A STUDY ON THE EFFECTIVENESS OF THE FLIPPED CLASSROOM AND BARRIERS TO ITS IMPLEMENTATION IN MATHEMATICS

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Abstract

The flipped classroom is a restructuring of the learning process so that the gathering of information occurs prior to class and class time is used for problem-solving, discussion and synthesis – it is an inversion of the typical classroom structure. It is an approach to teaching and learning which has been gaining popularity, and has been implemented in courses across all disciplines and programs. However, this approach is not routinely used in the Mathematics and Statistics Department at McMaster University.

How effective is the flipped classroom when used in mathematics? What are the challenges that instructors face when implementing this approach? This study will look at how effective the flipped classroom approach is in facilitating teaching and learning in a first year mathematics course, Math 1C03: "Introduction to Mathematical Reasoning". We surveyed students about their experience with the flipped classroom to learn about their thoughts and perceptions. Then, we conducted interviews with faculty members within the department to better understand the barriers that prevent instructors from implementing the flipped classroom approach as well as comparing and contrasting the views of instructors with those of the Math 1C03 students.

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Introduction

When speaking of teaching and learning innovations and practices, the idea of the flipped classroom will often come up. But what is the 'flipped classroom', really, and why has it been gaining so much attention? The flipped classroom is a restructuring of the learning process, where some (or in certain cases, all) of the gathering of information takes place outside of the classroom, prior to lecture, and lecture time is used for (some, or all of) answering students' questions, going over challenging parts of the readings (or videos), investigating applications, discussion and synthesis.

The flipped classroom approach shifts the paradigm of teaching and learning from a teacher-centered model to a learner-centered model. When using the traditional lecture style of teaching, the instructor typically controls the flow of the lecture, delivering pre-determined content to the students and taking questions about the material when asked. During lecture in the flipped classroom, learners have more control over the flow of the lecture. They have, presumably, already been exposed to the content and this is their time to do the consolidation work, under the guidance of the instructor. Having already had a chance to reflect on the material, students are ready to discuss it and work with it.

When it comes to what the flipped classroom looks like in mathematics or statistics - students are supposed to read the relevant parts of a textbook section or watch video lectures/ podcasts and then during lecture, the class engages in discussion, peer learning, and/or group or individual problem-solving. This is an inversion of the usual process, where the instructor will typically teach the material to the class in the form of a lecture and then assign practice problems for consolidation as homework. The availability and richness of online resources is perhaps the main reason why the flipped classroom is (somewhat) gaining in popularity in mathematics.

Some of the major advantages of teaching using the flipped classroom models are: students are able to move at their own pace; the in-class problem-solving and discussion provide the instructor with insight into students' difficulties, so they can appropriately customize and adjust the curriculum; teachers using the method report higher levels of student achievement, interest and engagement (Herreid and Schiller, 2013); and the use of technology can be more prominent and imaginative, as there is more in-class time left.

Needless to say, instructors have identified difficulties and problems of this approach: students may be resistant to the new approach as it requires them to do work at home initially, so they may come to class unprepared to participate; finding high quality videos/resources can be difficult and instructor-created videos take a lot of time (Herreid and Schiller, 2013).

In this study, we will take a deeper look at the flipped classroom approach in mathematics, in the hopes of gaining a better understanding of its effectiveness and the barriers to its implementation.

Motivation

The flipped classroom approach is not by any means a new concept; it is something that has been used, in various forms, for quite some time. For instance, one can argue that the Moore Method, a method in which the content of the course is presented by the students themselves (usually referred to as guided inquiry) is a form of flipped classroom, as students are required to work at home on suggested proofs and exercises and discuss them in the classroom. Further, when university lectures are depicted in films dating back decades, we see a professor standing at the front of the room calling on people and discussing readings with them that were expected to have already been done. A prime example of this is the scene in the movie "Legally Blonde" where the main character, Elle Woods, is called upon at the very beginning of class to answer a question based on the readings and was asked to leave for being unprepared. Now although this may seem like an extreme example, it does show that having students come to class already having learned the material is something that has been done for years.

Despite the fact that this approach has been around for so long, I myself, as a graduate from the Mathematics and Statistics program at McMaster University, have never experienced it in one of my mathematics courses. This approach is often used in other science disciplines including psychology and biology as well as other faculties outside of the sciences. This led me to wonder – why not mathematics? What are the barriers that prevent faculty members here at McMaster from using this approach to teaching? Is it the mathematics material itself, the attitudes and beliefs of instructors, or perhaps a lack of available resources? Is it even effective when used in mathematics? These are all questions that were floating around in my mind as I researched more about this approach. As I researched more about the flipped classroom in mathematics specifically, I quickly realized that it is not a very heavily researched topic which is why I felt that this study was important.

As with all studies on teaching and learning, the ultimate motivation lies in benefitting the students. There have been several noted advantages for students who are using using the flipped classroom, including the ability to work at their own pace, engaging with peers about concepts, lower frustration levels and a particular benefit to students whose preferred learning styles impair their performance in traditional education environments (Du et al., 2014).

Furthermore, the way that lectures are done presently, many students are not *truly* learning (we claim this as a matter-of-fact statement supported by anecdotal evidence, without attempting to lay blame on anyone; trying to analyze this further would take us too far from our goals). Students are mostly regurgitating information on tests and exams, writing proofs from memory, and trying to match a test question with a previously seen homework question, rather than thinking "fresh" on the spot. Students often fall behind and then cram for a test or an exam, which is known to lead to poor learning and retention. The flipped classroom provides students (who are willing to engage) with the motivation to stay on track as there is work to be done to prepare for each class.

It is no secret that that the vast majority of students often struggle with their mathematics courses in university, so if these benefits can help students enjoy and thrive in the subject, then it will be a worthwhile effort.

Research Questions

The goal of this study is to answer two questions; one about the effectiveness of the flipped classroom approach and one about the barriers to its implementation in the field of mathematics.

The flipped classroom approach has been gaining a lot of traction lately, and we wanted to take a deeper look at how effective it actually is when used in teaching mathematics at McMaster University. We wanted to learn what makes it effective (or ineffective) by asking students about their perceptions of the approach and contrasting them to the views of several instructors. Informed by the literature, we hypothesized that the approach could prove to be effective, under certain circumstances.

Thus, our first question is: How effective is the flipped classroom approach in facilitating teaching and learning mathematics in a first-year classroom?

The second question is: What are the barriers that prevent instructors from implementing the flipped classroom approach?

We wanted to learn what objective and subjective factors prevent instructors from adopting the flipped classroom approach – is it the lack of awareness of the approach, skepticism about its effectiveness, time constraints, or something else.

Our research questions have been inspired by our observation of the lack of prevalence of flipped classroom in the field of mathematics (compared to, biology or chemistry, or courses outside of Science), and are based on the existing research and literature on teaching practice.

Literature Review

Despite the fact that the flipped classroom approach is not by any means a new concept, it has been gaining a lot of traction in the field of mathematics recently. The majority of the references pertaining to the flipped classroom being used specifically in mathematics have only come about within the last decade. Although there are more studies on this topic available in the literature now than there were 10 years ago, the body of knowledge and practical experience dealing with the flipped classroom in mathematics are still quite small. However, the findings in the existing studies are fairly consistent with several key themes.

A study that has been central to our research was conducted at Simon Fraser University by Jungic, Kaur, Mulholland and Xin (2014). This study involved flipping approximately one class per week in four large enrollment first-year calculus courses over the course of two years. The flipped class consisted of four phases: information gathering, preliminary assessment, assimilation of information and homework. In phase 1, students are asked to watch audio-visual lecture modules created by the instructor based on the material to be covered during the flipped class. After watching the lectures, and before coming to class, students are asked to complete a quiz based on the video lectures (phase 2). The instructor then uses the data from the quiz to identify areas in which students are struggling, and bases the lesson plan for the flipped class on

this information. During class (phase 3), the instructor displays a multiple choice question on the screen and asks students to use their iClickers to answer the question individually at first. The instructor then reveals the results from the poll and asks students to turn to their neighbour and convince them of their answer. Students are given a few minutes to discuss and then another poll is taken and the results displayed. The instructor then reveals the correct answer and explains it to the students. Finally, students go home and reinforce the material they've learned through assigned practice problems (phase 4).

Upon analyzing the data from surveys administered to students in the middle of the term and at the end, Jungic et al. (2014) conclude that the flipped classroom encouraged students to take on a more active role in their learning process, both at home and in the classroom. They found that it encouraged students to engage better with their classmates as well as their instructor. The instructors also felt more engaged with the students and were able to identify misconceptions about the material immediately as they arose. The authors state that the long term impact on learning achievement was inconclusive, however they plan to conduct further research. Despite their positive results, they do state that switching to the flipped classroom required a significant investment of time and resources.

An article published by Herreid and Schiller (2013) reveals that STEM teachers have similar concerns to the ones that Jungic et al. (2014) raised when it comes to implementing the flipped classroom. Herreid and Schiller (2013) took a poll of high school STEM teachers to identify what they viewed as the pitfalls of the flipped classroom approach. The first area of concern that was raised in the poll was that the homework assigned prior to class has to be very carefully tailored in order to prepare students for the activities in class. They prefer to assign videos over readings and find it difficult to find high quality videos, and creating their own requires a significant investment of time, as pointed out by Jungic et al. (2013). The second area of concern that STEM teachers had with the flipped classroom was that students may be resistant to put in the extra work outside of class and consequently come to class unprepared to participate.

Although creating video lectures appears be the most popular method to flipping the classroom, there are other ways to do so. An obvious way to solve the issue of the amount of time and resources required in order to create videos is to assign readings prior to class instead. However, assigning readings in this technological age may not be as effective in engaging students with the material to be learned. Further, students may find it more difficult to read from a textbook than to have key information highlighted and explained in a video. In fact, a number of studies (referenced below) that have looked at readings as a form of preparation for the flipped classroom found that students' perceptions were more negative compared to their perceptions of assigned videos. We will look at a couple of studies that used readings as a form of preparation along with videos below.

A study we found relevant to our research was a case study conducted by Sahin, Cavlazoglu and Zeytuncu (2014). This study consisted of taking a first year Calculus for Engineering course and flipping 3 out of 10 sections. Similar to Jungic et al. (2014), they also flipped the class by creating lecture videos for students to watch prior to coming to class. The study set out to answer three research questions: "How do college students prepare for a calculus

class in a flipped classroom?", "How do college students' achievements differ by instruction types (traditional versus flipped classroom)?" and "What are college students' perceptions about the flipped classroom model?" They collected data to answer these questions by surveying students at the beginning of each flipped class, to get a better idea of how students prepared for class and then again at the end of the term about their overall thoughts and perceptions. They also administered a pop quiz to assess student's understanding of the material presented in the flipped classroom. Based on their results from the surveys prior to the flipped classes, they concluded that students, in significantly larger proportion, prefer to watch videos to prepare for class (35% of students) than to read from the textbook (13% of students). Further, their pop quizzes indicated that the flipped classroom resulted in increased student academic achievement. They believe this is due to the fact that students are better able to prepare for class and have more opportunities to interact with the instructor and their peers in the flipped classroom model. They also noted that the flipped classroom encouraged higher preparation efforts among students: 22% of students stated that they did not do any preparation at all for the flipped classroom sections compared to 41% of students that stated that they did not prepare for the traditional sections. Finally, Sahin et al. (2014) conclude that students much prefer and benefit from the flipped classroom approach due to the increased opportunity for interaction with their instructor and peers as well as their preference for watching video lectures to prepare for class. They believe students prefer this mode of preparation due to its convenience as they can watch the videos at the time that best suits them and they can watch at their own pace without the pressure of it being in class. It should be noted, however, that Sahin et al. (2014) only implemented the flipped classroom using video and did not try it with assigning textbook readings. Textbook readings can be read at the students' own pace without the pressure of it being during class similar to video lectures. This can lead one to wonder if they could have found similar results had they assigned textbook readings for the flipped classroom sections.

Similarly, a study by Kay and Kletskin (2010) revealed that students prefer video clips to written text when it comes to preparation. In this study, they made "learning objects" available to students in a first year Calculus for Engineering course three weeks prior to a pre-calculus diagnostic test. The three "learning objects" consisted of text-based summaries which contained the basic concepts of a topic, mini-clips which were short videos on how to solve specific problems, and finally an online assessment system which students could use to test their knowledge on a specific topic. After the students received their results from the diagnostic, they were asked to complete a survey about their attitudes and uses of the learning objects. Using a tracking program, they determined how many times each learning object was used. They reported that the learning objects had 8988 hits for their class of 289 students. Of the 8988 hits the learning objects received, 52% of them for the mini-clips, 45% the text summaries and 3% the self assessment tool. This was consistent with their survey results as they found that 68% of students reported that they used the mini-clips most often. Students commented that they found the mini-clips useful because they were clear, easy to follow, provided useful visual supports and that they enjoyed being able to proceed at their own pace. These findings are consistent with the findings of Sahin et al. (2014). Overall, the majority of students rated the learning objects as either useful or very useful.

Several studies on the flipped classroom in mathematics have yielded positive results, when considering performance improvements or positive student perceptions. However, one

can't help but wonder if this due to the flipped classroom approach itself, or if it is because the flipped classroom approach inevitably results in having the students spend extra time with the material. Often times, when an instructor switches to the flipped model, they assign videos or readings for students to watch or read prior to class and then class time is used for assimilation. However, students are still assigned homework problems to do after the flipped class. This means that students are spending more time learning the material than they would have in the traditional class which could be the main contributor to increased performance in the subject. The study we will look at next takes this into account and ensures that their control group as well as the experimental group are spending an equal amount of time learning and studying the material outside of class.

Wasserman, Quint, Norris, and Carr (2015) conducted a study on the effects of the flipped classroom on student performance and perception. Over the course of two semesters, each semester one section of Calculus III (Advanced Calculus) was taught using the traditional approach and the other was taught using the flipped classroom approach. Both sections were taught using the same lecture notes, assigned the same homework problems and were given the same assessments at the same time. The instructor for the flipped section created lecture videos for the more procedural problems and went through more conceptual problems during lecture. In order to minimize the effects of having students in the flipped section spending more time on the course outside of class, students in the flipped section were given class time to complete the homework equal to the amount of time they had to spend before class watching the videos. As a result, students in both sections reported spending the same amount of time on the course material outside of class. In order to answer their research questions, Wassserman et al. (2015) analyzed data from student assessment grades to answer the question about performance and analyzed data from student responses to an end of course survey, as well as conducting focus groups to answer the research question about students' perceptions about the flipped classroom. Their data revealed that the students in the flipped sections performed slightly to moderately better on the assessments, and specifically so on the more conceptual assessment questions. The data collected from the surveys and focus groups indicated that students in the flipped classroom felt that there was more interaction with the instructor and with their classmates. However, students in the flipped classroom felt that class time was not used effectively or efficiently, whereas students in the traditional section were satisfied with the use of class time and found it to be useful to their learning.

There appears to be a recurring theme in the results of several flipped classroom studies: students will perceive class time to be less useful or efficient; in some cases they feel that it is just a waste of their time. This is a result that appears in flipped classroom studies in fields outside of mathematics as well. Ferreri and O'Connor (2013) experimented with a flipped classroom approach on a large enrollment pharmacy course and also found positive results on student performance. Their students showed a significant increase in academic performance and reported a preference for working in teams. However, at the same time they saw a significant increase in negative course evaluations as a result of switching to the flipped classroom model. Similarly, Missildine, Fountain, Summers and Gosselin (2013) conducted a study in which they compared the traditional lecture approach to the flipped classroom approach when teaching an adult health nursing course. They hypothesized that the flipped approach would result in an increased course examination average and increased student satisfaction. They were correct

about the students' performance; the flipped classroom group had a significantly higher examination average in the course. However, student satisfaction was significantly lower in the flipped classroom group, contrary to what they were expecting. Students stated that this approach required them to put in more work and they did not see the value of the interactive learning approaches. Strayer (2012) had similar findings in the study he did on a statistics course. He flipped one of the classes and taught the other one using the traditional lecture style. He found that although students in the flipped section became more open to cooperative learning, they were less satisfied with the classroom structure. The findings from these studies indicate that perhaps student satisfaction is not a good indicator of student learning.

The study by Cardetti, Pon, and Christodoulopoulou (2013) also sets out to answer the research question pertaining to the effects of the flipped classroom on students' perceptions and performance. They flipped two out of seven sections of a first year Calculus for Business course by creating lecture videos for students to watch prior to class, and then using class time for problem solving. Overall, the majority of students reported that the videos helped them understand the concepts better and allowed them to learn at their own pace. Although they reported the videos to be helpful, about 60% of students stated that they would have preferred to have been able to ask questions during the video lectures. Further, about 50% of students found their interactions with the instructor and other students beneficial to their learning and found that the flipped classroom helped them better prepare for tests and quizzes. However, students reported little preference for having class time devoted to problem solving and about 70% of students stated that they learn better from lectures than videos. However, when comparing the videos to textbook readings, more than half of students reported preference for videos. This is consistent with the results from other studies mentioned in this review, including Sahin et al. (2014) and Kay et al. (2010). This may be due to the fact that students have difficulty understanding mathematics textbooks as instructors spend little to no time teaching students how to learn from printed materials. Further, more than 50% of students reported that they preferred working through problems on their own and that they were less likely to attend class in the flipped classroom model. Similar to the findings of Sahin et al. (2014), a key theme in the students' responses to the open ended question on the survey was that they appreciated the convenience of being able to rewind videos when they did not understand as well as being able to watch the videos whenever they wanted.

In summary, the findings from these studies have indicated that the flipped classroom does have the potential to increase student performance in mathematics (Sahin et al. 2014, Wasserman et al. 2015). However, despite the fact that student performance may be increased as a result of the flipped classroom, students' perceptions of this classroom structure are not always positive. Several studies have found that students reported that class time was not useful nor efficient (Wasserman et al. 2015) and that they would prefer to be able to ask questions during lectures (Cardetti et al. 2013). On the other hand, some studies have indicated that student engagement has significantly increased as a result of the flipped classroom and that students have positive perceptions of this classroom structure (Jungic et al. 2014). This may be due to the fact that although a consistent aspect of the flipped classroom approach is that students are required to do some or all of the learning prior to class, the way that class time is used can vary significantly within this approach - which could have an effect on how students perceive the entire approach. For example, in the study done by Jungic et al. (2014), students were assigned

videos prior to class and class time was spent on solving iClicker questions with classmates and the instructor. This approach resonated well with students as they felt more engaged and felt that class time was beneficial to their learning. The study done by Wasserman et al. (2015) consisted of assigning videos for procedural problems and talking through the more conceptual problems during class and then giving students time to work through the assigned problems individually while the instructor walked around helping students. However, this approach resulted in negative student perceptions of class time as they felt it was not an efficient use of their time and did not see the value, even though the study indicated increased academic performance. It is evident from the literature that students' perceptions can vary when it comes to the flipped classroom, however the results have been fairly consistent when it comes to student performance. Academic performance tends to increase when the flipped classroom approach is implemented (Wasserman et al. 2015, Sahin et al. 2014), however it is not entirely clear if this is necessarily due to the approach itself or if it is a result of students spending more time on the course material outside of class.

Methodology

The studies that exist so far in the literature pertaining to the flipped classroom approach in mathematics have mainly looked at the effects of the approach on students. They have looked at students' perceptions of this approach as well as the effects it has on their performance and engagement levels. Our study is unique in the sense that along with taking a deeper look into students' perceptions, we have been speaking with faculty members within the Department of Mathematics & Statistics at McMaster University in order to study the barriers that exist to implementing this approach.

At the start of our research journey, we set out discover which faculty members would be implementing the flipped classroom approach in the courses that they were teaching in the Fall 2018 semester. We were surprised to find that, out of the entire faculty, only one individual was planning to use the flipped classroom approach in her course, Math 1C03 (Introduction to Mathematical Reasoning). We felt that this fact alone provided even more of a reason as to why our study on the barriers to implementing the approach was necessary.

In order to answer our first research question about the perceptions of students about the flipped classroom, we spoke to the Math 1C03 instructor, Dr. Deidre Haskell, and she agreed to have us study the effects that the implementation of the flipped classroom approach had on her students. It was decided that we would gather information about students' thoughts and opinions on the flipped classroom through two anonymous surveys administered to students at the end of lecture. Our study group consisted of the approximately 60 students registered in Math 1C03 in the Fall 2018 semester.

Math 1C03 is an introduction to mathematical reasoning course which focuses on inquiry into the ideas and methods of advanced mathematics, including communication of mathematical ideas and exposure to rigorous approaches to learning abstract mathematical content. Students are introduced to formal mathematical proofs in this course which is, in most cases, brand new to students as they are coming from high school where formal proofs of theorems are not a typical component. In reviewing the Ontario Curriculum for Grades 11 and 12 (Ministry of Education,

2007), we found that the only theorems that are covered in the curriculum are the remainder theorem, the factor theorem and the Pythagorean theorem. Students are expected to apply these theorems in various problems, however they are not expected to be able to prove them.

Math 1C03 is mandatory for students in all programs in Mathematics and Statistics, so the majority of students in the course are future mathematics and/or statistics majors. The instructor decided to structure the course so that students were required to complete assigned readings from the textbook prior to each class. In order to ensure that students were completing the assigned readings, they were required to answer one question about the material prior to each class and these reading assignments accounted for 10% of their final grade. The reading assignments were to be submitted online by 8 am on each lecture day. The instructor then used class time to reinforce the material that was read through discussion as well as taking a deeper look into more complex and conceptual material. She began each lecture by asking students to summarize what was learned in the previous lecture as well as what they learned from the readings. Based on this information from the students, she structured her lecture to fill in any gaps in the students understanding of the material. Dr Haskell also took the time at the beginning of the semester to teach the students how to read the textbook; what to focus on, how to think about the information and how to take effective notes.

It was decided that we would gather information about students' perceptions of this course structure through the use of anonymous online surveys. We chose to use anonymous surveys as there is a general consensus that anonymity often produces more honest and objective responses. We wanted to get an overall picture of how students prepared for class, whether they felt the flipped classroom structure increased their engagement and helped them succeed as well as any other comments they wished to make.

We decided to administer the surveys two times throughout the semester; once in October and once in late November. We chose to administer the survey in mid October as we presumed that at this point enough time has passed since the start of the semester so students have already had a chance to formulate their opinions about the approach. The reason for administering another survey in late November was to analyze whether students' perceptions about the approach changed by the end of the semester.

The surveys were administered by researcher Sarah Abu-Ramadan during lecture. Sarah visited the class once in the beginning of October to explain the purpose of the study to students and distribute letters of information, as well as to answer any questions students had pertaining to the study. She then visited lecture again in October and late November to administer the two surveys. We decided to have the surveys administered during class in order to increase the participation rates as students already had the time scheduled for lecture, so we were not taking any additional time out of their day to complete the surveys.

The surveys included a series of ranking statements, based on a 5-point Likert scale, as well as open-ended questions which allowed for individual comments. In order to see how students' perceptions of the flipped classrooms changed from the middle of the semester to the end, we asked the same 8 ranking statements on both surveys. The open-ended questions were different on each survey. Informed by the literature, we asked our questions in a way that will

help us to answer our research questions. The following ranking statements were asked on both surveys (the full surveys can be found in Appendices B and C):

1 – I regularly do the assigned readings prior to coming to class.

The purpose of this statement is to gain a better understanding of how prepared students are coming to class in order to have a basis of whether the approach has been utilized. The purpose of the flipped classroom is for students to come to class having studied and/or learned assigned material (could be online modules, readings from a textbook, etc.). Students' willingness or unwillingness to do as suggested by their instructor could affect the instructor's views on the effectiveness/usefulness/viability of the flipping method.

2 – The readings helped me understand the material better.
3 – The readings helped me better prepare for class.

We asked students to rank these two statements in order to gain insight on how the readings affected students understanding and preparation, regardless of whether or not the approach led them to feel more engaged during class.

How do students conceptualize understanding in mathematics? As there was no opportunity to spend more time with the students in Math 1C03, we relied on their previous experiences. For instance, they developed some notions of understanding in working with definitions (e.g., "Can you restate such-and-such definition?"), theorems (what is the logical structure of a theorem? When can it be applied? What is a counterexample? And so on), and other mathematical objects. Perhaps the best intuitive way is to say that we understand something when we can communicate our ideas about it comprehensively, clearly, and correctly.

4 – I feel more engaged in this class compared to my other math courses.

We felt it was important to understand how engaged students felt during this class compared to other math courses specifically, as opposed to comparing it to their other classes in general. This is because, in practice, classes from other disciplines, such as humanities, can be (and are) more discussion based than courses within mathematics. We would like to study how the flipped classroom can make mathematics courses more engaging for students so it is more appropriate to compare it to other mathematics courses. As in the case of understanding, we relied on students' intuitive, previously formed notions about engagement.

5 – I feel that I understand the material better during class compared to my other math classes.

During lectures, students are often just mindlessly taking notes and struggling to keep up with the material being covered, not truly understanding or learning. The purpose of asking students to rank statement was to gain insight into whether the flipped classroom approach helped/stimulated students to follow along better during class and made them feel that they were understanding the material.

6 – When studying for the midterm, I felt I was better able to recall the material covered in class than I usually am in my other math classes.

In class above refers to a flipped class. The purpose of this statement is to collect data about students' retention of the material studied in the flipped classroom approach. When students are studying for midterms, they often have to go back and relearn the material from lectures as they have already forgotten it by the time of the examination. We want to know if the flipped classroom approach increased students' retention of the information they have learned so that they could more easily recall when it was time to study for the midterm/exam.

7 – I feel that the flipped classroom approach helps me learn better compared to the traditional lecture approach.
8 - I prefer the flipped classroom approach to the traditional lecture approach.

These two statements have a purpose to complete for us a picture of students' overall perception of the flipped classroom. We wanted to know whether or not students felt that the flipped classroom was beneficial to their learning process.

For more qualitative information on how the students felt about the flipped classroom approach, we included open-ended questions on the survey so that students could provide their thoughts and opinions. We included a question on the second survey asking students what they wish would have be done differently in Math 1C03, to gather information on what students would prefer to see in the flipped classroom.

In order to gain a full of picture of the effectiveness of the flipped classroom, through both the view of the students as well as the view of the instructor, we decided to interview the instructor of Math 1C03, Deirdre Haskell. The interview was conducted after reading the comments students made on the survey and analyzing them for various themes. This way, we were also able to discuss the themes and ask Dr. Haskell to provide us with her opinion about them. The interview was conducted by researcher Sarah Abu-Ramadan

To answer the second research question regarding the barriers to implementing the flipped classroom approach in mathematics, we decided to conduct interviews with faculty members within the Department of Mathematics & Statistics at McMaster University. An email was sent out to all faculty members and post-doctoral fellows in November 2018 inviting them to participate in a 30-minute interview with researcher Sarah Abu-Ramadan (the email script can be found in Appendix D). We conducted a total of 4 interviews with faculty member

We felt that a personal interview would be the best option to get a full understanding of what faculty members' perceptions are with respect to the flipped classroom approach. We chose to conduct interviews as apposed to a questionnaire or survey so that we could collect full answers from the interviewees and allow them to have the conversation flow without being restricted by a set of questions. Through the semi-structured interview style, the interviewer, Sarah Abu-Ramadan, was able to probe for more details and tailor the interview to the interviewee. These interviews were conducted in December 2018 and January 2019.

The topics discussed in the interviews included the interviewees' personal experiences with the flipped classroom approach; we wanted to know whether they had tried this approach in their own courses or thought about trying it, and what stopped/prevented them from implementing the approach if they hadn't done it; as well, we asked about their overall opinions on the flipped classroom. The full set of questions asked during the interview can be found in Appendix F.

Our study (including methodology, data gathering strategies, interview scripts, etc.) was approved by the McMaster Research Ethics Board on October 3, 2019 (Approval number: 2018165).

Limitations

We felt that it was very important to conduct this study in order to examine the effectiveness of the flipped classroom in mathematics and to shed some light on why it is not used often within this discipline. However, like most studies, this study did not come without its limitations.

The surveys were administered to students during lecture in effort to increase the response rate, however this may have created a biased sample. There were approximately 60 students registered in Math 1C03, however we had 32 participants for our first survey and 29 for our second. Students who regularly attend class are generally more engaged and motivated, and so their responses may not be representative of the population as a whole. In order to lessen this bias, we did have our surveys posted on the course website for students who did not attend class; however, this did not elicit many more responses. Only an additional 2 students completed the survey through the course website (included in the above numbers). Also, the sample size of our study is too small for statistically significant quantitative analysis, however with this in mind, we may use some qualitative tools with caution.

Further, having selected students registered in Math 1C03 as our study group may also have caused our sample to be biased. The goal of this study is to gain insight on how effective the flipped classroom is in the subject of mathematics for all students. However, the majority of students registered in this course are mathematics and statistics majors. This could cause our response set to not be representative of all students when studying mathematics. Also, the students who chose to take Math 1C03 in the fall term as apposed to taking it in the winter may be more brave or feel better prepared since they have chosen to take more mathematics courses in their first semester at university.

As noted in some of the studies in the literature (Ferreri et al. 2013, Missildine et al. 2013, Strayer 2012), student satisfaction is not necessarily an indicator of student learning. Our study only looks at the effectiveness of the flipped classroom from the angle of student perceptions. This is due to the fact that we did not have a control group to compare student achievement. In previous years, Math 1C03 was taught by a different instructor, using a different textbook. Comparing the grades from previous semesters to the grades in Fall 2018 and attributing differences to just the flipped classroom approach would have been inaccurate as there are several different variables.

Also, the method that the instructor chose for flipping Math 1C03 is just one of many ways to do so. Some examples include creating lecture videos instead of assigning readings or just strictly problem solving during class rather than lectures and discussion on conceptual material. The conclusions that we reached from this study about student perceptions of the flipped classroom may not generalize to all methods of flipping the classroom.

Due to the fact that we had a limited amount of time, we were not able to discuss, with the students who were involved in this research, certain concepts that appeared on the surveys, such as understanding or engagement. We relied on their previous mathematical experiences, both in high school and in university

Another possible bias could have come from the fact that this approach was brand new to students as, in most cases, they have not seen it in any other university course. Sometimes novelty proves to be beneficial, however sometimes it is quite the opposite. For instance, if students are not adequately prepared they may show resistance.

Finally, we recruited volunteers for faculty member/postdoctoral fellow interviews through an email invitation. This inevitably results in a voluntary response bias as the individuals who decided to participate are likely the ones who feel more strongly about the subject or have thought about it before. Ideally, we would have participants from all over the spectrum, including the ones who feel strongly as well as ones who know very little about the approach. It should also be noted that the results from our interviews are specific to faculty members in the Department of Mathematics & Statistics at McMaster University. The barriers that exist within this department may generalize to mathematics instructors in other post secondary institutions, however we cannot make that assumption.

It is our hope that in shedding light on the barriers to implementing the flipped classroom, we can make the approach more accessible, or at least make instructors aware of new possibilities for their classrooms. However, we must keep the mentioned limitations in mind.

Results

Survey

Ranking Statements

In order to answer our research question about the effectiveness of the flipped classroom approach, we surveyed students registered in the course Math 1C03: Introduction to Mathematical reasoning. We surveyed the students once in middle of the term (Survey 1) and once again at the end of the term (Survey 2). Both surveys consisted of the same set of 8 ranking statements, but had different open-ended question (see Appendices B and C for the complete surveys). The raking was based on a 5-point Likert scale, with 1 representing *strongly disagree* and 5 representing *strongly agree.*

The results in Table 1 show a breakdown by survey of the percentages of students that selected either a 4 (Agree) or a 5 (Strongly Agree) for each statement.

Statement	**Percentage Agree or Strongly Agree: Survey 1**	**Percentage Agree or Strongly Agree: Survey 2**
I regularly do the assigned readings prior to coming to class.	90.62	79.31
The readings help me understand the material better.	75	79.31
The readings helped me better prepare for class.	65.62	75.86
I feel more engaged in this class compared to my other math classes.	56.25	44.83
I feel that I understand the material better during class compared to my other math classes.	28.12	41.38
When studying for the midterm, I felt I was better able to recall the material covered in class than I usually I am in my other math classes.	25	24.14
I feel that the flipped classroom approach helps me learn better compared to the traditional lecture approach.	43.75	44.83
I prefer the flipped classroom approach to the traditional lecture approach.	43.75	41.38

Table 1: Breakdown by survey of percentage of students that agree or strongly agree with the statement presented in the survey

Figures 1-8 display the breakdowns of all responses to each statement for both surveys

For the first two statements, we see a very large proportion of *Agree* and *Strongly Agree*.

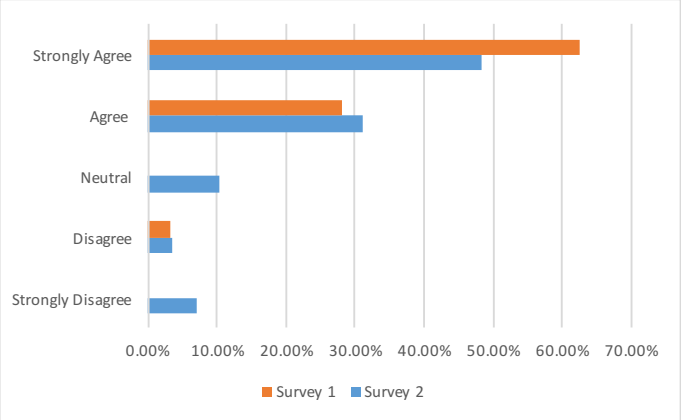

Figure 1: Responses to the statement "I regularly do the assigned readings prior to coming to class."

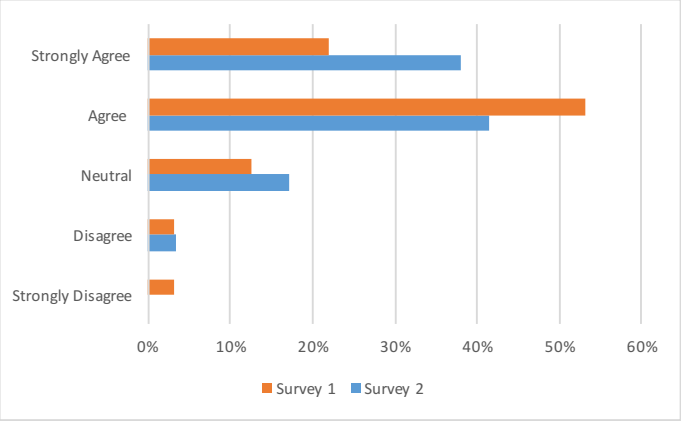

Figure 2: Responses to the statement "The readings help me understand the material better."

However, as we probe deeper, and judging by the emergence and growth of the *Neutral* category, we see that students are not so sure about certain aspects

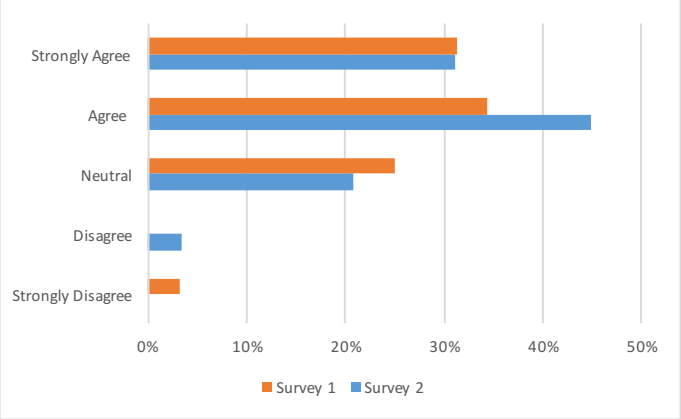

Figure 3: Responses to the statement "The readings helped me better prepare for class."

So while they believe that they are better prepared for class, students are less sure about the engagement and understanding (Figures 4 and 5).

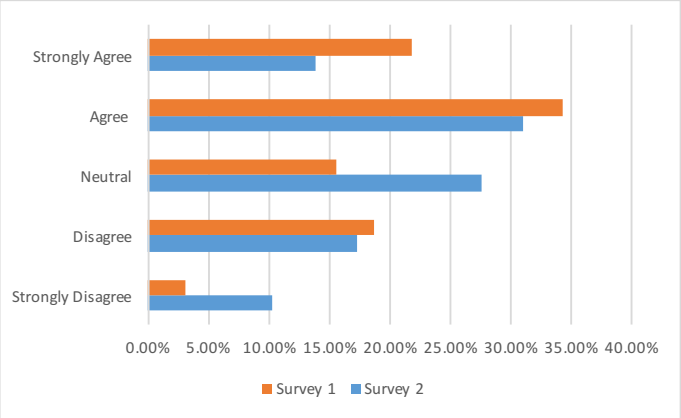

Figure 4: Responses to the statement "I feel more engaged in this class compared to my other math classes."

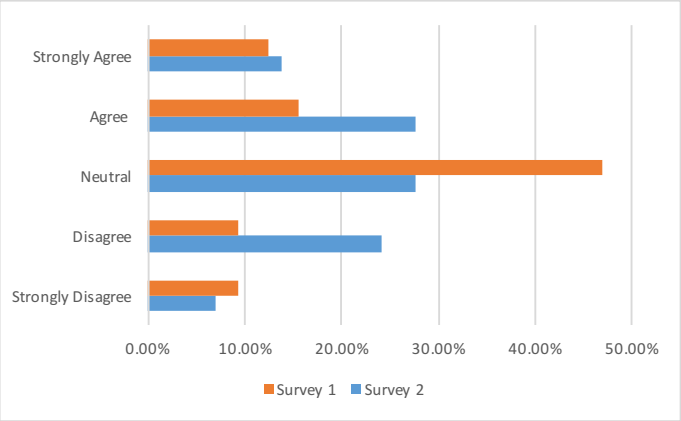

Figure 5: Responses to the statement "I feel that I understand the material better during class compared to my other math classes."

The *Neutral* category is dominant when students are asked about the recall, which is an important aspect of learning. We see that, over time, students seem to be less convinced that the flipped class improved their recall.

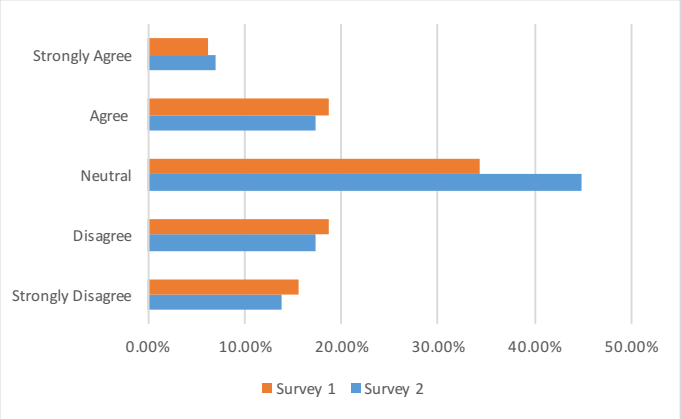

Figure 6: Responses to the statement "When studying for the midterm, I felt I was better able to recall the material covered in class than I usually I am in my other math classes."

Finally, the responses to two summative statements are given in Figures 7 and 8.

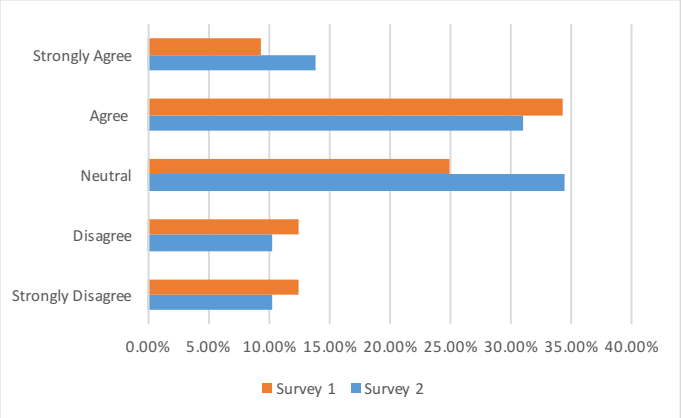

Figure 7: Responses to the statement "I feel that the flipped classroom approach helps me learn better compared to the traditional lecture approach."

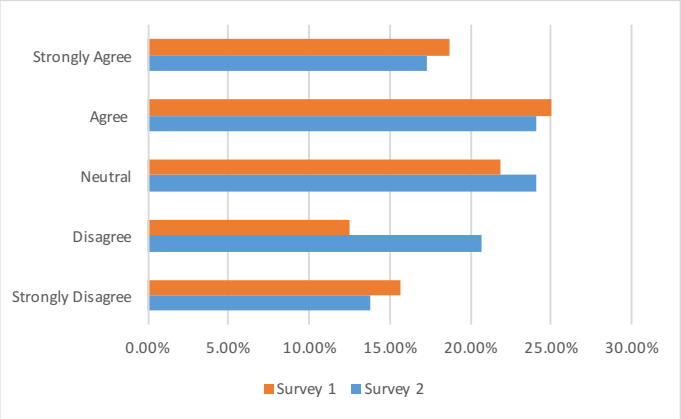

Figure 8: Responses to the statement "I prefer the flipped classroom approach to the traditional lecture approach."

Open-Ended Questions

In addition to the 8 ranking statements, each survey consisted of open-ended questions for students to provide context for their opinions on the flipped classroom and the course in general. We asked two open-ended questions on Survey 1 and three on Survey 2. We read the responses to the questions and categorized them by theme. The themes mentioned were not mutually exclusive, there were some comments that fell into more than one theme category. We assigned a code name to each student, "S1 Student Number" for Survey 1 and "S2 Student Number" for Survey 2. Due to the fact that the surveys were anonymous, we could not match students' responses to questions from Survey 1 to their responses from Survey 2.

Survey 1

The results for the question "What aspects of the flipped classroom do you find useful to your learning?" from Survey 1 are displayed in Table 2. We had a total of 28 responses to this particular question.

Theme	Frequency
Convenience of the readings	5
Having a better understanding during class/feeling more prepared for class because they've seen the material before	11
Staying on top of their course/not falling behind or procrastinating	4
Being able to come to class with questions ready/being able to have questions answered during class	6
Develop self-learning/study skills	5
Having more time to work on application problems/proofs during class	2

Table 2: Responses to the question "What aspects of the flipped classroom do you find useful to your learning?" on Survey 1

Responses that were categorized as "convenience of the readings" mentioned that they particularly enjoyed being able to work ahead as well as the flexibility to create their own schedule. One student also mentioned that it was useful to have the ability to go over the readings several times until they understood which is not possible during lecture:

> "It is easier to go over material that I am confused by the first time through because I'm learning it in my own time while reading not in lecture so I can go over it more than once while reading to get a full understanding" (S1 Student 10)

Responses that we classified as having the theme "having a better understanding during class/feeling more prepared for class because they've seen the material before" were the most common responses to this question. Student felt that having the opportunity to read the content and digest it prior to lecture helped them understand better during lecture, as illustrated in the following comments:

> "It was useful to understand of the content before coming into the lecture, and then being able to see specific examples applying the content. As well, if there was a section of the reading that I could not understand, I was able to have it explained, possibly in a different way. It felt sort of like I had two chances to learn the content, one on my own and one in an actual classroom setting." (S1 Student 3)

> "It is a good way for us to preview the course. It gives us enough time to consider by ourselves." (S1 Student 11)

> "By doing reading assignment, I know what is Dr. Haskell's topic tomorrow. While listening to the lecture, I don't get confused with some theorem or words." (S1 Student 16)

Students which had comments that fell under the "staying on top of their course/not falling behind or procrastinating" category stated that the reading assignments allowed them to work ahead and prevented them from being able to procrastinate:

> "The readings and quizzes force me to stay up to date on the class which I appreciate as I am often apt to become lazy and fall behind" (S1 Student 6)

> "I like how open the information is to access and how you can read ahead and do your assignments ahead of time." (S1 Student 2)

The second most common theme we found in the responses was "being able to come to class with questions ready/being able to have questions answered during class". Students appreciated the fact that they had the opportunity to go through the material prior to class and be prepared to ask questions and have their confusions cleared up during lecture:

> "I get to try to understand the material prior to the class so that if I do have questions about the material, I will get the answer to it in the lecture." (S1 Student 24)

> "flipped classroom helped me have an idea of what the concepts are that we will learn for the next class. Even if sometimes I will have questions on some of the concepts, I can still figure out during the lecture." (S1 Student 13)

Responses that had the theme "develop self-learning/study skills" indicated that the flipped classroom helped students learn how to properly read the textbook in such a way that they can learn and understand from it on their own:

> "To develop my self-learning skills, and make me understand the lecture materials better based on my own understanding…" (S1 Student 4)

> "It drives me to think about the materials when reading textbook, at least in the purpose of finishing the reading assignments. To have something you know you have to do before classes can prevent me procrastinating." (S1 Student 15)

Finally, a couple of students indicated that the flipped classroom allowed for more time during class to be allocated to solving application problems and going through proofs:

> "Better use of class time (more time spent exploring proofs as opposed to going over textbook material)" (S1 Student 22)

> "We have more time to work on learning problems and application with professors." (S1 Student 18)

The second open-ended question that we asked on Survey 1 was "What aspects do you not like about this approach?". We had a total of 28 respondents to this question. The results are displayed in Table 3. As we can see, the most common theme in the responses to this question was "Difficulty reading the textbook".

Theme	Frequency
Some concepts skipped over in class because of the assumption that they read and understood it	4
Do not get their questions answered	3
Difficulty reading the textbook	13
Struggle during in lecture if they do not get the readings done	3
Extra work/time consuming	7

Table 3: Responses to the question "What aspects do you not like about this approach?" on Survey 1.

Responses categorized as having the theme "Some concepts skipped over in class because of the assumption that they read and understood it" express frustration about not having concepts from the textbook reinforced during lecture:

> "Sometimes the professor doesn't cover everything since they think maybe we learned it by ourselves or understood it." (S1 Student 1)

> "I do not like how the practical material that we have to do is not reinforced in class. Most of the subjects we talk about in class do not help with the homework. If at least some questions were taken up in class and explained I would feel more comfortable. The book doesn't explain problems too well." (S1 Student 25)

There were also a few students that felt that they were not getting their questions answered as a result of the flipped classroom:

> "MATH 1C03 is a pretty difficult class, the fact that it isn't covered in highschool curriculum does not help either. I feel like the flipped classroom approach is beneficial for other classes, but it isn't working well for me in this one. Sometimes the concepts in the textbook are hard, and I don't want to ask questions in class because I don't want to interrupt the lesson and look stupid, and I usually can't come to office hours or the help centre because I'm busy with other classes, extracurriculars, etc." (S1 Student 2)

> "no chance to ask question or ask for a clarification" (S1 Student 12)

As expected, a high proportion of students felt that they had difficulty when reading the textbook. They mention that they have trouble understanding the concepts on their own without guidance and that they struggle to pick out key information:

> "It is always challenging to learn the new material without the explanation of the prof, so I always spend a lot of time on it" (S1 Student 17)

> "It wastes a lot of time for us. Actually, I do not know where I should focus on reading, so I only can read all of them." (S1 Student 11)

> "The textbook is not very easy to read and understand. It does not have the same kind of applicability as an in class lecture does." (S1 Student 27)

There were a few responses that we categorized as having the theme "Struggle during lecture if they do not get the readings done". These students felt that if they missed a reading assignment, they had difficulty keeping during lecture:

> "I don't like that if I don't do the reading before class, I find I am completely lost throughout the class and do not get much out of it" (S1 Student 5)

> "It sometimes feels like you are disconnected from the learning that is being done. Missing a reading can really throw you far back because you will have a much worse understanding of the lecture if you don't know the basis of what is being talked about" (S1 Student 10)

Finally, the second most common theme in the responses to this question was "Extra work/time consuming. Students expressed frustration about having to spend extra time on the course due to the reading assignments:

> "Puts more pressure on the student by creating more effort at home that could simply be done in class…" (S1 Student 28)

> "Sometimes I have lots of homework to do so that I cannot read all the paragraphs. I think it increases our pressure in some cases." (S1 Student 16)

Survey 2

We asked students a total of 3 open-ended questions on Survey 2. The first question that we asked was "Was there anything in this course that you particularly enjoyed/found useful to your learning?". Without directly mentioning aspects of the flipped classroom, we wanted to know what students particularly enjoyed about the course as a whole. We had a total of 21 responses to this question. The responses categorized by theme are displayed in Table 4.

Theme	**Frequency**
Readings	10
Review of the reading assignment at the beginning of class	4
Engaging	2
Subject	3
The ability to work ahead/review before class	3
The homework	2

Table 4: Responses to the question "Was there anything in this course that you particularly enjoyed/found useful to your learning?" on Survey 2.

Of the 6 themes that we categorized responses to this question into, 4 of them related to the flipped classroom approach, including "Readings", "Review of the reading assignment at the beginning of class", "Engaging discussion" and "The ability to work ahead/review before class". There were 16 out of the 21 responses to this question that fell into one or more of these 4 categories pertaining to the flipped classroom.

The students that mentioned the readings as something they particularly enjoyed talk about how the readings gave them a better grasp on the material, gave them more confidence in the course and that they found the readings interesting:

> "One thing that I find is that if I do my reading assignments on a regular basis, I feel more confident to go to classes. I am able to build a clear goal about what I want to know from today's class, based on which, to adjust the way I'll listen to the professor." (S2 Student 17)

> "The reading assignments we did is really a useful tool for testing how much we understand the content prior to the lecture." (S2 Student 9)

> "The reading assignments are actually very interesting. I think they're the perfect combination of thought-provoking and not-time-consuming." (S2 Student 2)

The instructor for this course took some time at the start of each lecture to review the reading assignment and engage in a discussion with the students about it in order to ensure that they understood it. This was a theme that emerged in the comments as something the students enjoyed and got value from:

> "Dr. Haskell made an effort to inquire about a summary of the assigned readings, which I found useful, as I was prompted to summarize the reading shortly into something that I could easily convey." (S2 Student 11)

> "Before every course, our professor would ask us for the summary of RA and contents in last class, which is very useful for me to consolidate my knowledge." (S2 Student 12)

A common result of implementing the flipped classroom approach is that class time become more engaging. There were a couple of students that mentioned this as something they particularly enjoyed about the course:

> "The teacher tried to get us engaged." (S2 Student 21)

> "Professor asked questions in the beginning-tried to engage students" (S2 Student 5)

Finally, a theme that emerged in the comments, pertaining to the flipped classroom, was "The ability to work ahead/review before class". This was something that was common in the comments on Survey 1 as well, when students discussed the convenience of the readings.

Again without directly mentioning the flipped classroom, our second open-ended question on Survey 2 asked students "Was there anything you wish would have been done differently in Math 1C03?". We wanted to see if students mentioned aspects of the flipped classroom without being prompted. There were 21 responses to this question. The results categorized by theme are displayed in Table 5.

Theme	Frequency
Go over reading assignments more	3
Readings	3
More practice questions	4
Easier content	3
Post notes and solutions/take up problems	3

Table 5: Responses to the question "Was there anything you wish would have been done differently in Math 1C03?" on Survey 2.

There was not an overwhelmingly dominant theme in the responses to this particular question, responses were spread out fairly evenly. Some students felt that the reading assignments could have been reinforced more during lecture:

> "I wish the lectures went over more of what the readings were about because a lot of the time I didn't understand the textbook and the prof didn't go over it much, she just jumped right into doing examples in class" (S2 Student 1)

Others felt that the readings were too time consuming and that there were just too many readings in general:

> "The weekly homework can get very tedious. I regularly spend maybe 7-8 hours per week on just the 1C03 homework. And only 2 questions out of all assigned ones are actually marked (and these are not specified beforehand), so it does feel like I spend an incredible amount of time doing all the homework, only for most of the work to be ignored. 1C03 homework is easily the biggest time drain out of all my coursework." (S2 Student 2)

> "Reading assignments are too many." (S2 Student 19)

A few students wished that there were more practice problems and examples to help them with their homework assignments:

> "Yes, I wish that professor can teach us some practice questions before we start to do our homework." (S2 Student 17)

> "I wish more problems similar to the assignment questions were done so that we had something to refer to." (S2 Student 21)

While other students felt that the course content was just too difficult in general:

> "Math1C is difficult in general. I'm always confusing by all the terminology in this course." (S2 Student 18)

> "I hope the course content can be easier, it's too hard for us now." (S2 Student 15)

And some wished that solutions were taken up during lecture and posted online:

> "Give out the answer to the homework assignments every time so that I can better prepare for my exams." (S2 Student 7)

Finally, we asked students to add any other comments they wished to add with our last open-ended question: "Please provide any further comments you would like to make about the flipped classroom model below." We had 12 responses to this question. A couple of students mentioned that they would have appreciated being assigned videos to supplement their learning:

> "The professor can provide us with links to some videos that can help us with the understanding beside the reading assignment." (S2 Student 9)

> "Offer some useful video link to help understand" (S2 Student 14)

A couple of students mentioned that they felt the flipped classroom could be an effective strategy in some cases, however they did not feel that it worked well in this course:

> "The flipped classroom model works well for math classes based on my experienced since learning math seems to be done by doing it yourself, which naturally leads to something like a flipped classroom. The flipper (sic!) classroom wasn't implemented very well in this course." (S2 Student 8)

> "I feel as though the flipped classroom approach works in some classes, but certainly not math classes where things need to be properly explained. As well it's unfair for the students to pay $7000+ in tuition fees only to have to learn everything on our own anyway." (S2 Student 6)

One student felt that the flipped classroom was an effective study tool, however they had concerns about the grading:

> "The flipped classroom provides students with a way to study, but when it comes to the grades, this can sometimes stress me out." (S2 Student 17)

Another student mentioned they would have appreciated having more support when studying at home:

> "I hope that the flipped classroom can have a tutor to talk online." (S2 Student 4)

Finally, the desire for more practice problems was mentioned in the comments to this question as well:

> "Practice questions are very important. Sometimes, only teaching knowledge is hard for us to understand." (S2 Student 3)

Interview with the Instructor

After analyzing the responses from the surveys, we interviewed the instructor, Deirdre Haskell, in order to gain a full picture of the effectiveness of this implementation of the flipped classroom. We used this opportunity to discuss the themes from students' comments in the open-ended questions on the surveys and ask for her opinions about them.

We mentioned to her that several students commented on finding the textbook very difficult to read and asked her for her opinion on why she thought this was the case. She expressed that she was not certain about the reason that students found the textbook difficult to read as she felt it was read similar to a lecture. She also mentioned that the students did not communicate much to her what they were finding difficult:

> "Well, see that's hard because, to me, the textbook was read like a lecture. So if I had been giving that as a lecture I imagine I would've said almost exactly the same thing. So I don't know why they found it hard. And I wasn't really able to extract that from the students. I had a very hard time getting the students to say anything, so I was really struggling to get feedback from them. So I mean, I'm not sure I can answer your question because I wasn't really getting feedback from them about what was hard so I wasn't going back and telling them about it. But it definitely was my goal that I was not repeating what was in the book. So if the book had the proof of some proposition I did not prove it again, I would rather prove something similar. So I was really very much intending to complement in my lectures what was in the textbook."

She also went on to mention that several students do not speak English, which could also be a possible reason that so many students found the textbook difficult to read.

Dr. Haskell mentioned that she had taught Math 1C03 several times in the past, however this was her first time teaching it with the flipped classroom approach. We asked her how she felt this time teaching the course compared with teaching it in the past. She said that that students found the course much more difficult this time around and that she had several students drop the course due to this:

> "I think the students found it a lot harder. The students always find this course hard, but I lost so many students. I think I had 80 students signed up at the beginning of the semester and I think I had 50 take the final exam. So I lost a lot. And then they did pretty badly on the final exam too which was… I thought I wrote a very straightforward final exam. So it did seem like I was expecting a little bit too much of them. And I don't know if that's because the student body has changed, which is certainly true. A lot more students who don't speak English as their native language. So that might relate also to the finding the textbook hard to read here because it's written in a somewhat colloquial style."

Further, we wanted to know if the implementation of the flipped classroom led to students being more engaged during lecture. Deirdre expressed that they were not actively participating, however she did feel that they were alert and engaged:

> "They would not speak up but I think that they were pretty engaged. I mean they were certainly alert. I didn't have a feeling that people were on their phones for example. I did have the feeling that they were alert and paying attention, not necessarily willing to contribute."

We were also interested in the students' academic performance. We wanted to know if the flipped classroom led to students achieving higher marks as an indicator of improved learning. Deirdre explained to us that the exam and midterms were done poorly overall, while the assignments had mixed results.

Finally, to give Dr. Haskell an opportunity to summarize her experiences, we asked "What was your overall experience with the flipped classroom in Math 1C03 and if you were to teach the course again would you do it again this way?" She responded:

> "I would think hard about whether it was effective. Certainly the kinds of things that the students asked me for would be things like work solutions to the homework. The reason why I don't post work solutions to the homework is because I want them to come and talk to me. However, this was not effective at getting them to come and talk to me. I really did not get students to talk to me last semester. It was it was astonishing the number of office hours I had which nobody came. And you know there are all these students that are struggling and yet they're not asking for help. And I just don't know what to do about that. Probably I would still use a component of flipped classroom because I thought it was, even though it was hard, I think it was very good for them to be forced to do that reading. And so I would still try to force them to do that reading by having the reading assignment. And I think that was a good component, and maybe that it would be better to do more standard lecturing on the content. Because maybe they would get more out of it if they both read it and then heard me talk about it they might get more out of it than if they read it but then I talked about something slightly different. Still the required readings I was happy with, but I was not so happy with their level of understanding of the required readings."

Faculty Interviews

This study began with two goals; to gain an understanding about the effectiveness of the flipped classroom and to take a look at some of the barriers to implementing such an approach. In order to study the barriers to implementing the approach, we interviewed faculty members within the Department of Mathematics and Statistics at McMaster University about their thoughts and opinions on the approach and whether or not it was something they had experimented with in the past. If they had used it in their classes, we wanted to know what their experience was, and if they had not, we wanted to know what stopped them.

When asked if they had tried to implement the flipped classroom, two of the faculty members we interviewed, Faculty Member 1 (FM1) and Faculty Member 2 (FM2), stated that they had experimented with the flipped classroom using assigned readings. We probed deeper into the subject and asked them to describe their experiences with it. FM2 described having had a positive experience, while FM1 explained that it had not worked very well.

FM2 told us that they had implemented the flipped classroom in one of their graduate level algebra classes. This class had a mixed range of students, 4 students which were very prepared for the course and 4 students who were lacking understanding of prerequisite material. In order to address this issue, FM2 decided to implement the flipped classroom as an optional supplement to the course. They assigned readings of the prerequisite material and held a tutorial once a week for 4 weeks for group problem solving based on the assigned readings. FM2 says that this worked very well in getting those 4 students up to speed in the course in order to be able to move forward.

FM1's experience was a little different; they assigned readings in a small upper year mathematics course and asked students to email them every morning before lecture with any questions they had about the readings or stating that they had done the readings and did not have any questions. This accounted for 5% of the students' final grade. When we asked FM1 about how this worked they stated that it hadn't worked as well as they were expecting, but that they would be willing to try it out again under the right circumstances:

> "It didn't work as well as I thought I would. And it was like a free five percent. I kept track, and so like, if they did all of it they got 5% and some students just didn't bother, which is surprising because it was free marks. And so I never really drilled down enough to see if they thought it was worthwhile. So I tried it and I never really followed up on it. I think it's a good strategy but it might only work for a class of maybe under 40. You know it's like the last thing you want to do, like I'm teaching abstract algebra now and I have maybe 70 students. I don't know if I want 70 emails every three days. I'd just be swamped. So the smaller class I could try again."

Faculty Member 3 (FM3) expressed concerns about using assigned readings for the flipped classroom. They explained that they felt that students struggle to read a mathematics textbook in the way that it should be read in order to properly understand:

> "In the past when they started talking about the flipped classroom, the initial stuff was all textbook based which I can see for courses very factually based, there's a lot of information to be conveyed and you don't really need a professor reading you facts that you could have read yourself without them doing it. So it makes a lot of sense and made less sense in those areas to do the reading first and then doing discussion and synthesis in the classroom and try to put some context meaning around it. That's not really what you have in mathematics, we're not facts-based. It's a skills course largely, in learning mathematics it's about building a mental model, building a framework of ideas that interconnectedness it's less about learning the formulas. Actually tell students to read a textbook, generally speaking it's not read in the right fashion. They're looking for how do we do the problems what are the rules, what are the formulas and trying to stick them in and we're constantly fighting that to turn it into you know what's the idea, what's the story behind it, what are these things about?"

This idea of students not knowing how to properly read the textbook also came up in the interview with FM2. They mention that they believed this was due to the fact that students had never properly been trained to read the textbook when learning mathematics in high school:

> "So most students will get through grade 12 without ever really looking at the book more than doing the homework exercise. So their whole approach to studying mathematics is going directly to the homework exercises seeing if they can do it, flipping back, seeing if they can find an example that matches the problem. And what do they learn? They learn this patchwork kind of version of mathematics that's, you know, that doesn't make any sense at all, really."

FM2 then went on to explain that they believe that students could really benefit from reading the textbooks before attempting to do practice problems. When students come to FM2 struggling with their courses, FM2 says they always suggest that the student begin by reading the textbook and that always helps them to understand the material they are struggling with:

> "I mean one of the advantages of pointing the students toward the book and making them actually read the book is that the ability to ultimately read mathematics and then learn to digest it yourself. I mean that's what's happening with the lecture, the lecture is already a distilled version of what's in the text, right. I mean so somehow I would think some of the advantage would be to try to get the student to read it because I mean in the end, content delivery is one thing but getting the students to learn how to learn mathematics is a totally different thing right."

When discussing the flipped classroom using videos, as apposed to assigned readings, it was a common theme in the interviews that faculty members felt that this would be more effective than readings, however they expressed several barriers to implementing this. All faculty members brought up the fact that creating videos would take a very large investment of time and resources. Faculty member 4 (FM4) said:

> "I think that making videos is a lot more work than you think it's going to be. And I've done a couple of little things, like one time, I created a video which I was just talking about how to do a solution to a problem. It took me the entire weekend just making this thing. I had to decide what I was going to say, I had to decide what I was going to write, I filmed myself writing and then I had to overlay it. It was just many, many hours and I just didn't have time to do that more. And creating videos, I mean in principle, I think the students would find it easier to listen to a video than to read, although again not every student. Some students prefer to read than to listen. But, the actual work of creating the videos needs to be done at a professional level. And anytime that I've tried to do something like that here, we just don't have the resources. I haven't found the resources on campus to help me do that."

FM1 actually went as far as to set up a meeting with the MacPherson Institute in order make videos for their class, however by the time that they were even able to get a meeting, the class had already started and there was not enough time to make them. FM3 felt strongly that the

flipped classroom using assigned readings was not effective in mathematics, however they felt that the videos could be, but not enough to warrant the extra work:

> "Yes, the textbook definitely doesn't work for mathematics. But, video you can convey the concepts and stories, it has a much stronger potential… I wasn't sure that it provided so much more benefit to warrant, to be blunt, all the extra work involved, which is pure pragmatism or cold laziness on my part. It does take a lot of work to create the content suitable to it, to create those videos and then to operate the actual flipped classroom"

FM2 expressed hesitation about the idea of creating videos for the flipped classroom. Their rationale was that they would not be able interact with students while they are learning (by watching videos) and answer questions about the material right away. They did, however, think that it would be helpful for students to be able to pause and rewind the videos when they did not understand something, which they would not be able to do in a live lecture (or not to the same extent). Moreover, they brought up the fact that this would be a lot of extra work for the instructor.

We also asked the faculty members what their thoughts were on using available online resources such as videos from Khan Academy for the flipped classroom. FM2 felt that it was a very good idea to use available online resources, especially for prerequisite high school mathematics concepts that were not properly learned:

> "So yes, first for the extremely mechanical basic stuff you know that there is an infinite number of Khan Academy videos that are useful. Actually, you know some that are pretty sophisticated. Yeah the basic ones which are the ones I've looked at mostly are good enough for recommending for, you know, in 1B or 1A or something like that."

FM3 also felt that it could be useful for filling in the gaps in students understanding of high school mathematics material, and they had even tried to create a hub for these types of videos:

> "That's also a good idea. We'd almost started an initiative a couple of years ago to try to make a hub for it with some high school teachers. It was our sense of feeling that a lot of the high school teachers also had found a lot of videos or were using a lot of videos. Yeah so that would benefit everybody. Especially, for instance, we were thinking too in terms of the remedial stuff. Things that they're supposed to know that they don't have because that's the heartbreaking thing in first year is all the students that are really working hard on your material and getting undone by high school stuff that they didn't learn properly or that was missing. So the idea was to have a hub for those videos." (FM3)

However, there was also a lot of mention of the fact the finding high quality videos online is very difficult and time consuming for the instructor:

> "It turned out to be a bit harder to do than it sounds. I mean a) you've got to sit and watch the videos. And that takes a while can be tricky. And they're, I feel a bit different than, I think, than you want. And that's the issue with using other people's material." (FM3)

> "I think that in principle yes sure there's a lot of really good stuff out there but you have to spend the time listening to it and making sure they get it right. I sometimes listen to these Khan Academy videos and say, no that's not that's not actually right. And so I would have to spend a lot of time. I don't object to it, but it would take more of my time than I'm willing to spend." (FM4)

We also asked our interviewees what they felt was the reason that not very many instructors in mathematics use the flipped classroom approach to teaching. One of the key themes that came up in the responses to this question were that instructors may be nervous to try something new and not have it work out:

> "A large part of it is the inertia. I mean a) being aware of it and how to make it work and b) having the confidence. So I guess there's both the confidence in doing so and the will to do so. But having the confidence in doing so and knowing exactly what to do." (FM3)

Another theme in the responses to this question was that they felt that instructors may not have an interest in rethinking their teaching and trying something new:

> "I think, first of all, it takes a lot of time to rethink the way you're teaching and I think that most of my colleagues aren't that interested in rethinking the way they're teaching. I think there's also some skepticism about how well it would work… People just don't want to think about that. It's like, they have other things to think about and they can do their teaching the way they have always done it" (FM4)

> "So I'm not a big believer in just delivering content but there are definitely faculty members who believe that their goal in life is for the 12 weeks that their lecturing is to maximally dump content into the students. And so flipped classroom, will slow that down. Yeah right, because heaven forbid the students will talk, they'll say something and they'll lose time you know… One thing that a flipped classroom does is it makes it painfully clear to the instructor what the students do and don't know, right. And if you stand at the front of the room and you just kind of go along with the blah blah blah, right theorem this theorem that definition this or whatever. you can convince yourself that, well you covered all this material so the students know it. But if you do the flipped classroom and you ask the students to tell you what they know and you discover that they don't actually know anything that you taught them. That could be demoralizing…so if you never asked the students about what they know you never have to face this." (FM2)

Also, something that came up often was the fact that instructors in most cases do not teach the same courses several years in a row so they would rather not invest the time in experimenting with new ways of structuring the course:

> "One of the aspects that I run into when I'm thinking of doing innovations is from year to year I can be complete different courses and so I'll take a course and then thinking 'what could I do with this?' but then I don't teach it again for several years and I do something else altogether." (FM3)

> "Well I think part of it it's just the start up time, just getting everything prepped. So I think if somebody is going to do it, they would want to do like three or four years of that so that they can refine it. I'm not sure we have that. I'm sure we could get it. I think if I were to go to the undergraduate chair or the chair and say I want to do this I'm sure they'd give me the course for 3, 4 years and build it. I'm not sure if I'd want to teach some of these courses three or four years in a row, that could be part of it. There's little bit of a culture, and I think it's a good culture, in our department where people flip courses quite regularly." (FM1)

Finally, our interviewees mentioned that a significant barrier to implementing the flipped classroom is the amount of time and resources that it would take.

When asked about their overall opinions about the flipped classroom, all of our interviewees brought up the fact that it was very time consuming for the instructor. There was also some disbelief about its effectiveness:

> "The flipped classroom, your idea is that the student can get that first exposure by doing something at home. And then it's the help with consolidation which is that step that needs help with the presence of the instructor. And there is a question about whether that piece of theory is correct. That maybe it's in giving a lecture that you. That you can understand what the emphasis is which you cannot understand by reading a textbook." (FM4)

FM3 brought up the fact that they saw the benefit of the flipped classroom, however they do not believe it is due to the approach itself, but rather the extra time that it forces students to spend learning the material:

> "I really see the benefit from that. The single biggest benefit being that it just forces them to put more time in. That's like, when you're looking at the success of the flipped classroom, I'm always trying to read and see the difference between the effectiveness of the approach or just flat out the issue that that you're compelling them to spend more time on that topic because they're now required to watch the videos on their own time ahead of time and probably putting in more time in the class than they were before when you did it the other way around… I don't know if that is the best way to force them to put that extra time in."

Overall, the faculty members that we interviewed could see the benefit of using an approach like the flipped classroom, whether that be through the use of textbook readings or assigned videos, however they did have their hesitations. They were not entirely sure that the flipped classroom was effective enough to warrant all the extra time and resources it would require to do it through videos and they felt it would be tough to flip the classroom completely through assigned readings due to the fact that students struggle to read mathematics.

Discussion

The first question that this study is set out to answer is "How effective is the flipped classroom approach in facilitating teaching and learning mathematics in a first-year classroom?".

We have attempted to do this by gathering information about students' perceptions of the approach through the use of anonymous surveys.

To start, we consider the following summative ranking statements from the surveys that serve as indicators of students' perceived overall effectiveness of the flipped classroom approach (students were asked to rank them on a scale from strongly disagree to strongly agree):

> "I feel that the flipped classroom approach helps me learn better compared to the traditional lecture approach."
>
> "I prefer the flipped classroom approach to the traditional lecture approach."

The two statements showed similar results; by the end of the course (Survey 2), 44.83% of students either agreed or strongly agreed with the first statement and 41.38% agreed or strongly agreed with the second statement.

In this discussion, we will explore and reflect on the reasons we believe some students found the approach to be effective, as well as reasons that others did not. We will also suggest ways that the implementation of the flipped approach could be modified in order to reach more students. We will do so by analyzing the responses of students and comparing and contrasting them with the views of instructors.

We noticed an interesting relationship between the statements that saw an increase in the percentage of students that agree or strongly agree over time (i.e., from Survey 1 to Survey 2) as well as between the statements that saw a decrease (displayed in Table 6). The statements that had an increase in score related to the issue of how the readings (and the whole approach in general) helped the students prepare, understand and learn. The statements that had a decrease in score related more to engagement and overall opinion about the flipped classroom. This might indicate that, as time went on, students, in larger numbers, skipped readings and thus felt (or were) less engaged. However, keeping in mind the statements that showed an increase in score related to how the readings helped students prepare, understand and learn, it might as well be that students became (or felt) stronger at reading the textbook and start to truly benefit and see the value. (This is definitely an issue that deserves further study.) In order to shed some light on these relationships, we will explore the following items in more detail:

- Difficulty reading the textbook
- Positive student perceptions
- Students' suggestions/ Room for improvement

Statement	Percentage Agree or Strongly Agree: Survey 1	Percentage Agree or Strongly Agree: Survey 2	Percentage Change from Survey 1 to Survey 2
I regularly do the assigned readings prior to coming to class.	90.62	79.31	-11.31
The readings help me understand the material better.	75	79.31	+4.31
The readings helped me better prepare for class.	65.62	75.86	+10.24
I feel more engaged in this class compared to my other math classes.	56.25	44.83	-11.24
I feel that I understand the material better during class compared to my other math classes.	28.12	41.38	+13.26
When studying for the midterm, I felt I was better able to recall the material covered in class than I usually I am in my other math classes.	25	24.14	-0.86
I feel that the flipped classroom approach helps me learn better compared to the traditional lecture approach.	43.75	44.83	+1.08
I prefer the flipped classroom approach to the traditional lecture approach.	43.75	41.38	-2.37

Table 6: Breakdown by survey of percentage of students that agree or strongly agree with the statement presented in the survey with percentage change from Survey 1 to Survey 2

Difficulty Reading the Textbook

When we asked "What aspects do you not like about this approach?" on Survey 1, the most dominant theme in the students' comments was about them finding the textbook difficult to read. This finding is consistent with what other studies have found (Sahin et al. 2014, Kay et al. 2010). This is also something that came up frequently in our faculty member interviews. Instructors mentioned that a danger of using the flipped classroom approach with assigned textbook readings was that students often do not know how to read a mathematical text appropriately (i.e., to learn). Faculty Member 3 (FM3) discussed this as the reason that they do not believe in implementing the flipped classroom approach through assigning textbook readings:

> "It's a skills course largely, in learning mathematics it's about building a mental model, building a framework of ideas that interconnectedness it's less about learning the

> formulas. Actually tell students to read a textbook, generally speaking it's not read in the right fashion. They're looking for how do we do the problems what are the rules, what are the formulas and trying to stick them in and we're constantly fighting that to turn it into you know what's the idea, what's the story behind it, what are these things about?"

We believe that the main reason that student struggle so much to read mathematics textbooks is that they simply do not have the practice. In high school, although students may be given mathematics textbooks, they are rarely (if ever) encouraged to actually use them, beyond as a source of exercises. Speaking from my own experience in a high school in Ontario, this is something that I encountered as well. Teachers would distribute handouts for every lesson with fill-in-the-blanks for students, as the teacher delivered their lesson telling them what the blanks should be. These 'easy to read' and straight to the point handouts were all that students would refer back to when studying, it was never the textbook. The textbook was often just used for the homework problems as well as to reference examples. Faculty Member 2 expressed concerns about this issue as well:

> "So most students will get through grade 12 without ever really looking at the book more than doing the homework exercise. So their whole approach to studying mathematics is going directly to the homework exercises seeing if they can do it, flipping back, seeing if they can find an example that matches the problem. And what do they learn? They learn this patchwork kind of version of mathematics that's, you know, that doesn't make any sense at all, really."

This idea of example matching is a very commonly encountered issue – students believe that "problem-solving" should be matching a problem with a previously shown template, rather than requiring them to think fresh. This is something that I have encountered very often working in the Math Help Centre at McMaster. Students will come in, often frustrated, and say "I followed the example exactly and I'm getting the wrong answer" or "I tried to solve this problem but I can't find any examples like it". This is also evident in some of students' comments on the surveys:

> "I wish more problems similar to the assignment questions were done so that we had something to refer to." (S2 Student 21)

> "Yes, I wish that professor can teach us some practice questions before we start to do our homework." (S2 Student 17)

This view is also supported by literature. Hughes Hallet (2003) gave a questionnaire to pre-calculus and calculus students at Harvard University asking them to rank the following two statements a scale of 1 to 5 (with 1 representing strong disagreement and 5 representing strong agreement): "A well-written problem makes it clear what method should be used to solve it" and "If you can't do a homework problem, you should be able to find a worked example in the text to show you how". The pre-calculus students ranked their agreement with the two statements, with averages of 4.6 and 4.7 respectively, while the calculus students ranked them both with an average of 4.1. This indicates that most students think of mathematics in a dominantly procedural way, one that does not require them to think, or "think outside the box".

In most cases there is a chain reaction; due to the fact students do not know how to read the textbook correctly, instructors do not assign readings nor expect it of students. We believe this is problematic as students will never have the opportunity to learn how to read mathematics (and will thus miss out on an important skill, as in their future careers, very likely, they will have to study manuals, long documents, etc.). It is especially problematic if these students later decide to pursue graduate school, which will involve a lot of independent learning through reading for which they will not be adequately trained.

Our suggestion to tackle this issue and perhaps increase the effectiveness of the flipped classroom is to introduce it slowly. For instance, the instructor can initially assign (shorter) readings but still go over them during lecture; then as the class advances they could spend less and less time reviewing the readings and more time engaging in discussion and examples. When we spoke to the instructor for Math 1C03, Deirdre Haskell, about whether she would use the flipped classroom again in Math 1C03, she also agreed that it was still important to teach the students how to read the textbook, but perhaps in a different way than the one she tried:

> "Probably I would still use a component of flipped classroom because I thought it was, even though it was hard, I think it was very good for them to be forced to do that reading. And so I would still try to force them to do that reading by having the reading assignment. And I think that was a good component, and maybe that it would be better to do more standard lecturing on the content. Because maybe they would get more out of it if they both read it and then heard me talk about it they might get more out of it than if they read it but then I talked about something slightly different"

We feel that this is a good idea to do at the beginning, and then gradually spend less time retelling the textbook content as the students gain experience at reading.

A further suggestion we have for instructors switching to a flipped classroom approach using assigned readings is make sure to have an introduction to students about how the course will be run. It is important to clearly explain to students what is expected of them in a flipped course structure. Students should understand the reading assignments are something that they absolutely must do, it is not an optional course component. Some students mentioned that they did not like how they felt lost during lecture if they did not read the relevant textbook sections:

> "I don't like that if I don't do the reading before class, I find I am completely lost throughout the class and do not get much out of it" (S1 Student 5)

> "It sometimes feels like you are disconnected from the learning that is being done. Missing a reading can really throw you far back because you will have a much worse understanding of the lecture if you don't know the basis of what is being talked about" (S1 Student 10)

As well, several students mentioned that Math 1C03 was taking too much of their time and this stressed them out. In the introduction to the course, it may also be useful for the instructor to announce the total time commitment for the course and compare it to other courses

to show to students that it is not much different. This can also give students an idea of how much time they should be spending on the readings and assignments. If they are spending too much time, there may be an issue in the way that they are approaching reading and understanding the problems, which is again something that an instructor should address. In this case students would be encouraged to seek help from the instructor or a teaching assistant. This is something that Dr. Haskell brought up in response to the fact that students felt that the course was taking up a lot of their time:

> "I think that maybe the students were spending more time than they should have done. I think a lot of students were just like sitting there agonizing over their homework for hours and hours without coming in and asking me. You know I would say, look, if you're you spend two hours thinking about one problem you're probably thinking about it wrong and you need to come and ask and they wouldn't."

Finally, to help students learn to read the textbook, we suggesting creating a video, or even just a handout, with tips and hints on how to efficiently and effectively read a mathematics textbook. Alternatively, a class time could be devoted to step-by-step instructions on how to read mathematics. Dr. Haskell indeed took the time at the beginning of the course to teach students how to read the textbook, however we suggest also creating something that students can refer back to in case they forget or if they need more guidance.

Positive Student Perceptions

When we asked students "What aspects of the flipped classroom do you find useful for your learning?", the most frequent theme that came up was that students felt they had a better understanding during class and felt more prepared due to the fact that they had already studied the material:

> "It is a good way for us to preview the course. It gives us enough time to consider by ourselves." (S1 Student 11)

> "By doing reading assignment, I know what is Dr. Haskell's topic tomorrow. While listening to the lecture, I don't get confused with some theorem or words." (S1 Student 16)

This, in our opinion, is one of the greatest benefits of the flipped classroom approach. In a traditional lecture, it is very common for students to not understand a concept that is introduced to them and then as a result, they feel lost and disengaged for the remainder the lecture, mindlessly taking down notes. (However, it is important that the students know that the point of a lecture is not to understand the material 100 percent, but instead to get a sense of what major ideas are.) In a flipped classroom, this is less likely to occur as the students will have already seen (and perhaps learned) the concepts and are, in class, working to reinforce that knowledge and understanding. Further, in the flipped classroom, students are supposed to come to class prepared with questions about concepts, calculations, anything that they did not understand. This was also something that was mentioned by students in the comments as a positive aspect of the approach:

> "I get to try to understand the material prior to the class so that if I do have questions about the material, I will get the answer to it in the lecture." (S1 Student 24)

> "flipped classroom helped me have an idea of what the concepts are that we will learn for the next class. Even if sometimes I will have questions on some of the concepts, I can still figure out during the lecture." (S1 Student 13)

Another aspect of the flipped classroom that students said they found useful to their learning was that it gave them the opportunity to develop their self-learning and study skills:

> "To develop my self-learning skills, and make me understand the lecture materials better based on my own understanding…" (S1 Student 4)

> "It drives me to think about the materials when reading textbook, at least in the purpose of finishing the reading assignments. To have something you know you have to do before classes can prevent me procrastinating." (S1 Student 15)

As we have seen, students struggle to read mathematics textbooks on their own so it is a great advantage that this approach can teach them this skill. This is something that is, again, very important - especially if students decide to pursue mathematics further. The importance of teaching students how to learn mathematics on their own was also something that came up in our interview with Faculty Member 2:

> "I mean one of the advantages of pointing the students toward the book and making them actually read the book is that the the ability to ultimately read mathematics and then learn to digest it yourself. I mean that's what's happening with the lecture, the lecture is already a distilled version of what's in the text, right. I mean so somehow I would think some of the advantage would be to try to get the student to read it because I mean in the end, content delivery is one thing but getting the students to learn how to learn mathematics is a totally different thing right."

We also noticed that on Survey 2, there were several more students mentioning that they enjoyed or gained value from the readings in general. They mentioned that the readings were interesting, thought-provoking and gave them more confidence in class:

> "The reading assignments are actually very interesting. I think they're the perfect combination of thought-provoking and not-time-consuming." (S2 Student 2)

> "One thing that I find is that if I do my reading assignments on a regular basis, I feel more confident to go to classes. I am able to build a clear goal about what I want to know from today's class, based on which, to adjust the way I'll listen to the professor." (S2 Student 17)

> "The reading assignments we did is really a useful tool for testing how much we understand the content prior to the lecture." (S2 Student 9)

These viewpoints could also explain why the ranking statements that had an increased score over time (from Survey 1 to Survey 2) related to how the flipped classroom helped students understand and learn. We believe that as the semester progressed, students became more proficient at reading the textbook, and understanding and making connections in lectures. We believe this is one important reason that more instructors should use the flipped classroom approach; it can help students "learn how to learn".

Finally, students appreciated how this approach helped them to stay on top of the course, work ahead and avoid procrastination:

> "The readings and quizzes force me to stay up to date on the class which I appreciate as I am often apt to become lazy and fall behind" (S1 Student 6)

> "I like how open the information is to access and how you can read ahead and do your assignments ahead of time." (S1 Student 2)

This is a great benefit to students in the flipped classroom, as they often fall behind in their courses and then resort to cramming for tests and exams. As already mentioned, such attitude leads to poor learning and retention.

Students' Suggestions/Room for Improvement

We asked students, in both surveys, about aspects of the flipped classroom they did not like, and about things they wished would have been done differently in Math 1C03. The students were also given an opportunity to provide further comments. We now discuss and reflect upon the suggestions we received on how to make the course more effective and noted the areas for improvement.

Go over the readings more

A few students suggested that the instructor should go over the readings more during lecture to reinforce their understanding. Flipping a classroom is a brand new approach to students, so they may be resistant to it in the beginning, as this not the way of learning they are used to. Teaching practice experience suggests (and here we have a confirmation) that it is important to ease students into any new aspect of their learning process. As previously mentioned, we suggest that instructors transition into the flipped classroom approach slowly, in the beginning lecturing on the same material that was read, and then slowly, as time goes on and students get stronger at reading and understanding the material on their own, spend less time retelling the material and more time on discussion and synthesis.

Provide more practice problems

A number of students mentioned that they would have liked to have more practice problems. Comments from students on the survey indicate that they were looking from problems that were similar to the homework:

> "I wish more problems similar to the assignment questions were done so that we had something to refer to." (S2 Student 21)

> "Practice questions are very important. Sometimes, only teaching knowledge is hard for us to understand." (S2 Student 3)

This relates back to the commonly encountered issue of the way students feel mathematics should be learned – by matching new problems with previously seen examples. We feel that instructors should continue to emphasize to students that they need to really spend time thinking about the problem at hand rather than trying to match it with previous problems. To this end, they should also be encouraged to seek help during instructor or teaching assistant office hours.

Math 1C03 is too difficult

Some students expressed concerns about the overall difficulty of the content of this course:

> "Math1C is difficult in general. I'm always confusing by all the terminology in this course." (S2 Student 18)

> "I hope the course content can be easier, it's too hard for us now." (S2 Student 15)

Our suggestion is that the content of the course be reviewed for difficulty. As the first response suggests, one reason could be the lack of language proficiency; there are many foreign students in Mathematics and Statistics, and 1C3 is taught during their first year (in university, as well as in an English-speaking country). The purpose of the course is to prepare students for upper year mathematics courses and to get them to start "thinking mathematically". The primary goal does not need to be the coverage of a certain predefined amount of material. Quality is more important than quantity and we feel that at this stage of the students' academic careers, it is very important to teach them to learn how to read mathematics as they do not have much of an opportunity to do so otherwise.

However, not all blame for the difficulty should be placed on the course instructor (as is often implied, implicitly or explicitly, by teaching-practice references and sources). We need to better understand our students' attitudes, motivation, and beliefs (as not all are in university to learn), how much time they spend studying and how (texting and "studying" math at the same time does not constitute learning).

Provide work solutions to the homework

Students mentioned that they wanted to have the solutions to their assignments posted and/or taken up during lecture. This is something that we discussed with Dr. Haskell. Her rationale for not providing solutions was to encourage students to seek help:

> "The reason why I don't post work solutions to the homework is because I want them to come and talk to me. However, this was not effective at getting them to come and talk to me. I really did not get students to talk to me last semester. It was it was astonishing the number of office hours they had which nobody came along. And you know there are all these students are struggling and yet they're not asking for help"

Our suggestion here is to continue to emphasize to students that if they can't figure out the solution to a problem, they can always come in and see the instructor or a teaching assistant to discuss and solve it together. As well, students should be strongly encouraged to approach their peers and work on mathematics together.

It is not uncommon for solutions not to be posted in upper year mathematics courses as well as graduate level courses, so it is important to get students comfortable with seeking guidance as many students in this course are future mathematics and statistics majors.

Provide videos to supplement learning

There were a few students that mentioned they would have liked the instructor to provide them with links to videos that could help them further understand the content:

> "The professor can provide us with links to some videos that can help us with the understanding beside the reading assignment." (S2 Student 9)

> "Offer some useful video link to help understand" (S2 Student 14)

Although we feel this is a good suggestion and can be a useful learning tool, it is somewhat surprising that in this technological age, students felt that the only way they could access supplemental videos was if the instructor provided them. There are plenty of great resources readily available online, often as simple as typing the subject into Google and seeing what comes up. Perhaps this is something that the instructor can keep re-iterating to their students, so that they seek additional resources on their own.

Barriers to Implementing the Flipped Classroom

The second research question this study was designed to answer was "What are the barriers that prevent instructors from implementing the flipped classroom approach?". After analyzing the responses we'd received in all of our faculty interviews, we have come to the conclusion that there are two main barriers to implementing the flipped classroom:

- it can take too much time and resources when done with videos
- instructors feel it would not work well when done with readings

When we discussed the flipped classroom approach using video lectures, all of our interviewees felt that, to various degrees, it could be effective. However, they all mentioned that this would take a lot of time and preparation for the instructor:

> "It does take a lot of work to create the content suitable to it, to create those videos and then to operate the actual flipped classroom" (FM3)

> "I think that making videos is a lot more work than you think it's going to be." (FM4)

FM1 and FM4 also mentioned that we do not have the resources available at McMaster to create these high quality lecture videos. FM1 attempted to create videos with the MacPherson Institute for one of his courses, however it took him too long to get a meeting and by the time he did get one, it was too late.

One way to remedy this situation is to create show-and-tell sessions, where instructors would bring in their experiences in creating videos to dispel common myths. For instance, using screen capture (i.e., no special technology), Erin Clements, in one go, recorded a half-an-hour video introduction to Python for her Math 1LS3 class, which has been viewed over 1,300 times (so, on average, twice by every student in her class!). The main point is that videos do not have to be perfect, nor is a professional needed to create graphs and diagrams.

Further, when we discussed using available videos from the internet rather than creating new ones, this was met with hesitation from our interviewees. They mentioned that it also takes a long time to find, watch and assess suitable videos, and they are often not done or explained the way that the instructor would have liked:

> "It turned out to be a bit harder to do than it sounds. I mean a) you've got to sit and watch the videos. And that takes a while can be tricky. And they're, I feel a bit different than, I think, than you want. And that's the issue with using other people's material." (FM3)

A way to overcome this barrier is to implement the flipped classroom using assigned readings instead of videos. (We have commented on students' resistance to this earlier.) However, based on the responses from the interviews about this topic, it seems that instructors are hesitant to assign students readings. FM3 felt very strongly that flipping a mathematics course using the textbook would not be effective:

> "Yes, the textbook definitely doesn't work for mathematics."

This is due to the fact that instructors feel that students do not read the textbook appropriately:

> "Actually tell students to read a textbook, generally speaking it's not read in the right fashion." (FM3)

To remove this barrier, we suggest to do the obvious, and not just for the flipped classroom - use the textbooks in the course, especially in the first year. Students need to be asked to read their mathematics textbooks, and some class time should be devoted to showing them how to do it effectively.

Currently, what we have is a chain reaction – students are not trained to read mathematics textbook in high school, and because of this, instructors are refraining from assigning them

textbook readings. Students are not having the opportunity to learn how to read mathematics and this is very problematic; it is a skill that they will need in the future, especially if they will be pursuing mathematics, as well as later in life. As previously mentioned, instructors do not need to automatically switch to a fully flipped classroom, but rather gradually ease the students into it.

Conclusion

We came into this study hoping to gain a better understanding of the effectiveness of the flipped classroom as well as the barriers to its implementation. However, in the process of doing so, we feel have uncovered a serious problem that requires immediate action – students do not know how to read mathematics from written sources (which very likely includes the Internet) and instructors are not dedicating class time to teach them about it.

Based on the responses we received from the surveys, students recognize the value in developing their self-study/ self-learning skills, and we need to give them the opportunities to do so. We feel that this implementation of the flipped classroom in Math 1C03 was effective in teaching students (or at least improving their skills in) reading mathematics. As the course progressed, significantly more students agreed that the readings helped them to understand the material inside and outside of the lecture. This indicates that, as time went on and they practiced more and more, students became more proficient at reading mathematics. The flipped classroom was also effective in keeping students on track with the course, thus preventing (or reducing) procrastination. However, this implementation of the flipped classroom was not effective at increasing students' performance and engagement. We feel that in future implementations of the flipped classroom, it can be more effective at increasing performance and engagement if it is implemented gradually, however this warrants further research.

From our interviews with faculty members in the Department of Mathematics and Statistics at McMaster University, we gathered that the two main barriers to implementing the flipped classroom approach are that it takes too much time and resources to implement (if videos are to be used), and that instructors do not want to implement it with textbook readings due to the fact that students do not know how to read mathematics texts. To overcome the former, we suggest creating a platform or a venue where instructors who have had experience creating videos and/or other non-text learning resources in a way that was simple yet effective can share their experience to help other instructors do the same. As for the latter, we feel that it is actually an important reason for instructors to begin to assign readings to students, whether or not they choose to do so using the flipped classroom approach. As we have seen from this study, the more students are encouraged to read mathematics textbooks, the better they will get at it. Students felt that it benefitted them to have read the relevant sections from the textbook prior to lecture, so even if the instructor still lectures on the same material, students will benefit from having had the chance to read or study the material beforehand.

We hope that our study will make instructors more aware of the possibilities for their classrooms and that they will begin to make a shift toward the flipped classroom. As is, many instructors are not happy with the present situation, and flipping a class might provide them with an option to improve their students' learning. Or, in the least, might stimulate instructors to rethink how they teach their courses.

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Appendix A
LETTER OF INFORMATION/CONSENT

A Study of the Effectiveness of the Flipped Classroom and Barriers to its Implementation in Mathematics

Student Investigator:

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Faculty Supervisor:

Dr. Miroslav Lovric
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Purpose of the Study

You are invited to take part in a study whose purpose is to determine the effectiveness of the flipped classroom approach to teaching. For those of you who are unfamiliar with the term "flipped classroom", this refers to the approach to teaching where the gathering of information takes place at home, instead of during class, and class time is used for inquiry and application. Your professor for the class Math 1C03 is using this approach and we would like to gather information about your thoughts, opinions and impressions about the flipped classroom approach. This study is being conducted for Sarah Abu-Ramadan's MSc Thesis and will be published as an article with with Dr. Miroslav Lovric.

What will happen during the study?

In this study, we will be administering surveys two times during the semester. On these surveys, you will be asked a series of questions about your experience in Math 1C03.

Are there any risks to doing this study?

It is not likely that there will be any risks to you in this study. You might worry what we will think of you, after analyzing your surveys; or, you might be bothered by the conclusions we reach.

Surveys are anonymous, we will not ask for any identifying information. However, it is sometimes possible to be identified through our responses to questions. Please keep this in mind when you answer the questions that ask for your written answers.

When we finish our analysis and publish our findings (which we plan to conclude by 31 July 2019), we will confidentially destroy all data we have collected (the data will be destroyed in the

same way as your private information, your exams, and all your work with your name and/or student ID number are destroyed on campus).

Are there any benefits to doing this study?

There are likely no direct benefits to participants. In this study, we hope to gather evidence about the effectiveness of the flipped classroom model. We also would like to identify the barriers to the implementation of the flipped classroom in mathematics. In identifying these barriers, we hope to find ways to break them down in order make flipped classrooms more common practice here in the Mathematics and Statistics Department at McMaster University. We hope that our research, and results, will encourage faculty to consider modifying their teaching of mathematics by flipping some of their classes.

Who will know what I said or did in the study?

You are participating in this study confidentially. We will not ask you any identifying information on the surveys, so it is not likely that anyone will know what you said in the study. However, it is sometimes possible to be identified through our responses to questions. Please keep this in mind when you answer the questions that ask for your written answers. All raw data will be destroyed (deleted) by 31 July 2019.

What if I change my mind about being in the study?

Your participation in this study is completely voluntary. You can skip any question that you do not wish to answer and you can withdraw from the study by hitting 'Quit' on the survey at any time. Once you have submitted your survey, however, you will not be able to withdraw since the surveys are anonymous.

Let us emphasize that your participation, or withdrawal from participation, will not, in any way, affect your grade in Math 1C03 as Dr. Haskell will not know who has or has not participated, nor will it affect how you are treated in any future math course(s) that you take at McMaster.

How do I find out what was learned in this study?

The study will be complete by 31 July 2019. If you would like a brief summary of the results, please indicate so on the bottom of this form.

Questions about the Study

If you have questions or need more information about the study itself, please contact Sarah Abu-Ramadan at aburamsr@mcmaster.ca. This study has been reviewed by the McMaster University Research Ethics Board and received ethics clearance.

If you have concerns or questions about your rights as a participant or about the way the study is conducted, please contact:

McMaster Research Ethics Secretariat

Telephone: (905) 525-9140 ext. 23142
c/o Research Office for Administrative Development and Support
E-mail: ethicsoffice@mcmaster.ca

CONSENT

- I have read the information presented in the information letter about a study being conducted by Sarah Abu-Ramadan and Dr. Miroslav Lovric of McMaster University.
- I have had the opportunity to ask questions about my involvement in this study and to receive additional details I requested.
- I understand that if I agree to participate in this study, I may withdraw from the study at any time
- I have been given a copy of this form.

___Yes, I would like to participate in this study. I.e., I am giving consent so that my data can be used for research.

Date: _____

Name of Participant: _____

Signature of Participant: _____

RESEARCH SUMMARY (PLEASE SELECT YES OR NO):

___Yes, I would like to receive a summary of the results. Please send them to the following email address: _____

___No, I do not want to receive a summary of the study's results.

Appendix B

Survey administered in class in October

For questions 1-6, answer questions using 1=strongly disagree, 2=disagree, 3=neutral, 4=agree, 5=strongly agree.

1. I regularly do the assigned readings prior to coming to class.

   1 2 3 4 5

2. The readings help me understand the material better.

   1 2 3 4 5

3. The readings helped me better prepare for class.

   1 2 3 4 5

4. I feel more engaged in this class compared to my other math classes.

   1 2 3 4 5

5. I feel that I understand the material better during class compared to my other math classes.

   1 2 3 4 5

6. I feel that the flipped class approach helps me learn better compared to the traditional lecture approach.

   1 2 3 4 5

7. When studying for the midterm, I felt I was better able to recall the material covered in class compared to my other math courses.

   1 2 3 4 5

8. I prefer the flipped classroom approach to the traditional lecture style.

   1 2 3 4 5

9. What aspects of the flipped classroom do you find useful to your learning?
10. What aspects do you not like about this approach?

Appendix C

Survey administered in class in November/December

For questions 1-8, answer questions using 1=strongly disagree, 2=disagree, 3=neutral, 4=agree, 5=strongly agree.

1. I regularly do the assigned readings prior to coming to class.

   1 2 3 4 5

2. The readings help me understand the material better.

   1 2 3 4 5

3. The readings helped me better prepare for class.

   1 2 3 4 5

4. I feel more engaged in this class compared to my other math classes.

   1 2 3 4 5

5. I feel that I understand the material better **during** class compared to my other math classes.

   1 2 3 4 5

6. I feel that the flipped class approach helps me learn better compared to the traditional lecture approach.

   1 2 3 4 5

7. When studying for the midterms, I feel that I am better able to recall the material covered in class compared to my other math courses.

   1 2 3 4 5

8. I prefer the flipped classroom approach to the traditional lecture style.

   1 2 3 4 5

9. Was there anything this course that you particularly enjoyed/found useful to your learning?
10. Was there anything you wish would have been done differently in Math 1C03?

11. Please provide any further comments you would like to make about the flipped classroom model below.

Appendix D

Email Recruitment Script for Interviews with Faculty Members

E-mail Subject Line: A Study on the Flipped Classroom Teaching Model and Barriers to it's Implementation

My name is Sarah Abu-Ramadan, and I am a master's student in the Department of Mathematics and Statistics working with Dr. Miroslav Lovric.

We are conducting a study on the effectiveness of the flipped classroom model of teaching and barriers to implementing this model. If you have an hour to spare, I would be very interested to meet with you for an interview about your thoughts and opinions. If you consent, the interview will be recorded and transcribed for research purposes. However, your name will not be published and you will remain anonymous. The interview would be held at a mutually agreed upon time and place.

This study has been reviewed by the McMaster University Research Ethics Board and received ethics clearance. If you have concerns or questions about your rights as a participant or about the way the study is conducted, please contact:

McMaster Research Ethics Secretariat
Telephone: (905) 525-9140 ext. 23142
c/o Research Office for Administrative Development and Support
E-mail: ethicsoffice@mcmaster.ca

This study is being conducted for my MSc Thesis and will be published as an article with Dr. Miroslav Lovric.

If you are interested in participating, please contact me at aburamsr@mcmaster.ca as soon as possible. If you have any questions about the study, please do not hesitate to ask. I would like to thank you in advance for your time and consideration.

Sarah Abu-Ramadan BSc,
Masters of Science Candidate in Mathematics
Department of Mathematic & Statistics, McMaster University, Hamilton, Ontario
aburamsr@mcmaster.ca

Appendix E

Letter of Consent for Faculty Member

A Study of the Effectiveness of the Flipped Classroom and Barriers to it's Implementation

Investigators:

Student Investigator:
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Faculty Supervisor:
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Department of Mathematics and Statistics
McMaster University
Hamilton, Ontario, Canada
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Purpose of the Study: In this study, we hope to gain a better understanding of some of the barriers to the implementation of the flipped classroom approach in the field of Mathematics. We would like to hear from you about your opinions, impressions and concerns about the model. This study is being conducted for Sarah Abu-Ramadan's MSc Thesis and will be published as an article with with Dr. Miroslav Lovric.

Procedures involved in the research: Your participation in this study involves a 60-minute semi-structured interview with the student investigator, Sarah Abu-Ramadan. During this interview, you will be asked a series of questions about your thoughts and opinions on the flipped classroom teaching approach. With your permission, an audio recording of this interview will be made and transcribed for the purpose of recording and analyzing your responses. The recordings and transcripts will be stored on a password protected computer.

Potential Harms, Risks or Discomfort: It is not likely that you will experience any harm, risk or discomfort as a result of participating in this study. However, if you do feel uncomfortable, please remember that you do not need to answer questions that you are not comfortable with or do not wish to answer. We will change all names/identifiable information about you when publishing our results, however, it is sometimes possible to identify people through their responses, even after names have been changed. Please take this into consideration when answering the questions

Potential Benefits: There are likely no direct benefits to participants. In this study, we hope to gather evidence about the effectiveness of the flipped classroom model. We also would like to identify the barriers to the implementation of the flipped classroom. In identifying these barriers,

we hope to find ways to break them down in order make flipped classrooms more common practice here in the Mathematics and Statistics Department at McMaster University.

Confidentiality: Any information gathered about you in this interview that could identify you will not be published or shared with anyone other than the research supervisor, Dr. Miroslav Lovric. In publishing our results, each participant will be assigned a unique study identification, the real names of the participants will never be published. The hard copies of information obtained during this interview will be stored in a locked filing cabinet and all electronic data will be kept on a password protected computed. The data will only be available to the investigators, Sarah Abu-Ramadan and Dr. Miroslav Lovric. At the end of the study, all information will be destroyed.

What if I change my mind about participating in the study? Your participation in this study is completely voluntary. If you decide not to be part of the study, all your data will be confidentially destroyed. If you initially agree to be part of the study, but then change your mind, you can withdraw at any time up until 15 January 2019 by sending an email to Sarah Abu-Ramadan (aburamsr@mcmaster.ca). If you decide to withdraw, there will be absolutely no consequences to you. In case you withdraw from the study, any data you have provided will be destroyed.

Information about the study results: I expect to have this study completed by April 2019. If you would like a brief summary of the results, please let me know at the end of this form and the results will be emailed to you.

Questions about the study: If you have any questions about the study, please email me at aburamsr@mcmaster.ca. This study has been reviewed by the McMaster University Research Ethics Board and received ethics clearance.

If you have concerns or questions about your rights as a participant or about the way the study is conducted, please contact:

McMaster Research Ethics Secretariat
Telephone: (905) 525-9140 ext. 23142
c/o Research Office for Administrative Development and Support
E-mail: ethicsoffice@mcmaster.ca

CONSENT

- I have read the information presented in the information letter about a study being conducted by Sarah Abu-Ramadan and Dr. Miroslav Lovric of McMaster University.
- I have had the opportunity to ask questions about my involvement in this study and to receive additional details I requested.
- I understand that if I agree to participate in this study, I may withdraw from the study at any time up until January 15, 2019.
- I have been given a copy of this form.

___Yes, I would like to participate in this study. I.e., I am giving consent so that my data can be used for research.

___Yes, I consent to having this interview recorded.

Date: _____

Name of Participant: _____

Signature of Participant: _____

RESEARCH SUMMARY (PLEASE SELECT YES OR NO):

___Yes, I would like to receive a summary of the results. Please send them to the following email address: _____

___No, I do not want to receive a summary of the study's results.

Appendix F

Interview with Faculty Members

Note: comments in []'s are for the interviewer

Are you familiar with the flipped classroom approach? [if not, give them an explanation about what it is]

[If they answered yes]:

1. Have you read any of the literature about the effects of implementing this approach?
2. Have you ever considered implementing this approach in your classes?
3. [If they answered yes to 2] Have you actually tried it in any of your classes? If so, what were your experiences? If not, what stopped you from doing so?
4. [If they answered no to 2] Why not?
5. In your opinion, why do you think not very many instructors use the flipped classroom approach?
6. [Talk about the Simon Fraser study on flipped classrooms (what they did, how they did it, the results they found)] What do you think of using iClickers in math? Do you think what they did in this study is something you would consider doing in one of your classes? Why or why not?
7. What is your overall opinion on the flipped classroom approach to teaching?

[If they answered no]:

1. After hearing what the flipped classroom is, do you think that it is something you would consider trying out in one of your own courses? Why or why not?
2. What issues do you see arising with attempting to implement an approach like this one?
3. What possible benefits do you think could come about from using the flipped classroom approach?
4. In your opinion, why do you think not very many instructors use the flipped classroom approach?
5. [Talk about the Simon Fraser study on flipped classrooms (what they did, how they did it, the results they found)] What do you think of using iClickers in math? Do you think what they did in this study is something you would consider doing in one of your classes? Why or why not?
6. What is your overall opinion on the flipped classroom approach to teaching?