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What in the World Just Happened? Students' Self-Regulation in Asynchronous PreCalculus During the COVID-19 Pandemic

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Synopsis

We describe students' learning practices in an online asynchronous PreCalculus course during Fall 2020, the first complete semester of distance learning induced by the COVID-19 pandemic. Results were compiled using a thematic analysis of a questionnaire administered to 43 students enrolled in PreCalculus at a university in the Midwest (United States). Students were given opportunities for active learning and various synchronous Q&A sessions, yet they primarily learned through watching videos and reading worked examples, minimizing interactions with the instructor and available tutors. The questionnaire results show that students knew active learning was helpful, but they were unable to curtail unproductive learning practices. The questionnaire also showed that students struggled to stay motivated and keep to a schedule. We conclude that by developing their study techniques and self-regulatory habits, students will be able to take more control over their learning, particularly in asynchronous classes.

Keywords: asynchronous teaching, online teaching, self-directed learning, active learning, COVID-19

1. Introduction

1.1. COVID-19

During the Spring 2020 semester, many universities in the United States and abroad suddenly transitioned to fully online instruction in response to the emerging COVID-19 pandemic. In many cases, faculty had only 1-2 weeks (mid-semester) in which to redesign their syllabus and course structure for online delivery. While some faculty were experienced with online instruction, many others were figuring it out for the first time. For some, the following Summer and Fall semesters presented a similar struggle: everyone knew that teaching online was a possibility, but some faculty were asked to prepare for both in-person and online instruction because an official plan had not been announced. All this presented a myriad of challenges to instructors in terms of learning new technology, creating content, planning and designing assessments, and many other aspects of their professional and personal lives.

Despite the tireless (yet exhausting) efforts of faculty and staff to prepare meaningful online instruction and assessments, many students struggled with the transition to purely online instruction. Even during Fall 2020, a semester that many students began fully online, we noted that among students in our courses and those of several of our colleagues in mathematics, student performance was down, and students lacked satisfaction with their courses and with their ability to retain information. Knowing that many faculty have prepared extensive resources to maximize the likelihood of student success, we asked the following research questions:

- How are students interacting with the resources made available to them for their mathematics classes?
- How are students behaving in this online environment (with respect to their mathematics classes)?

To provide insight into these questions, we collected responses to a short questionnaire from students who were registered for an entirely-online course in PreCalculus at a medium-sized university in the Midwestern United States. Despite the instructor following recommended best practices for online course development, the students struggled to connect with the course early in the

semester as the instructor had intended. The questionnaire was designed to motivate students to reflect on their study habits and to elicit their self-evaluation of the efficacy of those habits. We analyzed results from the questionnaire via thematic analysis. These results suggest that students experienced difficulty due to a misalignment in the expectations of the students and their teacher with respect to what kinds of activities learners should engage in to direct their own learning in mathematics. Two themes, *active versus passive learning* and *self-regulation*, emerged from the data. In the following sections, we discuss some recommended practices from the literature for structuring online courses and the influence such decisions may have on student performance. Then, we transition into a discussion of active and passive learning and self-regulation. Following our results, we provide recommendations for online teaching and course structure.

1.2. Best practices in online instruction

Prior research has identified differences between face-to-face instruction and online teaching. Most notably, analyzing several large scale studies of online mathematics teaching, Trenholm, Peschke, and Chinnappan found that "Clearly, from multiple perspectives, [fully online] mathematics instruction has not been successful in comparison with traditional [face-to-face] mathematics instruction" [26, page 1094], citing factors such as students' grades, retention, and withdrawal rates. Trenholm *et al.* further emphasized studies finding that mathematics as a subject area is more challenging to teach online than other subjects. Trenholm and Peschke identified six ways in which online mathematics instruction differs from face-to-face instruction and suggested that, if ignored, these differences may constrain the effectiveness of online mathematics teaching [25]. Among these differences, Trenholm and Peschke highlighted the necessarily student-led nature of asynchronous online learning, affecting teachers' ability to guide students' learning, and changes in the timing of communication between students and teachers, restricting teachers' ability to provide them with timely feedback.

Many "best practices" guides for online instruction have been produced, and many "crash course" versions emerged during 2020 for those educators who needed to make the sudden transition [13, 19, 23]. These guides often address the costs and benefits of teaching synchronously versus asynchronously,

tips for recording lecture videos, advice for preparing assessments, and other "standard" topics. Beyond making pedagogical decisions, teachers must also make organizational decisions, like how to structure deadlines and where to make the syllabus, lecture videos, study materials, homework, and other resources available to students.

What is missing from many of these guides is how to guide students to effectively use course material and other resources. Trenholm, Alcock, and Robinson found that the use of technology in teaching should be carefully planned, particularly with regard to students' needs [24]. Based on a meta-analysis of the literature on the use of technology in undergraduate mathematics teaching and learning, they deduced that until research findings are clearer, as traditional institutions consider providing e-lectures, it seems prudent to avoid what Baker *et al.* [1] refer to as a 'bolt-on' instructional technology strategy that ignores the bigger picture of pedagogic transformation. That is, there is a need to provide instruction to students on how best to make use of e-lectures. In a more demanding form, this planning may entail serious consideration of student demographic characteristics and how to mitigate the possible effects of any loss of community. [24, page 713]

Inglis, Palipana, Trenholm, and Ward found that, when given access to live (face-to-face) lectures, pre-recorded online video lectures, and university mathematics tutoring services, students rarely made use of more than one of these resources, if they used any at all [18]. Furthermore, students' favored choice of resource correlated with academic performance. Students who attended live lectures or the university mathematics tutoring center outperformed students who preferred video lectures. This result is reflected in Trenholm *et al.*'s [24] and Howard, Meehan, and Parnell's [17] meta-analyses as well: "Overall, the studies [24] considered suggested a negative correlation between online lecture usage and achievement, and they ask whether this is because struggling students tend to choose online lectures in preference to other methods or whether video flexibility caters for surface learning strategies" [17, page 532]. Looking forward, Inglis *et al.* noted that "what remains poorly understood is the overall pattern of study choices made when students are presented with many options" [18, page 490]. We present a partial answer to this question.

1.3. Student engagement in the undergraduate mathematics classroom

Engagement in active learning practices is critical for the development of mathematical understanding [4, 5, 15]. Collins and O'Brien provide the following definition of active learning:

> The process of having students engage in some activity that forces them to reflect upon ideas and how they are using those ideas. Requiring students to regularly assess their own degree of understanding and skill at handling concepts or problems in a particular discipline. The attainment of knowledge by participating or contributing. The process of keeping students mentally, and often physically, active in their learning through activities that involve them in gathering information, thinking, and problem solving.[9, page 5]

While the term often brings to mind images of elaborate projects, group work, and presentations, active learning can also refer to more commonplace activities such as note taking, question posing, example generation, generalization, and practicing routine procedures [15].

Results show that in undergraduate STEM education, active learning promotes student success on a variety of metrics, including course grades, making connections among content, and self-efficacy [15]. Teaching strategies such as interactive delivery of content, group work with discussion and feedback, student presentations of solutions, and guided mathematical exploration are common among proponents of active learning in mathematics. These activities contrast with practices that students often perceive as sufficient for learning, such as watching lecture videos (but not taking notes), reading over pre-worked examples (but not attempting to work the examples or try similar problems), or using the internet to search for solutions to homework or practice problems. Students are misled to believe that these practices, which we will refer to as *passive learning*, lead to quality learning, when in fact students often conflate genuine understanding with familiarity with a set of problems they have seen before or even memorized solutions to [4, 5]. In contrast, students tend to believe that active learning practices, such as trying to solve previously unseen problems and example generation, lead to less satisfactory learning outcomes because these methods require more effort and struggle on the part of the student.

1.3.1. Self-regulation

In an online course, students must stay on a schedule, monitor their own progress on assignments, and know how to identify and repair gaps in their own learning in order to be successful [10]. These skills are related to self-regulation, the ability to structure and monitor one's own learning. Zimmerman defines *self-regulation* as "the self-directive processes by which learners transform their mental abilities into academic skills" [29, page 65]. Berk identified the skills of continuously monitoring progress toward a goal, checking outcomes, and redirecting unsuccessful efforts as elements of self-regulated learning [3]. In some sense, these skills may be thought of as "taking responsibility" for one's own learning.

Nota, Soresi, and Zimmerman found a positive correlation between self-regulated learning and academic performance among college students in face-to-face instruction [21]. While it is not automatic that students will spontaneously develop self-regulation techniques, previous studies show that designing an online learning environment promoting the use of self-regulated learning strategies can lead to the adoption of such strategies by students [2, 12, 28] . Hodges and Kim found that simply sending students emails suggesting self-regulation strategies had no effect on the frequency of students' uses of those strategies [16]. Wandler and Imbriale, however, identified six approaches instructors can take to promote self-regulation strategies that have been correlated with improved student achievement: explicit instruction on self-regulation strategies, requiring students to keep study logs, prompting students to self-regulate, sending text-message reminders reminding students about important dates and office hours and sending encouragement, scaffolding tasks, and fostering help-seeking behaviors in students [27].

The research outlined in the previous sections demonstrates the importance of students' abilities to take charge of their own learning in the online setting. Students' engagement in self-regulation and active learning practices are paramount to their success. In the coming sections, we will provide evidence that many students enrolled in an online mathematics course largely did not engage in productive learning activities, and needed assistance with self-regulatory behaviours like scheduling and identifying weaknesses in their learning. In some cases, though, students did seem to be aware of the ben-

efits of self-regulation, despite their lack of engagement in such behaviours. We discuss the implications of these findings, and we conclude by presenting our recommendations for teacher-initiated activities to help students practice these skills in their online classes.

2. The Study

This study took place at a medium-sized regional comprehensive university in the Midwestern United States. With the anticipation of the COVID-19 pandemic during the 2020-2021 academic year, instructors were allowed to choose their content delivery method for their Fall 2020 courses. These choices were face-to-face, hybrid, online synchronous, and online asynchronous. The course enrollment system listed the delivery method for each course allowing students to choose a delivery method for each course. There were 11 sections of PreCalculus taught at the university in Fall 2020. Each of the 11 sections were offered either online synchronous or asynchronous. Prior to Fall 2020, the university had not offered an online PreCalculus course.

2.1. Course instructor and designer

The course used in this study was designed by an instructor with 18 years of college instruction and nine years' experience in both online instruction and online course development. Prior to designing this online asynchronous course, the instructor had developed two online asynchronous general education quantitative reasoning courses and an introduction to proofs course. In addition, the instructor worked as a member of a team that developed asynchronous calculus and linear algebra courses. During the nine years' of online instruction, the instructor taught the following courses in an asynchronous online format: Differential and Integral Calculus, Multivariable Calculus, Linear Algebra, Complex Analysis, Quantitative Reasoning, and Introduction to Proofs. The instructor was certified by their institution to develop online courses prior to the COVID-19 pandemic. This certification involved taking (and passing) a course in online development which was created by the institution's online course designers. As part of this course, the instructor created an online course which was vetted by the institution's online course designers.

2.2. Course Design

The instructor developed the course during Summer 2020 using best-practices in online learning [20] satisfying the pre-pandemic university requirements for online courses. The course was a 4-credit PreCalculus course delivered in an asynchronous online format. The course content was divided into segments called "lessons". For each lesson, students were given textbook readings, cliff notes of the readings, videos of content, and between three to seven examples. The examples were presented in both pre-recorded video and written form. Each week, students completed two or three lessons, each of which corresponded to one section of the textbook. Students were given both ungraded and graded homework. The ungraded homework consisted of selected exercises from each section of the textbook, *Algebra and Trigonometry* by James Stewart, Lothar Redlin, and Saleem Watson [22]. The textbook provided an answer key for the assigned exercises in the back of the textbook. The graded homework was administered through WeBWorK, an open-source online homework management system offered through the Mathematical Association of America (https://www.webwork.maa.org). Homework was due on Sunday for the lessons covered the previous week.

Students completed a timed one-question free response problem when starting a new chapter which served several purposes. The first purpose was to have students practice answering a question in a timed environment which required a file upload into the course management system. The second purpose was to provide detailed comments to students about their work prior to completing the free response portion of an exam. The question used in each free response was chosen to only require knowledge of the first two sections of the new chapter. Students had the opportunity to resubmit their first attempt for additional credit. The final free response submission was returned with comments before students started the exam for the corresponding chapter.

There were five chapter exams and one final exam during the semester. Students gained access to the exams on a Thursday morning and the exams closed the following Sunday evening. Exams were not proctored. Each chapter exam consisted of two timed portions: a six-question multiple choice portion and a three-question free response portion. The multiple choice portion was graded for correctness and had a time limit of 60 minutes.

The free response was graded allowing for partial credit, had a time limit of 90 minutes, and required students to upload their work into the course management system.

Students participated in a discussion designed to have them reflect on their overall experience with the last module/chapter after completing the assessments for each chapter. Discussion groups consisted of 4-6 students and remained the same throughout the semester. Students were required to submit an original post and then were given two days to post at least two responses to their group members' posts.

There were two sections of PreCalculus that were combined into one course in the learning management system (LMS). Each of the sections had two 1-hour blocks each week which were designated in the students' academic schedules for office hours. Students had a total of four hours of office hours each week that they could attend: Two hours were blocked in their schedule for their section and the other two office hours were blocked for the other section. Office hours were not mandatory.

2.3. Method

2.3.1. The students

The PreCalculus course in this study had 49 undergraduate students enrolled. Each student signed a consent form at the beginning of the semester agreeing to participate in this study. The consent form was approved by the university's Institutional Review Board. All of the 49 students enrolled were given the option to participate in this study. Six students opted out. Of these 43 students who participated, 27 were freshman, 11 sophomores, 4 juniors, and 1 senior. Among the 43 students, there were 35 STEM majors, 5 liberal arts majors, 2 education majors, and 1 business major. Twenty-seven of the participants had never taken an online math course before, 8 participants' only prior experience was in Spring 2020 when face-to-face instruction changed to online, 3 participants had taken an online math course prior to Fall 2020, and 5 participants did not indicate their prior online math course experience.

2.3.2. The Procedure

Students answered a five-question questionnaire at the beginning of the fourth week of class after completing the first module/chapter of content. The five questions were:

- If this is your first online math course, how are you adjusting?
- What are you doing to pace yourself with the material?
- Was there anything from the content that you found interesting? Why?
- What are some things that you are proud of yourself for from this last month?
- What are some areas where you can improve on for the next module?

The questionnaire was provided to the students as an online assignment delivered through the LMS. The participants responded in paragraph form and their responses were recorded in the text-box provided by the LMS. The 5 questions were designed to elicit each participant's background with online math learning, how they were interacting with the course content, as well as how they perceived their interaction with the course content.

2.4. Thematic analysis of questionnaire responses

After the initial reading of the students' responses, we used an inductive thematic analysis to generate a preliminary set of codes from the data [6]. The initial codes compared and grouped together the following initial set of sub-categories along with the tallies of each sub-category: technological challenges (4), technological advantages (5), community (6), study habits (5), student organization (4), course content organization (3), content (5), goals (4), positive/negative outlook (7), ability (3), and problems with knowledge transfer (8). Then, we revisited the sub-categories and reorganized the coded data. The following categories emerged: assistance, course logistics, the COVID factor, and course content. The two emergent themes from these categories are active versus passive learning and self-regulation, each with its own set of associated sub-themes (categories). The sub-theme for active versus passive learning is assistance. The sub-themes for self-regulation are course logistics, the COVID factor, and course content. These two themes and their sub-themes will be discussed in detail in the following sections.

Throughout the analysis several connections were observed amongst the subcategories which led to the categories and, in turn, the themes. These connections were:

- Online is hard because students are used to learning in a face-to-face environment.
  - They understand how to take notes from a lecture, but do not necessarily understand how to take notes from reading a textbook or watching videos.
  - In a classroom environment, they can get immediate feedback which is part of how they are used to getting help when they are confused.
  - In an online environment, their ways of seeking help have changed, despite many common features between the two environments, such as email, designated office hours, and tutoring services.
  - Students rely on classroom instruction to keep a schedule.
- There seem to be three motivational factors for students: the material, the course format, and outside activities. These factors can be either a positive or negative motivator.
  - Procrastination is causing stress and making the students overwhelmed.
  - Another motivation is to just get stuff done. This plays into having too much going on right now and being overwhelmed.

2.5. Results

The first online/remote learning experience that most of the participants had was during March 2020 when the majority of high school and college courses abruptly transitioned to remote learning with the onset of the COVID-19 pandemic. Fall 2020 was the first online math experience for 63% of the participants. This PreCalculus course was the first asynchronous online course for 81% of the participants. Overall, the responses indicated that the students in this class were struggling to adapt to the online learning environment for this course.

Our thematic analysis of students' responses to the questionnaire resulted in the emergence of two main themes: *active versus passive learning* and *self-regulation*, with each theme encompassing one or more sub-themes. Here, active and passive learning refers to students' descriptions of their study habits and their interactions with the learning materials provided in the course. Self-regulation describes students' planning-related activities and includes students' scheduling habits (or lack thereof) and factors that affected students' motivation. In a very broad sense, active versus passive learning provides insight into how students engage in learning activities, and self-regulation describes factors influencing when students decide to do their work. Of the 43 students who participated in this study, 32 (74%) of them had a response which was coded in active versus passive learning and 35 (81%) of them had a response which was coded in self-regulation.

2.5.1. Active Versus Passive Learning

Many students indicated that, although they used course materials provided by the instructor and even sought out additional resources, their interactions with those resources were largely passive. The majority of students reported *reading* the textbook, *reading* online notes, and *watching* the videos without additional engagement with those materials, such as taking notes or trying problems on their own. Students reported not immediately recognizing the need to take notes from textbook readings, online readings, or online videos or they recognized a deficit in their note taking.

- Taking notes is something that I struggled with as well, I felt that I understood the concepts but I didn't take many notes to use later when the content might not be as fresh in my head. (Participant 30)
- I am still adjusting to reading something then taking notes instead of having my teacher lecture and take notes during it. (Participant 1)
- I would like to take better notes from the textbook because in the first module I read the textbook but did not write it all down. (Participant 29)
- Another area I could improve in would be writing down notes from office hours. I have attended most office hours, but I have just been writing down the answers to my questions. I should be writing down all tips and notes. (Participant 35)

In fact, many of them regarded reading the text or watching the videos as sufficient interaction with the material despite acknowledging the role of note taking in previous mathematics courses. Additionally, some students recognized early on that reading the content and watching videos of others interacting with the content was not transferring to their own understanding:

- I have been looking at the bookwork and going through the lessons. (Participant 18)
- ...and just looking over the notes... I could never just read and understand what is going on when it comes to math ... (Participant 23)

Others, however, had not made this connection yet and intended to increase the amount of time they were spending using passive learning strategies during their study time:

- I am also trying to find videos of similar problems so I can try to understand the steps. (Participant 23)
- I have had to spend a little more time watching videos online of how to walk through some problems. (Participant 11)
- Although I read the respective chapters of the book, I could work on reading them more in depth so I don't have to go back and read it again when I am completing assignments. That way I will just know it the first time. (Participant 24)

Some students acknowledged value in note-taking, but they suggested that taking notes effectively from a textbook was more challenging than taking notes from a teacher.

- I am still adjusting to reading something then taking notes instead of having my teacher lecture and take notes during it. (Participant 1)
- For the next module I would like to take better notes from the textbook because in the first module I read the textbook but did not write it all down. (Participant 29)
- Taking notes is something that I struggled with as well, I felt that I understood the concepts but I didn't take many notes to use later when the content might not be as fresh in my head. (Participant 30)

Note-taking was the only active learning strategy reported by students in this study. Therefore, it is not clear if students employed other active learning strategies. For example, students did not mention the role of homework in learning, nor pausing the videos for reflection, etc.

Assistance: Many students reported being unhappy with the lack of avenues for communication and instructional support. Paradoxically, the ways in which students sought help shifted away from live interactions despite reporting a desire for immediate feedback similar to what they were accustomed to receiving in a face-to-face setting.

- I enjoy having access to a teacher in class when I have questions. (Participant 38)
- the worst part for me is the communication, I miss being able to ask a question and get immediate feedback. (Participant 9)

Opportunities for live interactions were made available to students in the form of four voluntary office hours per week hosted by the course instructor and live virtual tutoring sessions through the university tutoring center which had specific virtual rooms for math tutoring. On average, six different students (out of 43 total) attended office hours each week. Attendance was recorded on a spreadsheet as students joined the virtual office hour room. Since there were no academic scheduling conflicts with office hours, this leads to the assumption that students were making the choice to not attend office hours, or there were non-academic circumstances preventing students from attending. Of these six students who regularly attended office hours, two of them were regular attendees missing only a handful of office hours throughout the semester. Additionally, while the specifics for the PreCalculus course are unknown, the university's remote tutoring center also reported an overall 90% decrease in online attendance during Fall 2020 when compared to face-to-face attendance in Fall 2019. Instead of reaching out for personalized help, students turned towards online resources such as videos and written solutions of the problem (or a similar problem) using resources such as chegg.com, slader.com, and Khan Academy.

Despite many students choosing not to use these resources, several students indicated their belief that attending office hours and taking advantage of the tutoring center would improve their understanding of the material:

- At the beginning of the semester I had a really hard time understanding the material in full, however joining the office hours has been very helpful in learning the content. (Participant 26)
- To improve I definitely need to go to more tutoring and the help sessions because the one time I went, it actually helped me out a lot. The only problem is was [sic] that I didn't want to come into those help session[s] and say, "I don't understand anything" because I wanted to try it for myself and focus on more specific things to look at. But it took me so long to understand it alone that I might as well have went to those sessions just to understand a whole concept. (Participant 12)
- I was struggling with the material but I went to tutoring and they helped me figure a lot of my questions out. (Participant 9)

In contrast, students wanted to use online resources even thought they knew them to be ineffective:

- ... that we have things like google where we can always find out but sometimes it really feels like the answer to a question you have just isn't out there. (Participant 32)
- I am also trying to find videos of similar problems so I can try to understand the steps. (Participant 23)

Active Versus Passive Learning — Summary. Overall, students were aware that their initial, primarily passive, learning strategies were not sufficient in ensuring their success in PreCalculus. They reported *watching* lecture videos within the course content, seeking out additional videos on the Internet, *reading* their textbook, and *reading* worked problem solutions. Despite recognizing that these approaches were not effective, many students did not express intentions of changing these practices. Some students, however, did acknowledge a need to alter their approach to the course, typically by increasing the frequency of their note taking while watching videos or reading the textbook or by making more frequent use of tutoring services or the instructor's office hours.

2.5.2. Self-Regulation

Several students discussed their motivation and their ability to adhere to a schedule. Students found motivation to work on the course difficult. When

students have a specified class time they are expected to attend, such as in a face-to-face or synchronous online class, students feel the need to keep up with the course work in order to be prepared for the meetings:

- I like in person a lot better because even if I'm feeling unmotivated, I'm still forced to get my work done. I also get easily distracted when I sit down to do my work at home so it usually takes me longer than it should to complete an assignment. (Participant 17)
- I was hoping to have synchronous classes to keep a schedule going. I am having a hard time keeping my normal class schedule going because of this, but slowly adjusting still!... Areas that I can improve on for this next module could be to continue to work on keeping this class "synchronous" so I do not fall behind. (Participant 20)

The course schedule was deliberately designed in such a way as to give students a sense of structure and regularity. Although the course was structured asynchronously, office hours were scheduled during the course's regular meeting times, and weekly homework was always due on Sundays. Rather than working on tasks gradually throughout the week, many students did not work on the course until the homework deadline was looming. This caused unnecessary stress and anxiety.

- I was pushing my homework to the weekends within the last couple weeks and that was making it difficult when I had questions. (Participant 8)
- I was tempted to push everything to the end because I thought I had the time. But as the due dates got closer, it became quite overwhelming. (Participant 21)
- Just in general having so much "freedom" for say, I find it really challenging to dedicate time to this class having no face to face contact. (Participant 39)
- I need to get better at being on top of things and doing assignments well before their due date so that I don't get too overwhelmed and stress with the amount of work that I have to do. (Participant 36)
- One thing I would like to work on is starting assignments earlier on in the week so that I don't have a bunch of work to do on the weekends. (Participant 14)

Course Logistics. While some students were aware of deadlines and admitted to simple procrastination, other students struggled to keep track of deadlines at all. In a typical face-to-face or synchronous course, students are verbally reminded multiple times about upcoming deadlines. For instance, many classes start with an instructor reminding students about upcoming homework due dates, quizzes, or exams. In an asynchronous online course, students are reminded of upcoming deadlines through a schedule that is presented at the beginning of the course, through course announcements, and by emails.

This distinction may appear small at first - but managing a schedule for an asynchronous course requires students to be more attentive. Instructors must also be attentive because there is a fine line between sending too many announcements or too few. By sending too many announcements, students can be overwhelmed with sorting and prioritizing them. This was especially challenging for students in Fall 2020 when most, if not all, of their classes were online and used announcements and emails as the primary way to contact students. On the other hand, without the instructor's constant reminders, students are responsible for reminding themselves of upcoming due dates.

- Things I think I can improve on is writing down more due dates to make sure that I am actually on task and I have one place to reference it. (Participant 33)
- [The course management system] is hard to keep up with and I'm having a difficult time staying on top of all my assignments and getting on track... I'm not the best at pacing myself with my work and I tend to let all of my assignments pile up, but I'm trying my best to work on it. (Participant 7)

Students found something as simple as writing down a weekly schedule including due dates and designated study times helpful. When students were able to maintain their own calendar and schedule, they had a more positive experience with the course logistics:

- I also have a calendar with due dates for every assignment that helps. (Participant 2)
- I try to do something everyday to accomplish the module we are on. I also keep an agenda of when assignments are due and try to schedule my week out with all my classes. (Participant 3)

- In order to stay on schedule I use the recommended pacing schedule that was provided to us in canvas, and I have found this to be very helpful. (Participant 27)
- I have set out a schedule of what time I will sit down and strictly work on Pre Calc. (Participant 31)

Course Content. The course was designed to align with the textbook sections and the topics in the course were covered in the same order they were presented in the textbook. The first module covered logarithmic and exponential functions. Most students had already seen this material in high school and came into the course with preconceived notions about logarithms and exponential functions. When students had negative feelings towards the material, their lack of interest in the content affected motivation to study:

- Finding the motivation to solve problems you don't understand is difficult. (Participant 32)
- I am not a math person, so the content was not very interesting to me. (Participant 40)

When students had positive experiences with the content, their interest contributed to a desire to work on the homework and course:

- I found the laws of logarithms interesting. For me it's like a puzzle. (Participant 4)
- I really enjoy working with logs...I don't know why they are just problems I like to work to solve, its kind of like a puzzle. (Participant 31)

The COVID-Factor. The COVID pandemic contributed to students having a difficult time self-regulating, as well. One student described what most everyone, including instructors, felt:

- I do like that I can do work on my own time, but I actually also find that very hard for me because I won't sit down and do work when I have time. I usually just want to rest because I've been going and going. (Participant 24)

Some students described idiosyncratic challenges to learning that either they had not experienced prior to the emergence of the pandemic or had been compounded as a consequence. In addition to the general fatigue brought on by the pandemic, students also faced additional pandemic obstacles such as inconsistent housing, quarantining, (other) classes transitioning from face-to-face to online and back again, getting tested regularly for COVID, unstable technology, etc. For example, after the first week of classes, a two-week "shelter in place" order was put into effect. Students were given a few hours to decide if they wanted to remain on campus or go home. Many students abruptly left campus, returning home with the intention of remaining at home for the duration of the semester.

- With covid, poor wifi, and going between school and home this first month has been everything except leisure. Although things haven't been ideal I feel like I'm doing the best I can with understanding, learning, and reaching out when I need a little extra help. One thing I would like to work on is starting assignments earlier on in the week so that I don't have a bunch of work to do on the weekends. (Participant 14)
- My schedule has also been busy with one-on-one [meetings] with [people for work], so this last week has been difficult to keep up. Some things I am proud of myself for this month are adjusting to [my job] responsibilities, actively social distancing and wearing a mask, actively getting myself tested for COVID, and being dedicated to my studies. (Participant 20)

Self Regulation — Summary. In summary, we found students' ability to self-regulate was deeply connected to their overall experience in the course. Finding motivation and time to work on the course provided consistency for which many students indicated a need. Students expressed that "so much freedom" was problematic and reduced their drive to complete work for Pre-Calculus and indicated a desire to "work on keeping this class 'synchronous'." Those students who wrote down a structured weekly schedule and adhered to it expressed less anxiety and more satisfaction with their performance, including less procrastination. Writing down deadlines and due dates also seemed to reduce students' stress. Unsurprisingly, students' drive to work

was also affected by their interest (or lack thereof) in the specific topics covered in the course, but students also had to contend with a variety of unanticipated challenges related to COVID-19 and working from home, over which they had little control.

3. Discussion

Two overarching themes emerged from our data on students' practices in the online PreCalculus class: active versus passive learning and self-regulation. Speaking broadly, these themes can be thought of as reflecting how and when students engage in learning activities, respectively. In particular, students reported largely employing passive learning strategies like watching videos and reading pre-worked example problems, but research has shown that active engagement with mathematical content improves understanding and recall [4, 5, 15]. Some students recognized that taking notes while doing so could be an effective supplement to these activities, but they expressed difficulty in taking notes from a textbook when compared with taking notes from a teacher's lecture. Furthermore, taking notes was the only active learning strategy students mentioned as a possible supplement to their current activities.

From our perspective, both the teacher and the student were in violation of the implicit didactical contract [7], but the reason for this is quite subtle: teacher and student were operating under different didactic contracts, though neither was aware of it. In the physical classroom, students and teachers often hold to socially negotiated norms; often, that the teacher will lecture, and the student will take notes, among others. These norms may be societal, and taken as typical roles of teachers and students broadly, or else they are negotiated in the classroom, for example, by the teacher prompting students to generate examples of a definition or to discuss strategies with a partner.

The online environment, however, is not a typical learning environment for many students, nor for many teachers, and behavioral norms for this setting may not be well understood by all participants. The teacher may see it as their role to prepare content and simply be available to answer students' questions, while tacitly assuming that students will employ the same study habits they, themselves, might use: namely, note taking, problem solving,

proof construction, example generation, etc. Students, for their part, may see it as the teacher's duty to provide content, and their role as students is simply to consume that content, whether it be in the form of videos, worked examples, or textbook excerpts. This is reflected in students' intentions to simply find more videos online or to use search engines to find worked solutions to problems: rather than changing their approach to learning, some students chose to double down on practices that had already proven insufficient for their learning. This may be because students are not aware of the teacher's expectations that they should engage in other, more productive, practices. Alternatively, students may genuinely believe these practices to be effective, as repeated visitation of the same procedures and the same examples can create the illusion of learning, while active learning strategies feel unproductive because they require more effort [4, 5].

Some students also mentioned having benefited from attending virtual office hours or online tutoring sessions, and other students stated that they believed making use of these resources would benefit their learning. Yet throughout the semester, attendance at the instructor's office hours remained low (never more than 6 out of 43 students in a given week), and while we cannot say exactly how the students in our sample utilized tutoring resources, virtual tutoring services saw a 90% decrease from Fall 2019. Based on these results, we conclude that students made the decision not to use these resources, despite a prevailing belief (sometimes based on personal experience) that they could be beneficial. Instead, some students reported an intention to simply look for more videos and worked examples, rather than evaluating the effectiveness of these behaviours and investigating other means.

Monitoring progress and redirecting unsuccessful efforts toward learning are part of the process of self-regulation [3]. Though many of the students in our study were aware that their study habits were not sufficient for them to attain their learning goals, and in this case were even aware of possible alternative avenues for learning, they were not particularly good at implementing changes in their routine. Some students explicitly expressed their desire for more synchronous interaction with the teacher or another expert:

- I enjoy having access to a teacher in class when I have questions. (Participant 38)

- the worst part for me is the communication, I miss being able to ask a question and get immediate feedback. (Participant 9)

Yet, despite having time deliberately built into their schedule for this purpose, only a small percentage of students took advantage of the opportunity for this kind of interaction. Asynchronous online learning is an atmosphere in which students must learn to be self-directed learners, and thus are "expected to assume primary responsibility for their own learning" [8]. In this setting, the teacher cannot know when the student needs help; rather, the student must develop the self-awareness to be able to seek out help when it is needed.

In addition to struggling with monitoring the effectiveness of their study practices, students struggled with motivation and procrastination as well as simply keeping track of due dates. Without regularly occurring mandatory course meetings, students found themselves putting off their work until the last minute, completing large chunks of coursework at once and generating unnecessary stress. On the other hand, students who wrote down and maintained a weekly routine for studying and including deadlines reported satisfaction with this strategy and generally seemed more satisfied with their performance in the course. These students who reported lower levels of stress with regard to deadlines and procrastination are those who demonstrated epistemic agency [11, 30]; they took a proactive approach to the course, developing personal schedules and accountability measures to ensure that their work was done gradually and ahead of schedule.

Level of interest or disinterest in course content was a factor indicated by students to influence their motivation to work. Challenges also arose that were beyond students' control due to COVID-19, including challenges with Internet connectivity, distractions when working from home, and surprise changes in course delivery instituted by the university. These factors are not always within the control of either the teacher or the student. Such issues, however, may also be mitigated by careful adherence to a schedule. To be clear, we do not mean to suggest that students who do not adhere to a schedule are to be assigned blame when unexpected issues arise. On the contrary, for the students' own sake, we propose that the stress from such events (or dispositions) can be minimized by piecemeal productivity.

4. Implications for Teaching

The widespread turn toward online instruction forced by the COVID-19 pandemic provided a unique opportunity for introspection and reflection about instructional practices, particularly in mathematics. Moving forward during and after the COVID-19 pandemic, when academics can return to (a new) normal, instructors should reflect upon the successes and failures of remote teaching during Spring 2020, Fall 2020, and Spring 2021 and use these reflections to improve teaching and enhance learning. Based on the results from this study, we present the following observations and recommendations which are motivated by obstacles that were observed in this study. The recommendations are designed to further develop students' self-directed learning which can then be applied to different learning environments and subjects, whether face-to-face or online, and whether synchronous or asynchronous.

4.1. Teach students to find and reflect upon classroom information

The role of the teacher is to help students develop skills and knowledge that will enable them to succeed in the future. More than just content knowledge, this includes skills that help students to become self-sufficient, including seeking out and keeping track of pertinent information such as deadlines, assignments, and criteria for evaluation. In face-to-face and synchronous online learning, this information is often presented verbally in the form of announcements made by the teacher during class meetings. Students who are accustomed to face-to-face courses may be dependent on these announcements to stay up to date on their work. However, during asynchronous online courses, such announcements may not be possible, and this information is often posted either in the course syllabus or in the LMS, requiring students to seek it out themselves. Well-meaning teachers might try to remind students about upcoming deadlines via email or announcements through the LMS, but sending too many of these reminders may decrease their effectiveness, and if students are enrolled in multiple online classes, it is likely that some messages will be overlooked.

Rather than inundate students with reminders, we recommend designing tasks to teach students how to find important information on their own.

A syllabus reconnaissance is one such task, in which students are asked questions about the structure of the course and they must consult the syllabus to find the answers (some versions of this require the students to generate questions about the syllabus as well, which they will pose to the teacher). For online courses, a similar task might require students to "Write down the example problem in Video 4," or "Identify three of the criteria on which Project 2 will be assessed." These tasks require students to demonstrate that they can navigate the LMS to find the syllabus, textbook, video lectures, assignments, and rubrics, and it ensures the teacher that they have read this information at least once. Ideally, students will then be able to return to these documents to find needed information later in the course. Short, low stakes "gatekeeper" assignments might also be implemented: for example, a short 1-2 question quiz, on which a student must score 100% before a homework assignment can be started, worth zero points, about the date of an upcoming test. The student is not penalized for not knowing the information, but they must demonstrate that knowledge before they can submit the assignment for credit. By implementing these recommendations, students can be taught to seek out important information on their own and be less dependent on others.

4.1.1. Teach students to manage their time and monitor their learning

When teaching face-to-face, instructors may think carefully about the tasks they ask students to complete and the amount of time allotted for those tasks. In asynchronous instruction, teachers have less direct control over these elements of their classes, and students are often unaware of the types of tasks they should engage in and for how long. As our data show, students who stick to a schedule and who engage in more active learning practices were more successful. We propose two suggestions here.

First, encourage students to create a weekly schedule, including times when they will study for each of their courses, when they're scheduled to work, when they will eat meals, etc. Some students may not adhere to their schedule, but those who do may find it beneficial to stick to a routine, as the students in our study did.

Second, provide students with suggestions and resources for active learning. Some of the students in our sample seemed to realize that taking a more ac-

tive approach to the content would improve their learning, but taking notes seemed to be the only idea that came to mind for most of them, and the procrastination that many students reported likely led to big chunks of blocked practice rather than smaller bursts of learning. As noted in the introduction to this manuscript, practices such as interleaving, recall practice (stimulated by taking breaks during learning), and mixed practice (as opposed to blocked practice) can improve students' learning. Furthermore, students reported struggling to take notes from a textbook; providing scaffolded notes for the first section or chapter of the course may help students identify important information and provide a framework for future note-taking. Students should be encouraged to engage in specifically mathematical activities as well, like trying to solve progressively more challenging problems, explaining how and why procedures work, trying to solve problems in two or more different ways, drawing graphs and diagrams, creating their own problems, working problems backward (e.g., instead of "Solve the following quadratic equation," try "Create a quadratic equation with the following solutions"), and others. Given examples of active learning strategies, students may be more inclined to try a few of them and find something that works well for them.

4.1.2. Be explicit about your goals and encourage student buy-in

Our results showed that students in our sample lost motivation when they encountered mathematical topics they had previously found to be uninteresting or confusing. This loss of motivation does not necessarily mean that students will not do the work, but it is likely that unmotivated students will not exhibit the same curiosity other students might, nor approach the topic with a similarly open mind.

For this reason, we recommend that teachers be explicit in communicating their rationale and learning objectives for students. Because a lack of motivation may lead to a lack of natural curiosity, providing students with a sort of checklist of skills and knowledge can help guide them to see what the teacher thinks are the important aspects of a topic. This also helps students with their self-regulation by establishing a method for checking and monitoring their own understanding. More specifically, these learning objectives should be concrete and measurable. For example, a student who understands their learning objective as "understand logarithms" might have

a hard time determining whether they understand logarithms sufficiently well to pass an upcoming assessment. A student who has been provided the learning objective "Be able to convert an exponential equation into an equivalent logarithmic equation" will have a much better sense of where they stand with regard to the content: either they can do this or they cannot.

As stated in the previous section, we recommend that teachers provide students with examples of active learning strategies or giving more active tasks aside from simple note-taking. We also recommend that teachers be explicit with their rationale for these activities. Floyd, Harrington, and Santiago observed that when students' perceived value of a course is low, then they are more inclined to use surface level strategies such as rote learning and focusing on passing the course instead of learning the material [14]. It may not be immediately obvious that there is an advantage to mixed practice over blocked practice, for example. After all, as long as I do all the problems in my homework, I receive the same number of points regardless of the order I worked the problems. However, making students consciously aware of the advantages of this strategy (namely, that it forces recall of different strategies and provides practice in selecting the appropriate strategy for a given problem) can help them know whether this strategy is appropriate for a particular difficulty they might be experiencing, and it may encourage them to use this strategy more often if they perceive it to have a benefit.

While we do not claim that these recommendations will necessarily alter students' motivation, they may at least motivate more pragmatic students to work on specific tasks, and students may be more motivated to work on a topic that intimidates or confuses them if they are given specific tools with which to address that topic.

4.1.3. Summary

The recommendations above stem from observations in this study of obstacles that the students encountered while trying to engage in an online asynchronous course. In summary, students struggled with connecting their learning methods from synchronous environments to asynchronous learning environments. While no one could have predicted a situation where the majority of learning would be online and/or asynchronous prior to the COVID-19 pandemic, it is clear that in moving forward, we can do a better job of

developing students' epistemic agency and self-regulation which will improve student learning in all academic environments.

5. Conclusion

In an effort to describe the effects of e-lectures (video recorded lectures posted online), Trenholm *et al.* examined the research on online instruction and found that students' use of e-lectures was negatively correlated with student achievement [24]. In their investigation of how mathematics students use resources in a blended course setting, Inglis *et al.*, found that students who chose to use e-lectures under-performed when compared with students who chose to attend traditional face-to-face lectures, and they called for further investigation into how students choose to use (or not use) resources [18]. Our study gives a glimpse into the behaviours and uses of online resources of students who are accustomed to face-to-face instruction when they enroll (many, out of necessity) in a fully online asynchronous mathematics course.

We emphasize that our goal in this study was to describe students' practices and awareness of their own behaviours and their perceived efficacy, but not to correlate these practices with academic performance. Reports on online learning (both before and during the COVID-19 pandemic) have largely focused on the teachers' perspective, so we sought to give insight to educators on the behaviours in which their students might engage in order that they may better meet the needs of their students.

Furthermore, we have provided recommendations for practice based on our knowledge of the literature on teaching and learning in undergraduate mathematics and our own experiences as educators (with a combined 26 years of experience). We acknowledge that many of our recommendations are not novel, and in fact are pulled directly from the literature on teaching and learning. However, many of our recommendations are novel with respect to the research literature in the context of online asynchronous mathematics instruction. Future work must investigate the efficacy of these suggestions in this new environment not only with regard to students' self-perceptions of their practice but with regard to students' achievement as well.

Another set of questions arose as a matter of course during our review of our data: when, how, and why do students develop epistemic agency and become

independent, self-directed learners, particularly with regard to mathematics? Our results describe a class of students who, by and large, are still learning how to direct their own learning. In contrast, we hypothesize that a class of 43 advanced PhD students in mathematics would have produced a very different set of responses to our questionnaire. While PhD students would likely express struggles with content, we suppose that their approaches to learning content – i.e., development of routines and schedules, active engagement with content, and methods of self-assessment and monitoring – would look vastly different. At what point do these changes in learning habits develop? What causes these changes? Can these changes be taught or facilitated? We believe that students' approaches to active learning and self-regulation significantly contribute to the struggles that students experience in mathematics learning, particularly in the online asynchronous environment. We believe that changes in the ways students approach active learning and self-regulation can be nurtured, and we hope that our work provides a step in that direction.

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