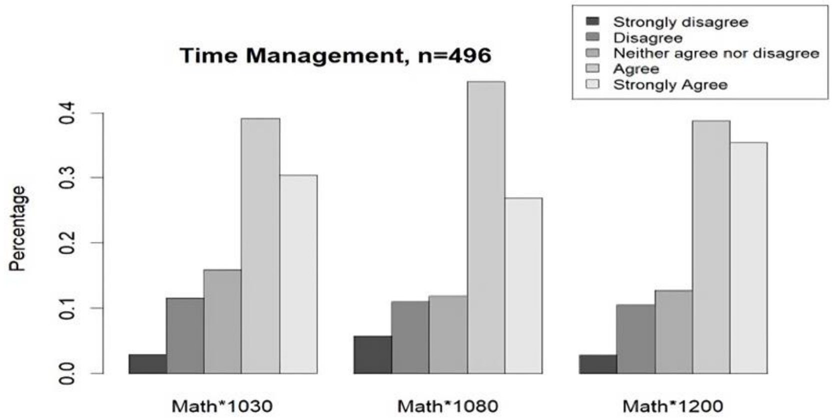

Figure 8. Histogram of student survey percentages for questions "using synchronous learning in my mathematics class helps me to manage my time effectively since I know when I will attend class & what readings needs to be done for class" for MATH*1200 students & "using asynchronous or DE learning in my mathematics class helps me to manage my time for reading effectively" for MATH*1030 & MATH*1080DE students (Source: Authors' own elaboration)

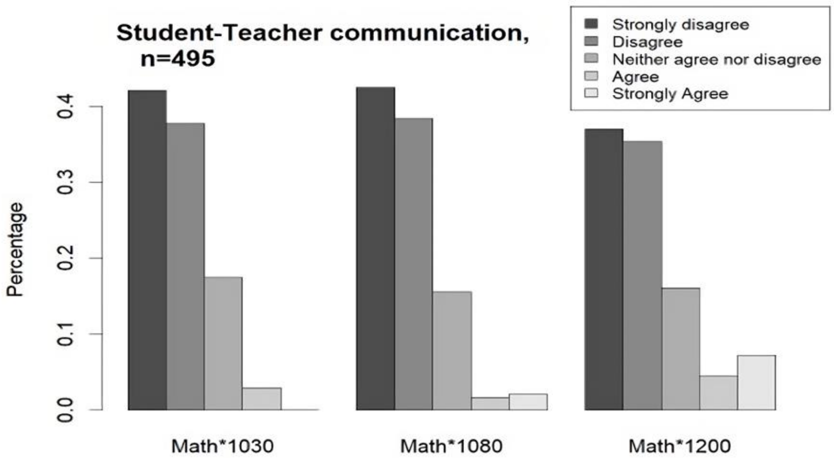

Figure 9. Histogram of student survey percentages for questions "with synchronous learning in my mathematics class I have communication challenges because of different time zones" for MATH*1200 students & "do you have communication challenges because of different time zones in your asynchronous or DE mathematics class?" for MATH*1030 & MATH*1080DE students (Source: Authors' own elaboration)

5=strongly agree). A total of 496 students answered this question of the survey (181 from MATH*1200, 246 from MATH*1080DE, and 69 from MATH*1030).

The results of KW test indicated that there were no significant differences between the three learning groups (H=2.7045, df=2, p=0.2587). In general, students rated their responses high in each class: MATH*1200 (39% agree and 35% strongly agree), MATH*1080DE (45% agree and 27% strongly agree), and MATH*1030 (39% agree and 30% strongly agree) (see **Figure 8**). Overall, students in all three learning groups felt that they could manage their time for coursework and readings effectively.

Interactivity

Student-teacher communication challenges: To measure student-teacher communication challenges, students were asked if they experience communication issues or challenges due to differences in time zones (from 1=strongly disagree to 5=strongly agree). A total of 495 students answered this question of the survey (181 from MATH*1200, 245 from MATH*1080DE, and 69 from MATH*1030).

The results of KW test indicated that there were no significant differences among the three learning groups (H=4.2241, df=2, p=0.121). In general, students rated their responses low in each class; MATH*1200 (35% disagree and 37% strongly disagree), MATH*1080DE (38% disagree and 42% strongly disagree), and MATH*1030 (38% disagree and 42% strongly disagree) (see **Figure 9**). Overall, students did not deal with many communication-related issues or challenges in online mathematics learning.

Qualitative Analysis

Student comments

Student comments for each class were counted based on topics and frequency of the comments being mentioned. The biggest advantages and disadvantages from each course are shown in **Table 4**.

Table 4. Student comments organized into most common advantages & disadvantages, as well as representative comments

	Advantages	Disadvantages
MATH*1200	57 students commented on **being able to ask questions in real-time**. • "Biggest advantages are that students can ask questions in real-time & instantly get an answer, students can feel a sense of community among their peers, & that [instructor] is very enthusiastic which has ability to bring smiles to faces of students who are anxious about material." • "With synchronous classes, asking questions, & receiving answers becomes a faster process." • "Can ask questions in real-time & get a sense that you are in a real class."	23 students commented that synchronous learning causes more **distractions**, & it can be harder to pay attention during live lectures. • "With synchronous learning, there are a ton more distractions during a lecture as you are not in a classroom setting. This caused me to sometimes not be as focused as I possibly could be." • "Throughout semester using synchronous delivery for mathematics classes, biggest drawback for me was that I was distracted by my phone during class since no one could see me looking at it/know that I was not giving my full attention at times." • "Biggest drawback is having to sit in a chair all day learning different courses. This caused me to become very disengaged & I miss being able to talk to peers. This ultimately affected my mental health & made it much more difficult to learn online."
MATH*1080DE	144 students commented on being able to **work on their own time and pace**, as well as being able to set **schedule**s for themselves. • "You can go through material at your pace, going over things a couple of times if you do not understand instead of having to continue on in a lecture setting." • "Largest advantage to a DE class is that you can work on your own schedule & learn at your own pace." • "Ability to work at my own pace & schedule learning/assignments to when was most convenient for me." • "I can work at my own pace & learn material when it is most convenient for me."	54 students commented that MATH*1080DE course causes for a **lack of demonstrative learning** & having to **independently learn course material**. • "I have to pretty much teach myself using textbook most of time." • "Only drawback is not getting to see problem-solving process in live or a video, & it is more of an independent study, where I have to figure out everything by myself in textbook." • "I feel biggest drawback of DE delivery is lack of in-person examples & watching a professor or TA go over complex problems, but this is aided by video tutorials posted to help students get a grasp of material."
MATH*1030	40 students commented regarding being able to **work at their own time and pace**. • "Students can learn at their own pace; students have more control over when they want to complete course material." • "I can go at my own pace everything is very accessible & it's easier to focus on a specific topic I was having trouble with."	21 students commented that **asking questions** in an asynchronous setting can be difficult. • "You are not able to ask questions in real-time with lectures. It makes it more difficult to ask questions in discussion or email." • "Questions cannot be answered in real-time. If I did not understand a concept, I would have to email a TA or instructor & wait for a response, which is not always most convenient."

DISCUSSION

Online learning environments pose idiosyncratic challenges in the instruction of post-secondary mathematics courses, particularly when consideration is given to the applied, feedback-dependent, and cumulative nature of the coursework. Many studies have been conducted about the effectiveness of online learning, and the challenges and restrictions that it can cause to students. Among these, are studies conducted by Adnan and Anwar (2020), Fauzi and Khusuma (2020), Najib et al. (2017), Saidon et al. (2020), and Wargadinata et al. (2020). However, the major focus of this study was to investigate the impacts of synchronous and asynchronous instructional elements within the online learning environment. This research was dedicated to a study of first year undergraduate mathematics classes at the University of Guelph, in order to better understand student perceptions of their learning experience and course performance. The study revealed several interesting conclusions.

There was not a significant difference in students' perception of their ability to communicate or their time management abilities between the three online delivery course formats. Students can participate in chat rooms in real time or asynchronously by posting to newsletters or forums (Morrison et al., 2019). According to Garnham and Kaleta (2002), "introverts, who are quiet in the face-to-face class, really participate online."

Overall, first-year mathematics students regarded their experience very positively. Many students in all three classes said they preferred face-to-face classes, but students experiencing synchronous lectures responded significantly higher, with 78% of the students preferring face-to-face classes. Face-to-face classes are preferred by many students, possibly because students mentioned feeling distracted and disengaged during live online lectures. Over time, both teachers and students may experience various negative effects from Online learning, such as sight problems (due to long periods in front of the screen) or back pain, and, at the same time, they may feel the lack of activities in open spaces (Nazarlou, 2013). Future considerations for the design of synchronously held lectures should address the heightened need for students' attention to be held.

There were statistically significant differences related to student attitudes towards asking questions. Students in the synchronously held lectures were more comfortable asking questions while students in the courses receiving pre-existing instructional recordings were significantly less comfortable with asking questions in the alternately offered modalities of asynchronous chats, virtual coffee breaks, virtual office hours, and correspondence emailing (see **Table 2**). Synchronous lectures give students the chance to ask questions during live lecture sessions, whereas students in asynchronously held lectures only enjoyed the advantages afforded by real-time feedback through synchronously held virtual office hours and coffee breaks. Samat et al. (2020) supported that the readily available online platforms that encourage social learning is found beneficial to enhance learning engagement between teachers and students, and students to students (Samat et al., 2020). Thus, this will create a positive learning environment for students. Without course design considerations towards making these virtual office hours accessible across a multitude of time zones, as well as incenting students to actually attend these office hours, there is little assurance that students will have access to the informal, real-time feedback that they would glean from asking questions *in-lecture.* It is evident that each student's potential for learning is upheld and strengthened by the presence of instructor-peer real-time interaction (Ryan & Deci, 2000) during which students must systematize their initial understandings of a concept in the form of a meaningful question. The opportunity to regularly converse with an instructor or TA in problem-solving time is of the utmost importance in mathematics teaching, where the cumulative nature of the coursework poses a particular risk to students–namely, that foundational misunderstanding is built upon to propagate an entire concept-view that is inherently wrong.

Students in the synchronous lectures also felt the greatest sense of collaboration amongst their peers and students, while students in the pre-recorded, asynchronous lecture group felt the least sense of collaboration (see **Table 2**). This may be due to the fact that live lectures most closely resemble traditional face-to-face classes, where collaboration among peers is easily enforced. This conclusion is supported by the findings of Fabriz et al. (2021), who contend that students enrolled in mostly synchronous instructional settings received more feedback and were afforded greater participation in peer-focused activities than students in mostly asynchronous instructional environments. Asynchronous classes are independent in nature, leading to a lack of student-to-student collaboration and limited student-to-teacher interaction. Such issues instantiate the shortcomings that may arise in distance mathematics education as viewed through COI framework, particularly as they relate the pillars of cognitive and teaching presence. In fact, it has been suggested that cognitive presence, realized in this context through online course interactivity, is best achieved by promoting "active synchronous discussion" (Murphy & Collins, 1997). An extrapolation of this conclusion may entail the institution of a synchronous tutorial or peer-to-peer teaching component in which the student has an opportunity to engage in a dialogic reflection that orients and coheres the many elements of mathematical teaching (particularly as it relates to the marriage of theoretical and applied mathematical materials). Such an opportunity may also imbue students with a sense of responsibility for their own learning, which is supported by SDT framework tenant that the most important element in supporting intrinsic motivation for educational attainment is social support (Fabriz et al., 2021).

Similarity to face-to-face learning was reported as being statistically significantly different between the students experiencing synchronously and asynchronously held lectures, with the synchronously-instructed group rating the similarity to face-to-face classes higher (see **Table 2**). Students in synchronously held lectures felt that they had a learning experience resembling traditional classroom experience more than students in the pre-recorded, asynchronously held lecture group. Pre-recorded videos, particularly having not been recorded by the course instructor themselves, lack the live lecture component that synchronous learning has. This can be understood through COI framework as a failure to uphold the pillar of social presence. Lecture slides are simply posted on a web page, otherwise useful in a traditional classroom, do not encourage engagement and interactive communication (Grosso et al., 2012). Certainly, absent any form of personal interaction between student and instructor in the lecture course component, and further absent any personal presence of the course instructor in the delivery of the lecture, students will not have the capacity to project their individual personality into COI. This conclusion is supported by the finding of Najib et al. (2020) that students' motivation during online learning was low as this learning required students to be self- motivated and independent in their learning.

Students in synchronous learning environments experienced issues with technology more often than those in a corresponding asynchronous environment. This can be due in part to the live component of synchronous course elements. Issues with the internet have a larger impact on student learning in live, real-time classes, whereas in the asynchronous instructional environments, learning materials are posted online and are accessible at any time and location to students. This conclusion is supported by the findings of Adnan and Anwar (2020) who contend that internet access problems, a lack of interaction between teachers and students and a lack of technological facilities challenge the efficacy of online learning.

Students in synchronously-held lectures felt that they could stay on top of course material very well, while students in asynchronous instructional environments had a harder time staying on top of the course material (see **Table 2**). As part of the synchronous course design, weekly scheduled live lectures gave students structure and forced students to keep up each week, lest they contend with missing a lecture altogether. Although a large percentage of students in the asynchronous lecture group enjoyed being able to plan and complete their work at their own time and pace, this may have absolved the students of the perception that keeping up with the intended course schedule was absolutely necessary. This conclusion is supported by the findings of Al-Areibi et al. (2022), who argue that "hosting synchronous lecture sessions with interactive components reinforces student accountability to their instructor and their fellow students".

Ultimately, students in the synchronous lecture group tended to rate their responses lower when asked if they preferred asynchronous lecture delivery learning (see **Table 3**). In contrast, students in the asynchronous lecture group rated their responses higher, as well as students in the pre-recoded, asynchronous lecture group to preferring the synchronous delivery of lecture materials (see **Table 3**). Based on these results, synchronous instruction is generally more preferred by students than its asynchronous alternative, based on the survey questions asked.

CONCLUSIONS

This study found that the three formats of teaching large first-year mathematics classes online at the University of Guelph can be effective ways to teach undergraduate courses with high overall student satisfaction. Each class had their advantages and disadvantages, with differences among the three learning groups in several areas. Significant differences were found among the three groups in student attitudes towards questions, similarities to face-to-face learning, technology related issues, ability to keep up with course material, student-student collaboration, and learning method preferences. Students in synchronously-held lectures were more comfortable asking questions, and this limitation could not be compensated for through the simple addition of synchronous office hours or virtual "coffee breaks" in courses featuring asynchronous lecture components. However, students in synchronously-held lectures reported more issues with technology compared to students accessing time-independent lecture materials. Synchronous students also felt that they were able to stay on top of course material successfully and had a stronger sense of collaboration among their peers. This is consistent with the findings of Fabriz et al. (2021), who argue that synchronous instructional settings inherently facilitate the student-student and student-teacher interactions that provide informative feedback to students. Asynchronous course designs must make special efforts to plan and support the social interactions that are precluded by the characteristics of this teaching modality. Synchronously-lectured students were more likely to prefer face-to-face classes, although a majority of students from all three online formats still prefer face-to-face. Moreover, the synchronous delivery of online learning materials was generally more preferred by students in all three courses. The results of this study suggest that synchronous instruction can allow students to ask questions more comfortably and collaborate with their peers and stay on top of course material.

Our results suggest that courses providing instruction in a pre-recorded or asynchronous format should plan and facilitate social events (e.g., virtual coffee breaks) to support a sense of community and interaction among students, as prescribed within SDT framework (Ryan & Deci, 2000). In addition, frequent online office hours were found to give students the opportunity to interact, discuss course materials with their peers and ask questions in a similar style to the traditional face-to-face office hours. Together, these results provide further insightful information for all online learning environments. Online office hours may be a useful tool when accommodating those students that are located across different time zones, or those that experience technology issues. Posting complete lecture notes can alleviate challenges for those that were unable to attend live lectures for similar reasons. Making these resources readily available serves as a learning tool for any student that wishes to go back and review lecture material later.

Particular initiatives to integrate cognitive presence as a pillar of DE in mathematics must also be emphasized. It is the informal discourse between peers, oftentimes taking place amidst a lecture, that forces students to articulate their understanding of a concept, and in doing so reveals any existing conceptual gaps. Such a prescription is grounded in the "learning by teaching" pedagogical technique (Martin, 1985). Moreover, whether synchronous or asynchronous, the elements of COI theoretical framework must be upheld through conscious course design. In the particular context of first year, post-secondary mathematical instruction, instructional quality may benefit from integrating

1. A dedicated question period during the problem-solving component of a synchronous lecture, or asynchronously through a peer-to-peer chat forum (COI pillar: Social presence)
2. The encouragement of course programming of peer-to-peer teaching of mathematical concepts in a synchronous or asynchronous setting (COI pillar: Cognitive presence)
3. The institution of synchronous tutorials and "coffee breaks" during which time students should be encouraged to realize personally impactful learning outcomes (COI pillar: Teaching presence)

Prescriptive guidelines may also be extended to improve the self-reported experiences of students in the online, post-secondary mathematical instructional setting. It is imperative that course design facilitates real-time feedback and interaction, so as to promote the basic psychological needs described in SDT framework (Ryan & Deci, 2000). This prescription is supported by the work of Fabriz et al. (2021), who offer that "students' needs to feel competent as well as socially related cannot be taken for granted, especially for asynchronous settings", and further indicate that the support of SDT framework "enhances students' learning experience comprising higher satisfaction, less procrastination, and greater learning gains".

Limitations

The scope of this research has several limitations that bear discussing. This paper focuses on the first-year mathematics student population in large classes; therefore, the implementation of the results is restricted to colleges that have similar student body and academic majors (Graziano & Raulin, 2013). Further, this paper follows an observational study design, so we expect many confounding variables. For example, the instructor's attitude could be completely different in running these different formats of teaching, which could inform students' responses. Even different major or higher-level students may have an effect on the student's response.

Recommendations & Future Directions

Running an experiment rather than an observational study will solve the issues with the confounding variables. For example, if it is possible, let one instructor teach different sections with the same major in different formats (synchronous and asynchronous instructions) or one section, where you can divide the students randomly into two groups or three. This way you can solve the issues of the confounding variables, but that will require approval from the ethic board and the students.

Regarding areas for future studies, the inclusion of a mathematics course with a blended or hybrid learning approach would be beneficial in providing insights about how online learning components can be used alongside face-to-face components to improve student experience. Additional research questions can be asked such as "does the type of course delivery have an effect on student achievement?", or "do upper-year students have similar preferences for online learning formats as first-year students?"

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Declaration of interest: No conflict of interest is declared by authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author. Fulfillment of these requests will be subject to the permission of the Research Ethics Boards at University of Guelph.

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