

Effect of Students' Engagement with Calculus I on Students' Success.

by

Svetlana Oshkai

B.Sc., Voronezh State University, Russia, 1995

M.Sc., Lehigh University, USA, 2000

A Dissertation Submitted in Partial Fulfillment  
of the Requirements for the Degree of

DOCTOR OF PHILOSOPHY

in the Department of Curriculum and Instruction

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University of Victoria

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Supervisory Committee

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Dr. T. Milford, Supervisor  
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## ABSTRACT

The purpose of the study is to analyze the association between students' engagement in the first-year Calculus courses and students' success in the concurrent and following Mathematics courses using quantitative and qualitative methods of statistical analysis. I used Design-based research (DBR) analyzing data collected in Math 100, 109 (Calculus I) and Math 101 (Calculus II) courses in the 2015 - 2020 years. The data was collected by the University of Victoria through the anonymized Course Experience Surveys, and by the course instructors through the assignments and assessments.

I describe an approach to a cyclic course design and improvement that should allow instructors and course coordinators to identify desirable area for improvement

and gradually increase students' engagement and satisfaction with the offered courses through sustainable changes.

Quantitative analysis of the data shows that: 1) There exists association of the course grade with the number of attempts on the not-for-grades practice tests; 2) Multiple iterations of communicating the pedagogical intent of the specific course design (based on the existing level of preparedness and existing previous experience with calculus; importance of the Tutorials) to the students is required for the students' buy-in; 3) Successful course redesign requires full support and ownership of the course by the entire teaching team (including all instructors and Teaching Assistants) as well as the Administration of the University.

This thesis ends with recommendations to the students and the instructors related to positive outcomes in first-year Calculus courses through increased engagement.

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## DEDICATION

I dedicate this research to my students, who shared with me their experience and drive to succeed.

# Chapter 1

## Introduction

We, the people, use many forms of engagement to socialize, work and learn. We talk face-to-face, write letters and postcards (real or virtual), exchange text messages, read and write blogs, and comment on the articles in social media. Or, if we are not “sending” out information, we are switching to the “receiving” mode: browsing the Internet, or listening to music, audiobooks or podcasts. Those communications take place at home, in school, in public transportation, on the street.

There is a potential to gain useful information through discussion about the other persons engagement in an activity. “What have you been doing?”, “What’s going on?”, “What have you been up to?” are the common questions we ask when we are reconnecting with our friends, family members, or acquaintances. Notice that we are asking about the other person’s activity they have been engaged in. Through interaction, we can find out more about the person and the activity itself. In this study we would like to find out more about first-year students and their engagement in learning mathematics, and more specifically “Calculus”, at the University.

In Calculus classes, instructors are trying to engage students in learning through in-class participation (in lectures and tutorials), formative feedback (homework as-

signments, midterm tests) and learning tools (online and in the Assistance Centre). With this research, I would like to understand which Calculus learning tools are used by students who are successful in their studies at the University, and which tools are not sufficiently used by the students who are not so successful in the University. Also, I would like to see if any information obtained by the course instructor throughout the term can be used as a predictor of the success or failure of an individual student. Results of this study can be used by the instructors while designing activities in the Calculus courses to improve the success of their students, and to provide students with motivational information, as part of the regular constructive feedback. The results of this study can be also used by the University to allocate sufficient resources for supporting the students' learning needs.

This research will provide the Education community with a formative tool useful for Mathematics Departments in general (to improve Calculus courses' structure) and the students (to improve the learning experience and success in first-year Calculus courses).

## **1.1 Why study “engagement” in mathematics?**

Calculus instructors are aware of the common struggles of first-year students to complete Calculus I and II courses. A weak mathematical foundation is one of the underlying reasons for struggles with Calculus. This is why, for example, at the University of Victoria, only the students with a sufficiently strong background (scores 73% or higher on a Precalculus course) are permitted to take the Calculus I course. However, year after year I observe about 35% of the initially registered students unable to complete the course (either by dropping out in the first month of the term or by

achieving a failing grade at the end of the term). I have also observed that some students with stronger backgrounds failed the course, while some students with lower Precalculus scores have completed the Calculus I course. Therefore, the fact that the students did well on the prerequisite course does not guarantee their success in the current course. Substantial quantitative and qualitative research has been done on trying to identify underlying factors that affect students' success in post-secondary mathematics courses, studying the correlation between students' success in the course and their gender, high school location, high school GPA, and (self-reported) attitude towards mathematics (Adamuti-Trache, Bluman, & Tiedje, 2013; Brownlie et al., 2003; Ellis, Hanson, Nuñez, & Rasmussen, 2015; Fayowski, Hyndman, & MacMillan, 2009). Through out-of-class interactions with students, I observed an interesting dilemma. Students often claim "I have done all that you have recommended, and I still failed the midterm." However, after being asked to describe exactly how they study, students explain that they spent less than three hours on the weekly homework assignments, have not done any self-assessment tests, and have not solved the recommended (optional) practice questions. The literature contains many analyses of students' engagement in learning throughout different levels of the educational system (Finn, 1993; Fredricks, 2011; Fredricks, Blumenfeld, & Paris, 2004; Henrie, Halverson, & Graham, 2015; Lamborn, Newmann, & Wehlage, 1992; Munns, Lawson, O'Brian, & Johnson, 2006; Skinner, Wellborn, & Connell, 1990). I believe that analysis of measurable evidence of students' engagement through the data collected by the course instructor over a term will extend our understanding of the effect of the engagement on students' success in the Calculus courses. Based on my experience, I believe the individual students engagement with their mathematics course is one of the determining factors, contributing to the student's success in the course. Through this research, I analyze the success of the students in Calculus I and II courses based

on:

- 1) the students' previous experience with Calculus, if any, and their choice for the Calculus I course (Math 100 is designed for students with some experience in Calculus, while Math 109 is designed for students without experience in Calculus),
- 2) the students' level of engagement with graded coursework and its correlation to the overall course grade,
- 3) the students' level of engagement with not-for-grades practice tests (number of attempts and the highest achieved score on the practice test) and the correlation with the overall course grade,
- 4) the students' engagement with the Calculus tutorials and their satisfaction with the offered courses, and
- 5) the students' overall course grade in Calculus I and its correlation with the overall course grade in Calculus II.

If through analysis, I discover that students' engagement with the course does not correlate to the students' success in the course, then I either attempt to redesign the course or provide students with additional resources designed to improve students' success in the course. If I observe a correlation between students' engagement with a course structural element (assignment, assessment or recommended practice material) and their subsequent success in the course, the observations are used as an additional motivation factor for the students in the current and subsequent terms.

## **1.2 Engagement and Success in Calculus I and II**

There are events in the students' lives that are identified in literature (Grehan et al., 2016) as critical, as they are affecting the engagement of students with their mathematics studies in the course. Students often become disengaged from their

mathematics course when they experience one of the following three critical events: experiencing difficulties with lectures, tutorials, or homework assignments. There are different types of difficulties that students may experience during lectures: missing or not being able to understand the explanation as a result of inattention (common among students repeating the course), or due to the lack of required background knowledge; not feeling comfortable to ask the lecturer or peers a clarifying question (common in large classrooms, or among people who are afraid to appear incompetent). In the current research, we do not intend to analyze or affect students' engagement in the lectures. In the small-size tutorials the students may experience the following difficulties: not feeling comfortable asking a tutorial instructor or peers for help when working on a practice problem (common when students have not worked on the practice questions before tutorials, and come in not ready to ask for the instructor's help); not attending the tutorials. In this research, we will work with the redesign of the tutorial worksheets so that the students will see the usefulness of the tutorial questions. We will also engage Teaching Assistants running tutorials in designing the worksheets and weekly meetings in preparation for each tutorial. Common difficulties with homework assignments can be classified as: not completing the homework assignments (often observed where assignments are not for grades, or have low weight on the overall course score); not spending sufficient time on the homework assignments (or underestimating how much time is needed to work on each assignment or starting the work on the assignment too late); relying on outside resources (textbook, solution manual, on-line material, videos, tutors, peers or instructors) to solve the majority of the assigned questions. In this research, we will analyze correlations between students' engagement with their weekly assignments and their overall course grades and communicate results to the students, as a motivation factor.

### 1.3 Methods of Analysis

For this research, I used information typically available to an instructor teaching a course in the Department of Mathematics and Statistics, University of Victoria. The data set contains detailed information about grades for each student registered in Calculus I and II courses from 2015 to 2020 inclusively. The data includes students' grades for assignments (such as weekly homework assignments, weekly tutorial assignments, and pre-class assignments in the flipped classroom), assessments (such as weekly quizzes, Calculus Readiness tests, midterm examinations, Gateway Tests) and, when recorded, lecture and tutorial participation. Not all of the above-mentioned assignments and assessments are given in each of the courses included in this research. The detailed structure of each course is available in Table 2.1 "Course Structures Within Three Research Cycles" on page 53.

Typically, a course instructor at the University of Victoria does not have any more information about the students. For example, not available information includes students' gender, time of graduation from high school, GPA, information about high school scores for precalculus and calculus courses, number of courses students have been registered in during the current term, and the list of terms when each Calculus course (I, II) was attempted if the course was taken repeatedly.

Some information that is available to the Calculus instructor at the University of Victoria will not be used in the current research, such as information about how long it took each student to complete online assignments and the list of completed optional online course mastering components/quizzes that are available through log data in the online practice database of questions.

In this research, the aim is to find a correlation between the type of student's engagement with the different elements of the Calculus course and their success in the current and following calculus courses using statistical methods.

## 1.4 Research Questions

I aim to incorporate current developments in technology to tailor the learning process to each student in the large first-year Calculus classes, consisting of over 200 students in each class.

### Research question #1:

Does offering Calculus courses based on previous Calculus experience improve students' success?

More specifically, based on the data collected by the University administration, the course instructors, and the online software, the current research is aiming to determine:

1. whether the students who self-select to enroll in Math 100 or 109 (Math 100 - for the students with previous experience in Calculus; Math 109 - for the students without previous experience in Calculus) have better overall course grade distribution than their peers who did not have a choice (before the Calculus I split into Math 100 and 109),
2. how a student's success in Calculus I corresponds to the student's success in Calculus II; does Math 100 and 109 prepare students equally well for the Calculus II course.

I believe that offering distinct Calculus courses will create better opportunities to engage students in the learning process in this and future Calculus courses. By analyzing students' success in the different Calculus I courses this research aims to determine if students' engagement with Calculus material in courses designed to build on students' previous exposure to Calculus (in high school, at university, as well as the lack of exposure) is increasing students' success.

Research question #2:

What element of the course structure do students find least useful?

With Calculus courses having an extensive course structure to stimulate students' engagement with the course material (through tutorials and tutorial worksheets, weekly assignments and quizzes, gateway tests, recommended questions, etc.) it is important to know what students think is the least useful element of the offered course structure, as such information could help with identifying where students are potentially disconnected from learning, and which element of the structure needs some improvement or redesign.

Research question #3:

Do students typically find instructors' recommendations or feedback useful?

Based on the data readily available to the instructors this research aims to determine:

1. what proportion of the students would practice not-for-grades questions recommended by their instructor,
2. if the strong students are more likely to follow the recommendations of the instructor, or the weaker students would be more likely to follow the instructor's recommendations, say, in the hope of improving their chances of success in the course,
3. if looking at a not-for-grades practice test is sufficient to improve students' overall course grade or if repeated practice and a sufficient level of completion of the practice test would be needed to see an improvement in an overall course grade.

As an instructor, I hope that students hear and take to heart my observations and recommendations. But does following instructors' recommendations make a measur-

able difference in the success? Using logs in the online database of practice questions it is possible to answer research question #3.

Research question #4:

Do students who fully engage with a flipped classroom structure by solving most of the pre-class exercises achieve a better overall course grade than the students who do not fully engage with those pre-class exercises?

The question related to the flipped classroom format effectiveness in a first-year Calculus course is not answered fully in the literature. Helping students to focus on the course material before coming to class sounds like a good way to engage the students. I would like to determine if a flipped classroom in the first-year Calculus course is an effective way to engage students with the course material in the courses that I teach and if the flipped classroom structure will improve students' success in these courses.

Research question #5:

If there is a tutorial section that fully focuses only on sorting for the first half of every tutorial, would the students who focus on practicing sorting techniques in tutorials of the Calculus II course do better in the course than their peers?

After a midterm in the Calculus II course, students often commented on how they did not know where to start when facing an integration question that did not specify which integration technique needed to be applied. Learning to sort questions in one of the possible applicable technique categories most often happens through practice outside of the classroom, when completing homework assignments, quizzes, and tutorial worksheets. However, it does not appear to be sufficient, despite an instructor providing a table with listed techniques and examples of the appropriate problems.

Research question #6:

Would the results of a low-stake test be drastically different on a non-invigilated test when compared to an invigilated test?

An academic integrity question is always on my mind when designing graded assessments. Having invigilated exams increases stress on the students, and requires additional resources from the Department (such as the rooms and invigilators). Having take-home tests creates opportunities for the students' collaboration, and gives access to the learning material and technology (such as notes, textbooks, internet, etc.), so the instructor's concern is that the assigned grade might not reflect students' knowledge or mastery of the expected learning outcomes.

Analysis of research questions 1 through 6 will proceed via the employment of quantitative and qualitative statistical methods.

## 1.5 Layout of the Thesis

In this section, we briefly outline the structure of the thesis.

**Chapter 1** contains an introduction to the research questions, and to the claims we make about the importance of this research.

**Chapter 2** describes in detail the terminology used, as well as the up-to-date summary of the research on the subject.

**Chapters 3, 4 and 5** contain the description of the research conducted in Cycles 1, 2 and 3: course structure and participants, methodology used to conduct analysis, instructors' intent, the detailed analysis of the data collected and conclusions.

**Chapter 6** contains the summary of the current research, limitations and future research discussion.

## Chapter 2

# Literature Review

In this Chapter, I describe in detail the terminology used in the thesis, such as “engagement”, “success”, and “failure”, as well as provide an up-to-date summary of the research on the subject of students’ engagement and success in first-year university courses. I identify what the literature describes as students’ “success” and “failure”, which factors are attributed to students’ success, what the practices employed for redesigning a university course or program to improve students’ success, and tools that are available for online learning keeping students’ success in mind. I conclude with an outline of the context of my Design-Based approach for this thesis.

### **2.1 Historical background of student engagement**

In “The World is Flat: A Brief History of the Twenty-first Century, Release 3.0”, Friedman (2007) highlighted how technological developments forever directly or indirectly changed the ways people around the world engage with aspects of life such as personal interactions, working and learning. Rapid changes are coming, and the speed of changes can feel unbearable. Being able to develop a pathway for people to accept and adapt to the changes without feeling overwhelmed is an important goal

of institutions such as universities and requires imagination and leadership.

One way for the students to best navigate rapid changes is via engagement. Fredricks et al. (2004) have written a comprehensive literature review about students' engagement in school. These authors have identified three ways for the students to engage in learning: behavioural engagement, emotional engagement, and cognitive engagement. Academic, social and extracurricular activities are viewed as examples of behavioural engagement. Students' reactions to their instructors, classmates and the administration of the school are examples of emotional engagement. Student willingness to exert thoughtful effort to master "complex ideas" and necessary skills are examples of cognitive engagement.

Similarly to behavioural, emotional and cognitive engagements, Munns et al. (2006) identified that "Student engagement operates at cognitive (thinking), affective (feeling) and operative (doing) levels" (p. 10). While cognitive and emotional levels are common to Fredricks et al. (2004) and Munns et al. (2006), we observe some difference in terminology adopted by the two studies. "Behavioral engagements" allow students who are following instructors' lead and are involved in the learning activities, to do so willingly or unwillingly. "Operative levels" specifies that the students are successfully and actively participating in their learning, and not just following their teacher's instructions or going "through the motions". Therefore, according to Munns et al. (2006), an engaged learner cannot be an unwilling learner.

More specifically and in the domain of mathematics, studies by Skinner et al. (1990) at the elementary level, and by Lamborn et al. (1992) and Finn (1993) at the secondary level, uncovered that student engagement in mathematics classes historically was low, which typically results in a lack of success in the courses. Klem and Connell (2004) highlight the importance of the teacher's support with the students' engagement and success in the elementary and secondary levels. Marzano (2013) and

Fredricks (2011) studied ways to effect students engagement in class and out of class through meaningful and interesting contexts. They uncovered that clearly mapping ways for students to navigate the course and creating a supportive environment in a small learning community improved engagement.

As we have seen in the previous paragraphs, there is no unified agreement on what constitutes students' engagement in learning. This lack of unified agreement was explored in a literature review conducted by Henrie et al. (2015), which noted a hardship in reviewing and studying published papers on students' engagement because of a "lack of cohesion around definitions, models, and operationalization of student engagement" (p. 49). The authors also commented on the shortage of studies of students' engagement, based on log data collected by different learning technologies. Most often, this research was based on surveys that were completed by the students voluntarily. In the next section, I will explore how the use of data collected by learning technologies is useful in uncovering student engagement.

## **2.2 Students' success: terminology, methodology**

### **2.2.1 Views on students' "success" and "failure"**

There are many ways to define students' "success" in a course. According to a report by Brownlie et al. (2003), published by the British Columbian Ministry of Education "a useful definition of student achievement should be broad enough to encompass all areas of learning for all students and provide a combination of approaches" (p. 9). As a result of having a very general definition of "success", the authors defined it as "an improvement in learning that develops both the individual and the individual's ability to contribute to society" (p. 9). While this definition provides a general framework for analyzing success, objective assessment of an individual's

ability to contribute to society is inherently difficult or, arguably, impossible.

Therefore, in the present study, I focus on a more practical definition of students' success that will allow me to objectively classify a learner as being successful or unsuccessful in completing a course. For this research, I focus on students' short-term success being defined as completion of the course in consideration with a grade higher than a failing grade ("F", fail or "N", incomplete) during the considered term. I will view students' long-term success in a particular mathematics course if the following required/selected mathematics course is completed on the first attempt with a score sufficient for the program originally selected by the student.

One of the implications of this definition of students' success is that it leaves multiple ways of how to define students' failure to complete a course. Clearly, the students who completed all required coursework, but did so at an unsatisfactory level (as defined by the Department offering the course), have failed the course. However, there is no clear agreement in the literature on whether the students, who chose to formally remove themselves from the course should be viewed as having failed to complete the course. For example, if 1,000 students are registered in the course, and 20% of the students drop the course for unspecified reasons, then only 800 students will be considered to have taken the course. With 25% failing grades, based on the 800 students who remained registered in the course after the deadline to formally drop the course, the success rate can be viewed as acceptable. However, the total number of students who originally intended to complete the course but were not able to do so in the considered term was 400, making it 40% of the original class of 1,000 students.

To explore this idea of the total number of students in a course, Rasmussen and Ellis (2013), analyzed a Calculus stream and interviewed students, who changed their minds and after completing the Calculus I course chose not to take Calculus II. The

authors looked for the underlying reasons for leaving the Calculus stream instead of attempting its completion. They investigated the exhibited behaviour by the students and their instructors.

For this study, I believe that the entire original class should only be considered when the students' success and the effectiveness of the implemented course structure are analyzed. When discussing students' failure to succeed in a course, we should distinguish between failures based on the final course registration (number of registered students who were assigned a total course grade), and failure to complete the course, which is based on the original course registration. Unless an instructor, who is conducting research related to the students' success and failure is tracking changes in registration throughout the term, it is nearly impossible to calculate how many students were registered in the course at some point but removed themselves from the course and were not assigned a final course grade. In this research when calculating class size, I will be using a total number of students who were registered in the course at the end of the term and were assigned a total course grade.

### **2.2.2 Factors attributed to students' success in a course**

Many factors have been identified as affecting students' success in courses. Some factors are internal to the university and therefore can be controlled (such as Department or instructor actions), while some factors are external (controlled by students, and parents), and are not in the direct control of the university.

Internal factors that I include in the current study are course structure: types and frequency of the assignments and assessments; traditional lectures vs flipped classroom; invigilated vs non-invigilated quizzes; and feedback from the instructor. All those course elements are controlled by the instructors. External factors that I include in the current study are students' study habits, amount of non-graded

practice through provided online resources, knowledge obtained in the prerequisite course, previous experience with Calculus, and the time gap between Calculus I and Calculus II courses. Many other internal and external factors could be included in research on students' success, but such information typically is not available to the course instructors (such as students' workload, gender, and living conditions).

In a report by Brownlie et al. (2003), multiple factors both internal and external are identified as important to student's success (referring to students of all levels, in all fields of studies). Some internal factors identified by these authors were:

### 1. Instructional

- course structure (lectures, tutorials; coordinated vs. independent instruction)
- class size (number of students in the classroom)
- classroom management (lecturer-centered vs. learner-centered)
- feedback (immediate or delayed, formative or summative assessments)
- curriculum (design, flexible, and relevant)
- delivery (face-to-face vs. online)

### 2. Environment

- interaction between instructor and student (instructor encouraging a lot of after-class one-on-one interaction vs. instructor promoting independent learning)
- instructor's expectations (instructor consistently projects high expectation and presents challenges)
- parent's involvement (through sharing the instructor's expectations of the student with parents through curriculum guidelines and learning outcomes).

Some external factors are identified as follows:

1. Learning

- students' study habits and discipline (working in small periods vs. allocating large periods; working every day vs. working infrequently)
- use of available resources (working with tutors, in study groups; watching videos; practicing through online learning databases of questions; using formative assessment for further learning)
- parents' influence and guidance (helping in choosing their program, the courses, study- and/or workload vs. student acting alone without parental support)

2. Knowledge

- courses completed before the current course
- level of comprehension of the prerequisite material
- the period between the prerequisite required course and the current course
- ability to read and write using the language used for instruction of the course

3. Student's socio-economic status (SES)

- family income
- parents' education background
- gender
- nationality (majority vs. minority, home language)
- high school attended (country in which student attended it, school's rank, private vs. public)

With the vast variety of factors that could potentially contribute to students' success, it became obvious during the literature review that in the qualitative and quantitative cited studies only a few factors (rarely more than three) were considered. The combination of the factors that the cited studies focused on greatly varies from study to study, but the commonality between those studies is that in each study only a limited number of factors are included (Adamuti-Trache et al., 2013; Ellis et al., 2015; Fayowski et al., 2009). The reason for not including a larger number of possible factors in each study might be that in statistical analysis, considering too many factors might result in an over-fitted model to the given data set (which is typically used in this area of research) which would not be generalizable to another data set (Raudenbush & Bryk, 2002). An over-fitted model is therefore useless for predicting possible outcomes. Adding non-essential factors to the statistical analysis also reduces the precision of the estimates of the valid factors.

In the remaining paragraphs of this subsection, I give examples of the factors included in previous studies of students' success. When studying the effects of the structure of homework assignments on students' success in universities with programs deemed as relatively successful (Ellis et al., 2015), researchers determined that the following three factors feedback, content and structure were important variables. Feedback reflected the amount and frequency of information provided by the instructors to the students through the assigned homework, with successful programs employing homework assignments that were due every week, or even in every class. Content is used synonymously with knowledge at stake "and refers to the potential mathematical knowledge one might learn through instruction" (p. 270). The content of the homework assignments has been observed as more varied in the universities with successful Calculus programs (when compared to less successful Calculus programs), emphasizing skill-building problems, including simple procedural questions, as well as

non-routine and conceptual questions. The observations made by Ellis et al. (2015) are supported by White and Mesa (2014) who have found that successful programs had half of each homework assignment consisting of simple procedural questions, while the rest of the assignment consisted of unorthodox and conceptually driven questions. The third factor, structure, unites six ways to code the nature of homework: existence of homework, amount of homework, coordinated homework assigned to all students across all course sections, online homework, written homework or group homework. The structure of the homework assignments varied greatly in successful Calculus programs, employing online individual assignments and group assignments.

Fayowski et al. (2009) developed models designed to predict a student's success in Math 100 (Calculus I) based on the following three factors: gender, completed antecedent coursework in calculus, and a student's grade in BC Mathematics 12. The regression model fitted by the authors showed that female students outperformed male classmates by 7.3 points out of 100. Students with previous calculus experience achieved 10.3 points higher on their overall course grade than the students without previous calculus experience. Similarly to the first two factors, a letter grade difference in the Mathematics 12 course resulted in a 7.5 points difference in the overall calculus grade. This was a small-scale study, based on a single course with a sample size of 140 students, who completed the Math 100 (Calculus I) course in the Fall of 2004 at the University of Northern British Columbia. The authors commented on the limitations of their models and anticipate that the models are not generalizable for other courses, terms, and institutions.

There are many parallels between first-year Calculus and Physics university courses (e.g., high school classes Mathematics 12 and Physics 12), both demanding subjects that require dedication, practice and persistence from students. Observations made regarding females outperforming males in Calculus (Fayowski et al., 2009), are sup-

ported by research on the first-year UBC Physics course (Adamuti-Trache et al., 2013). In addition, these authors also found that socioeconomic and high-school grades were correlated with the student's first-year Physics university grades.

From the literature review presented above, I determined that when designing a study on students' success, one should focus on a limited number of factors at a time. Students' grades in the prerequisite course, assessments (formative and summative), engagement (with the practice work and the feedback of instructors and students), the format of the class (regular vs "flipped" classroom) and previous experience with calculus are the five factors that I would focus on in my current research. With more than three factors in consideration, the Design-Based Research format appeared to be a good choice. The research would be divided into separate cycles, in each of the cycles only a subset of the factors of interest needed to be analyzed. Since I am interested in redesigning my courses to improve students' success, I present a literature review on redesigning the courses or programs in a later section (in section 2.3).

### **2.2.3 Features of successful Calculus programs**

When we are considering students' success in completing Calculus courses, we should consider how students' grades are calculated. In this research, the largest portion of the total course grade in Calculus is determined by the grades achieved in the assignments and assessments. In particular, the midterms and final examinations weigh in total between 75% and 84% of the total course grade, while assignments (with the follow-up quizzes, when applicable) and tutorial worksheets combined contribute between 10% and 23%. In this section, I present a literature review on how assignments and assessments are designed in different Calculus programs.

Tallman et al. (2016) analyzed 150 post-secondary Calculus I final examinations

completed in the United States in 2010/2011, which contained a combined 3735 items. Those examinations were randomly selected from a collection of the final examinations electronically submitted to an Exam Characterization Framework project by 253 universities. Tallman et al. (2016) used three dimensions to classify each of the examination items: item orientation (based on the students' intellectual behaviour needed to address an examination item), item representation (based on whether an examination item is presented in a question or as a problem statement as well as for the form of the response needed), and item format (based on the type of the response required).

Seven categories of the item orientations were defined as: remember, recall and apply procedure, understand, apply understanding, analyze, evaluate and create. Eight categories of the item representation were defined as: applied/modelling, symbolic, tabular, graphical, definition/theorem, proof, example/counterexample, and explanation. Item format had only two categories, multiple-choice and open-ended, with open-ended responses having three subcategories (short answer, word problem and broad open-ended). The authors identified that out of the 3735 items, 6.51% were placed into the category remember, 4.42% into understand, 10.3% into apply understanding, 0.11% into analyze and 78.70% into recall and apply procedure. Zero percent of the questions were placed into evaluate or create categories. While within each education institution, the percentage of final exam items presented for analysis was different, the category recall and apply procedure was the highest in all institutions (above 69%). Symbolic item and solution representation were also the most presented among final exam items (over 73%), while tabular and example/counterexample types of items and responses were present no more than 1% for each category. Short answers format was required in 76.1% of the items, while the multiple-choice format constituted 11.7% of the items.

When comparing item distributions in 2010/2011 with the items' distributions in 13 Calculus I final examinations in 1987/1988, there was a statistically significant difference observed between the proportion of items requiring students to recall and apply a procedure. Tallman et al. (2016) concluded that “while there is significantly less emphasis on recalling and applying procedures in contemporary Calculus I exams, compared to those administered 25 years ago, our results suggest that the proportion of exam items eliciting the cognitive behaviour of applying to understand has not significantly changed” (p. 127). Their conclusion also highlights that a lack of items in “evaluate” and “create” categories leave instructors without tools to evaluate students' understanding concepts, giving evaluation of mostly computational and procedural work. Tallman et al. (2016) in their research are also highlighting how between different educational institutes there is no uniformity in how Calculus I final examinations are created, and students' knowledge is assessed.

White and Mesa (2014) also researched the examinations and assignments content in successful Calculus I programs, by analyzing bookwork, worksheets and examinations used by five instructors in a two-year Suburban College during the fall term of 2012.

In their research authors categorized 4,953 mathematical tasks labeling each task as either “Rich Tasks”, “Complex Procedures” or “Simple Procedures”.

Simple Procedures consist of all tasks that fall into one of the two categories: remember and recall and apply procedure. Complex Procedures consist of all tasks that fall into the category: recognize and apply procedures. Rich Tasks consist of all tasks that fall into one of the five categories: understand, apply understanding, analyze, evaluate, and create.

There are many similarities in the descriptive naming of the categories presented by Tallman et al. (2016) and White and Mesa (2014): categories remember, under-

stand, apply understanding, analyze, recall and apply procedure, evaluate and create are present in both papers. Despite the similarities, it is impossible to compare the proportions in the two above-mentioned researches, as in White and Mesa (2014) instead of reporting outcomes for each category, the results are presented for the total Procedure or Task. For example, categories evaluate and create had no items in Tallman et al. (2016), but in White and Mesa (2014) report Rich Tasks (that contains 5 categories) was present for all five instructors on all examinations. Which of the five categories were used by the instructors is not specified.

**Figure 2.1**

*“Ternary plot showing the proportion of the three dimensions of cognitive orientation of tasks instructors assigned on Exams”, White and Mesa (2014)*

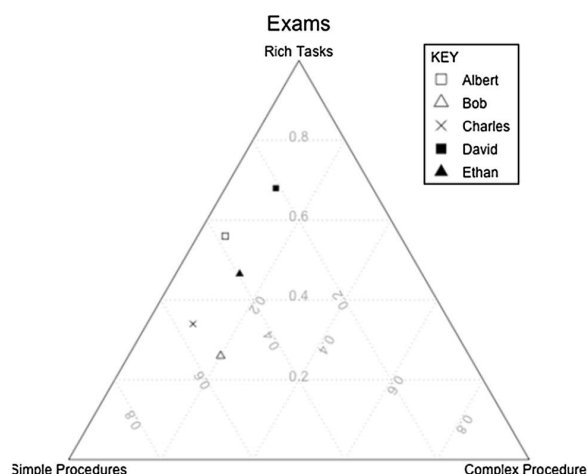


Figure 2.1 illustrates how final examinations created by five different instructors within the same institution differ in the percentage of different categories of items included on the test. From Figure 2.1 we observe that the instructors choose to include between 5% and 20% of “Complex Procedure” tasks on the examinations, while the range on “Rich Tasks” varied between 25% and 70%, with “Simple Procedures” constituting between 20% and 55% of the examination tasks.

Opposite to research by Tallman et al. (2016) showing that universities mostly focus on procedural and computational work in testing, White and Mesa (2014) show that the successful colleges (i.e., the ones with low students' failure rates) use 25% - 70% of "Rich Tasks" in their final examinations, testing whether the students are able to understand, apply understanding, analyze, evaluate, and create mathematical tasks. The difference in observations of these two independent research groups could be attributed to the difference in the rules used for categorizing items/tasks into categories constituting 'Rich Tasks', and how "Rich Tasks are assessing students' understanding of concepts.

The importance of the White and Mesa (2014) study for my research lies in the differences observed between the five instructors' examination designs within the same program. While the proportions of the rich tasks vary greatly within the same learning institution, the entire Calculus I program is deemed successful. Without knowing how the tasks were graded, we can only assume that examinations did not appear unfairly designed and graded by the students despite the drastic differences between assessments created by the different instructors.

In my research I will not be analyzing the differences between examinations and assessments created by different instructors at the University of Victoria, allowing for the course coordination and communication between different instructors to make assessments and assignments comparable within any given term and between the terms.

## 2.3 Redesigning a Course or a Program

### 2.3.1 Analyzing effectiveness of a redesigned program

Striving to improve the situation with Calculus courses at post-secondary institutions, course restructuring or re-design is viewed as a natural solution to an existing problem. Surprisingly, in some cases even after the re-design, no follow-up evaluation assesses the course effectiveness and success of the redesign (Twigg, 2013).

Hopkins and Reynolds (2001) listed the commonsense practices and philosophy that one should keep in mind when attempting to redesign a program:

- focus on *students' achievement* by analyzing what affects students' learning experience and outcomes,
- *empowering aspiration* by involving teachers and students in the educational community, to promote individual growth,
- proposed changes should be *research-based*, and have been demonstrated to be effective,
- changes should be implemented *systematically*.

This chapter describes the tools used by researchers to test five previously identified factors (students' grades in the prerequisite course, assessments, engagement with the practice work, format of the class regular vs "flipped" classroom and previous experience with calculus) to scientifically determine which of them correlate with students' success in first-year Calculus courses. I also identify methods used to study the effectiveness of a particular course structure in terms of improving students' success.

Rasmussen et al. (2014) conducted a large multi-university survey to identify the main features of successful calculus programs. Their result shows the following seven features that appear together in support of students' success:

- implementing strategies for adaptive placement of the students within calculus courses, providing students with learning resources outside of the classes (such as tutoring classes and assistance centers),
- regularly collecting data on students' performance in Calculus I and following mathematics courses (as well as using this data in the subsequent decisions about the course and the program),
- supporting instructors in the development and implementation of new teaching strategies designed to promote students' active learning,
- having a well-developed Graduate Teaching Assistants program, supported by seminars and close mentorship through each term,
- having calculus courses coordinated by a permanent Course Coordinator, who arranges meetings with instructors to discuss material coverage, pacing, students' difficulties and learning pitfalls, develop common final and midterm examinations, and, in some cases, common homework assignments,
- delivering courses that are rigorous and designed to challenge students mathematically (by offering not only the technique and skill-oriented questions but also the questions that help students develop conceptual understanding and prepare for proof-type questions).

To determine which of the elements of the redesigned first-year Calculus course was most influential in improving students' success, I completed this redesign in three research cycles.

In Cycle 1 (May 2015 - April 2017), the Math 100 course was split into two courses (Math 100 and Math 109) based on the students' previous experience in Calculus. Instead of a mandatory placement of the students in one of two courses, the self-identified comfort level with basic Calculus I topics was used to guide students' self-selected placement into the course they believed would better fit their current Calculus experience. During Cycle 1, the Mathematics and Statistics Department completed large-scale work communicating to all other Departments and Student Advisors about the differences between the two courses (Math 100 and 109) and completed all changes needed to the calendar, that are related to adding a new course. I analyzed the effectiveness of the course redesign by analyzing students' performance in Calculus I (Math 100 and 109) before and after the course was split, as well as students' performance in the Calculus II (Math 101) course.

In Cycle 2 (Math 2017 - June 2019), I developed mechanisms for providing students with individualized feedback after each midterm. I also reviewed the current effectiveness of the tutorial worksheets and students' satisfaction with the tutorial design. Analyzing students' engagement with the tutorials and the level of engagement with the optional course material recommended by instructors through the individualized feedback allowed me to identify if further course restructuring was needed to increase students' engagement with the course. I also determined the sustainability of the process of providing individualized feedback.

In Cycle 3 (July 2019 - August 2020), I designed an alternative to replace individualized feedback with a tool providing students with a high level of engagement (i.e., the Gateway Tests). I then correlated the level of completeness of the Gateway Test with students' total course grades. In cycle 3, I continued working on the redesign of the tutorials, improving TAs training and redetermining the focus of the tutorials. The first-year Calculus courses format changed to adopt a flipped classroom approach.

I then correlated the level of completeness of pre-class assignments with students' total course grades.

### **2.3.2 Design-Based Research (DBR)**

In the literature review, Anderson and Shattuck (2012) identify the following eight characteristics of DBR research: it takes place in a real context (so there is confidence that the results of the DBR will be used to assess, inform and improve practice at least in this specific context), focuses on the design and assessment of the educational intervention's effectiveness, uses mixed methods with the variety of research tools and techniques, involves multiple cycles needed to improve the design of the intervention, requires collaboration between the researcher and the educators, produces practical design principles and theoretical knowledge, is different from Action research, and has a practical impact on learning. While Action Research and DBR have many common features (iterative research or cycles, an aim to improve local context), the DBR uses both qualitative and quantitative methods, while Action Research mostly relies on the qualitative methods; DBR relies on collaboration between the members of the design team, the researchers and the instructor, while the Action Research mainly conducted by the solo researcher/teacher.

As such, DBR would be particularly valuable for studying student engagement in Calculus courses. Its iterative nature allows me to develop theoretical insights about learning and teaching, while simultaneously refining practical interventions in real educational settings, in large first-year Calculus courses at UVic. For a typical large mathematics course with hundreds of students, student engagement often faces significant challenges, DBR enables researchers to work collaboratively with instructors to identify specific barriers to engagement, implement targeted interventions, and systematically analyze their effectiveness through multiple cycles of design, im-

plementation, and refinement (Anderson & Shattuck, 2012; Kennedy-Clark, 2013; Reeves & McKenney, 2012). With the collection of both qualitative and quantitative type of data, I can get an insight into how students feel not only about calculus concepts but also about different elements of the course structure, which, in turn, can be directly translated into improvement of the teaching practices. Furthermore, DBR’s recognition of the complexity of learning environments aligns well with the multifaceted nature of student engagement in mathematics, accounting for cognitive, emotional, and behavioural dimensions of learning (Fredricks et al., 2004).

Limitations of the DBR include “researcher bias” (Kelly, 2004): how the observed elements of learning are selected for further investigation; and how one decides what observations are meaningful. Donaldson, Han, Yan, Lee, and Kao (2024) identify a “lack of confidence” that collected data is representative of the learner’s experience as another possible limitation of the DBR. Other possible negative aspects of using DBR include the length of time needed to complete multiple cycles of the research; ethical considerations of the implementation of the intervention; difficulty in replication of the DBR as it can be highly context-specific and adaptive; buy-in is required from the research group members, learners, instructors and administration.

### **2.3.3 Course Experience Survey (CES)**

Surveys, or more specifically Course Experience Surveys (CES), can be used as tools in quantitative and/or qualitative analysis of students’ perceptions of a course or a program, based on the collected feedback from the students.

#### **Multi-Institutional Survey:**

Law and Meyer (2011) worked on adapting a Course Experience Survey (also called Course Experience Questionnaire, CEQ) used in Western Universities and Chinese Universities. Six institutions were involved in collecting data on students’ perceptions

of the learning environment. The questions were translated into Mandarin with the intent to preserve the spirit of the questions. The results of the surveys consistently showed lower levels of satisfaction with the offered program among Chinese University students. Law and Meyer have recommended that the CEQ be further developed to reflect local contexts.

#### **Internal (Single) Institution Survey:**

Ariovich and Walker (2014) relied on quantitative and qualitative analysis to assess the success of newly introduced modular mathematics courses at a large community college. The quantitative analysis focused on comparing students' performance in traditional vs. modular classes. The qualitative analysis captured students' and faculty members' opinions and reflections. Their research showed that the outcomes of the course redesign were both positive and negative. As a positive outcome, the faculty members were able to "tailor" instructions to students with different levels of mathematical skills, while the students were able to influence the pace of the material delivery. The negative outcomes of the course redesign were distancing between the students and the instructors (instructors were not able to learn their students' names) and unexpected gaps in material delivery through instructional software. Because the designed structure of the modular course (including the expectations, requirements, and grading schema) was specific to that particular class and college, the students' comments were course-specific and could not be generalized.

#### **2.3.4 Scores on assessment tests and completion rates**

Twigg (2013) directly compared completion rates of traditional and redesigned remediation courses as part of the redesigned mathematics courses through the National Center for Academic Transformation (NCAT) Changing the Equation (CTE) initiative. CTE was a three-year program that started in September of 2009 and in-

cluded 38 of the nation's community colleges. Six out of 38 institutions were not able to meet the programs' requirements (i.e. engage students by making participation in laboratories mandatory, clearly communicate to the students the instructor's expectations and due dates, and award participation points) and withdrew from the CTE program. With participation in this initiative, completion rates improved in 20 courses (or 23.3%), five courses (or 5.8%) experienced no significant difference, and for the remaining 61 courses (or 70.9%) the completion rate was significantly lower or had either no previously collected data (as the course was newly created as a combination of other courses) or had insufficient data collected to conclude completion rates.

In this project, the author also compared median scores of the midterm tests and/or final examinations. The author claims that out of the 86 redesigned developmental-math courses in the 32 institutions remaining in the CTE program, 71 of the redesigned courses (or 82.6%) had "significant improvements over the traditional format" (p.7), while the remaining 15 courses (or 17.4%) had insignificant improvement, no improvement, insignificant decrease in students' performance or insufficient data collected to conclude the effectiveness of the redesign.

Twigg (2013) identifies the following aspects of redesigned courses that are important to the success of their new course structure:

- having mandatory completion of the online labs in classrooms equipped with computers; common elements between course sections such as online textbooks, lecture videos, animated examples, study plans, homework assignments, quizzes, and practice tests;
- each topic on the study plan came with a proctored post-test where a mandatory mastery level was set as a prerequisite to accessing the following topic in the study plan;

- using preview quiz where each student could demonstrate mastery of the topic in a study plan and bypass it completely, without doing corresponding assigned homework;
- before attending the proctored post-test and after all homework was completed each student had access to the practice quizzes for that course that could be taken multiple times;
- a student who was not able to demonstrate the required mastery level on the proctored post-test met with their instructor and discussed the student's work and possible "remediation techniques before the student retook the test" (p. 12).

Out of all the course aspects listed above, Twigg (2013) believes that having mandatory completion of the online labs in classrooms equipped with computers is the most responsible for improving students' success in the redesigned courses. Analysis of standard deviations of scores in traditional and redesigned courses was not performed, so it remains unclear whether the course grade distribution had been affected by the implemented redesign. Instead of relying on the total course grade, the author believes that the researchers should track the combination of the "completion of the developmental-math sequence and success in subsequent college-level math courses" (p. 13).

Based on the conducted literature review introduced in section 2.3, for this research I focused on iteratively implementing changes to the Calculus I and II course structures and analyzing students' success and/or feedback. I used the following data:

- in-term grades on all assessments and total course grades before the structure of Math 100/109 (Calculus I) and Math 101 (Calculus II) courses was changed,

including students' total course grades in a combination of courses Calculus I and a subsequent course Calculus II;

- logs in an online database and students' in-term and total course grades to analyze students' achievements after course structures were changed;
- anonymous feedback was provided in the university-developed Course Experience Surveys (CES) to analyze students' impressions of the tutorials.

## 2.4 Students' Success and E-Learning

The purpose of this section is to present recent research trends on issues related to electronic learning (E-Learning) on the integration of technology in different aspects of teaching and learning of mathematics (e.g., inside of the classroom; for accessing and completing homework assignments; for completion of proctored and non-proctored examinations). This is relevant to my research since I am exploring ways to enhance students' engagement with Calculus material using technology.

Before Cycle 1 in the first-year Calculus courses at the University of Victoria, students already had an extensive engagement with learning using technology. In the in-person classes, the instructors often use laptops or tablets in combination with the projectors to develop and present the class notes. Some instructors use Clickers (a wireless personal response system) to conduct in-class surveys and collect students' lecture attendance. Often instructors use an online graphing applet (such as GeoGebra) or computational technology (such as Wolfram Alpha) for visualization purposes. Online course pages in addition to containing course outlines and learning outcomes contain a library of the old midterm and final examinations. Textbooks, weekly assignments, follow-up quizzes, and recommended practice exercises were available online through the MyMath Lab database of questions.

At the University of Victoria, first-year Calculus courses typically consist of hundreds of students. As an instructor who intends to address each students' individual need in the large course, technology might be a possible tool that will allow the instructor to improve students' success rate.

### **2.4.1 Difference between “Distance” and “E-Learning”**

With the development of the technologies, online tools became more prominently included in the first-year Calculus courses at the University of Victoria. As I am researching ways to improve students' success, I completed a literature review, through which I discovered that online learning tools are often used in distance learning and E-Learning.

Since distance learning does not imply a necessity of learning with the use of technology, it is important not to use the terms Distance learning and E-Learning as synonyms, according to the independent studies of Bates (2005) and Guri-Rosenblit (2005). While distance learning implies separation between the educator and the learner, at least for some portion of the education process, E-Learning does not require any physical separation of the instructor and the student (Guri-Rosenblit, 2009). However, although E-learning has always relied on technology, more and more often distance learning also relies on technology through approaches used in delivering a learning environment and an assessment environment, as well as tools for interactions between the instructors and the learners, and peer-to-peer interactions.

Before March 2020, Calculus courses at the University of Victoria were offered only in an in-person format, where students would come to lectures and tutorials and sit in the same classroom with their peers and work with an instructor and Teaching Assistant. However, during COVID-19 starting from March of 2020, the University of Victoria moved to distance education, where students remained physically separated

from their peers, instructors and Teaching Assistants.

Distance learning and E-Learning in higher education have been a topic of active discussion, as it has a strong potential to affect the teaching and the learning processes through the integration of new achievements in technological development (Bernard, Abrami, & Lou, 2004; Tallent-Runnels, Thomas, & Lan, 2006; Siemens, Gašević, & Dawson, 2015; Park & Shea, 2020).

Many commonalities between the areas of Distance learning and E-Learning can be observed from the journal publications on these subjects. The following is a list of some journals publishing peer-reviewed research papers on E-Learning and distance education:

Research in Learning Technology journal of the Association for Learning Technology (ALT);\*

Contemporary Issues in Technology and Teacher Education (CITE);\*

International Journal of E-Learning & Distance Education (IJEDE);

International Journal on E-Learning (IJEL) (formerly International Journal of Educational Telecommunications and the WebNet Journal);\*

Journal of Distance Education (JDE);

International Journal of Distance Education Technologies (IJDET);

American Journal of Distance Education;\*

Quarterly Review of Distance Education;\*

Distance Education (The official journal of the Open and Distance Learning Association of Australia Inc. (ODLAA));\*

Electronic Journal of E-Learning (EJEL);

Journal of Interactive Learning Research (JILR);\*

Journal of Educational Multimedia and Hypermedia (JEMH);

Journal of Technology and Teacher Education (JTATE);\*

Journal of Technology, Learning, and Assessment;

Journal of Computers in Mathematics and Science Teaching (JCMST).

Journals with an asterisk (\*) alongside their names were identified by the National Institute for Digital Learning at Dublin City University on their website, together with links to over 130 journals publishing research on E-Learning and Distance education (<https://www.dcu.ie/nidl/resources/online-journals.shtml>).

From the number of journals publishing peer-reviewed research on the integration of technology in education (i.e., Distance learning and E-Learning), one can gather the presence of this newly emerging research area that combines these two areas (e.g., Bernard et al., 2004; Park & Shea, 2020; Siemens et al., 2015; Tallent-Runnels et al., 2006).

### **2.4.2 Characteristics and definition of E-Learning**

Guri-Rosenblit and Gros (2011) presented an expanded literature review, highlighting research gaps, as well as the inherent difficulties in effectively integrating technology with distance education. The authors identified non-uniformity in terminology used when E-Learning is discussed. According to the literature, currently, there is no unified view on the definition of E-Learning and its characteristics (e.g., Koohang & Harman, 2005; Qvortrup, 2006; Moore, 2006; Abbas et al., 2005; Herrington & Oliver, 2000; Anderson & Elloumi, 2004; Rovai, 2004; Woo & Reeves, 2007).

Sangrà, Vlachopoulos, and Cabrera (2012) published a literature review of what the community understands as E-Learning based on journal publications, books, reports, dissertations, webpages, and blogs by influential online authors starting from 2005. Like Guri-Rosenblit and Gros (2011), Sangrà et al. (2012) listed four ways to classify the existing definitions: “1) technology-driven, 2) delivery-system-oriented, 3)

communication-oriented, and 4) educational-paradigm-oriented” (p.148). After conducting surveys of 33 experts from 16 countries on the characteristics of E-Learning, Sangrà et al. (2012) proposed the following definition of E-Learning that reflects aspects from the four categories mentioned above:

*“E-learning is an approach to teaching and learning, representing all or part of the educational model applied, that is based on the use of electronic media and devices as tools for improving access to training, communication and interaction and that facilitates the adoption of new ways of understanding and developing learning” (p. 162).*

### **2.4.3 Introduction to online courses**

Distance learning is not a new concept in education. One of its pioneers in the 19th century was Isaac Pitman, who was teaching his students through weekly correspondence (Tait, 2003). Since that time, many universities have been recruiting many students by offering distance education. For example, Athabasca University in Alberta and Thompson Rivers University in British Columbia are well-known Canadian universities that are focused on distance education programs. The courses and programs offered by those universities are for credit and have fees associated with each course. With the technological developments in the late 20th and early 21st century, distance education has taken on a new trend: many universities have begun to offer free online courses. For example, Massive Open Online Courses (MOOCs) are currently offered by over 980 universities in 56 countries (<https://www.mooc-list.com/>). Many of the free courses are not for credit, but some courses provide an option of obtaining a certification at the end of the course, for a small fee, compared to face-to-face course fees at the universities.

#### 2.4.4 Students' success in MOOCs courses

MOOCs have been steadily gaining popularity among students. In 2011, Stanford University offered a 10-week-long course on “Artificial Intelligence” (CS221), with 160,000 students from 190 countries registered. This course was Massive, just as the name MOOC implied, and it was free. However, like other MOOC courses offered by Stanford that term, the percentage of students who completed the course was low, at 12.5% (Jordan, 2015). Similarly, from 104,000 students registered in the “Machine Learning” MOOC course at Stanford, only 13,000 (or less than 13%) completed it (Lewin, 2012). Also, of the 92,000 students registered in the “Introduction to Databases” course only 7,000 have completed this course (which was less than 8% of participants). Jordan (2015), presented statistics about completion rates in MOOCs, specifying the courses' lengths, the total number of students enrolled, and the name of the university running the course. The data can be sorted by completion criteria (such as “certificates issued”, “eligible to purchase certificate”, “passed course”, etc.), by platform used (Coursera, EdX, Futurelearn, Open2Study, etc.), by university offering the course (Stanford, Oxford, Delft University of Technology, MIT, etc.), and by grading policy (computer-based and/or peer grading). The author calculated the current MOOCs average completion rate at 15%. All courses with over 55,000 students registered had a lower average completion rate below 13%. Most of the courses that produced the highest completion rate (over 20%) had the following common characteristics: 1) short in length (5 weeks or shorter); 2) assessed by computerized grading; 3) “small” enrollment (less than 1,500 registered students).

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The reasons behind high dropout rates in MOOCs were studied by Onah, Sinclair, and Boyatt (2014). The authors argued that the courses contained a mix of students, some of whom did not intend to complete the course. Those students either do not engage with the course or while showing some level of engagement, do not complete the assignments. Many of the registered students appear to not understand the level of difficulty of the course, lack prerequisite skills, have time to commit to studying or have inadequate study skills. Another potential reason for the low completion rate might be the structure and the dynamics of online courses. Many of such courses suffer from being transferred online instead of being transformed to provide the most

effective learning experience to students (Siemens, 2012).

Quinn (2012) highlighted an important difference in MOOCs: some courses are designed for individualistic study (using sets of videos, interactive exercises, and tests), while others rely on interactions between learners (using blogs, forums, and social media). These differences might result in different success rates from students and aligning the type of MOOC with students' needs and expectations should be considered in planning and implementation.

Ratnasari, Chou, and Huang (2024) provide a review of the current landscape of MOOCs, identifying several themes of the research including self-regulated learning (SRL), learners motivation, engagement and performance, as well as continuance intention. Kizilcec, Prez-Sanagustn, and Maldonado (2017), and Littlejohn, Hood, Milligan, and Mustain (2016) discuss SRL and iits direct relation to the low level of learner support in MOOCs. Badali et al. (2022), Borrs-Gen, Martnez-Nez, and Martn-Fernndez (2019) identify motivation as a major factor related to the success in the completion of MOOCs. Gamification and social network interactions are useful tools in motivating participants of MOOCs. Joo, So, and Kim (2018) and Yan, Filieri, and Gorton (2021) identify the importance of continuance of intention to succeed in MOOCs courses. Perceived ease of use and usefulness of the course were linked to students' attitudes and intent to continue with the courses. Padilla Rodriguez, Armellini, and Rodriguez Nieto (2020) describe a positive effect of shortening course length (one of MOOC design characteristics) on an increase in students engagement and retention rate.

### **2.4.5 Defining Students' Engagement**

The concept of learner engagement has been studied using different definitions, depending on the researchers focus. For example, Fredricks et al. (2004), described

engagement as a model with three factors: behavioural (student being involved in school activities), cognitive (mindfulness and effort exerted by the student when mastering material), and emotional (students' reaction to interactions with peer and instructors, as well as the school's environment). Appleton, Christenson, Kim, and Reschly (2006) identified students' engagement through four indicators: academic (time of task, credit hours toward graduation, homework completion), behavioural (attendance, voluntary classroom participation, extracurricular participation and extra credit options), cognitive (self-regulation, relevance of school to future aspirations, value of learning and strategizing), and psychological (belonging, identification with school and school membership).

In their extensive review of students engagement, Finn, Zimmer, Wylie, Christenson, and Reschly (2012) highlighted the importance of the school environment (its size and safety, for example), the quality of student-teacher relationships, and the instructional approaches used in classrooms. As future research direction, those authors advocated for "creating more complete ways to identify students at risk of nonengagement or disengagement."

Ding and Zhao (2020) examined the connections between procedural engagement and affective engagement, suggesting that different emotional engagement with educational videos and assignments. Video engagement is predicted by a wider variety of emotions, including enjoyment, excitement, boredom, and annoyance, while assignment engagement is solely predicted by excitement and annoyance.

Ben-Eliyahu, Moore, Dorph, and Schunn (2018) defined "engagement as the intensity of productive involvement with an activity" (p.87). Their study analyzed the effect of different types of motivation (achievement goals and self-efficacy) on affective, behavioural, and cognitive engagement and how engagement affected motivations.

In this research, I am focusing on learners' engagement with the course through

three closely connected observable indicators identified by Fredricks et al. (2004): behavioural engagement, emotional (or affective) engagement, and cognitive engagement.

In my research, affective engagement was observed through comments students left in surveys when expressing their preferences for liking or disliking specific elements of the course structure (textbook, tutorials, assignments, etc.). Behavioural engagement was observed through students' participation in lectures/tutorials, completion of assignments, midterms, quizzes, gateway tests, and tutorial worksheets. Cognitive engagement was indicated through the number of repeated attempts on the not-for-grades practice gateway tests, which is evidence of self-regulated learning.

This behavioural perspective is particularly valuable because it provides concrete, observable metrics for measuring engagement, making it especially useful for educational research and practical classroom assessment. However, it's worth noting that this is just one dimension of student engagement, and should be considered alongside cognitive and emotional aspects for a complete understanding of student engagement.

#### **2.4.6 Students' engagement with graded online material**

In calculus courses (whether online-based or in the face-to-face environment) we often see at least some portion of mandatory course material available only online. For example, online homework assignments have been used to engage students with course material and to provide them with frequent feedback. Callahan (2016) concluded that online homework assignments appear to benefit students with higher SAT scores (better prepared for Calculus), compared to the students with lower SAT scores (less well prepared for Calculus due to weaker basic skills). This study also showed that the students were attempting and completing a larger portion of the online assignments when compared to the traditional paper-based homework assignments. The author

also observed a statistically higher retention rate in the course with online-based assignments.

However, if instructors consider replacing paper-based, hand-marked assignments with online-based assignments with the same content, they should be aware of research conducted by Lenz (2010). The author found that while offering online assignments saves time and funds allocated to marking, it does not improve students' performance on the follow-up proctored midterm examinations.

Given the contradicting results of Lenz (2010) and Callahan (2016), we should consider that the six-year difference between these studies most likely resulted in improvements in Web-Based Homework Systems (WBHS). We should also notice that in the case of Lenz (2010), the homework assignments were “transferred” online, but not “transformed” for an improved learning experience.

When talking about the effects of engagement with online homework assignments, Halcrow and Dunnigan (2012) attributed the increase in students' confidence to their ability to engage with the assigned problems multiple times and to receive immediate feedback from WBHS. However, what is not clear is the structure of the homework assignments: whether the questions were procedural, or conceptual, and how these might impact student engagement. WBHS tends to emphasize procedural questions, which are easier to master through repetition. Developing conceptual understanding proves to be more difficult for an average student. Perhaps, in the future, WBHS will include more conceptual questions with informative feedback.

#### **2.4.7 Students' engagement with on-line social media**

A common practice at universities is to use Forums as part of the Learning Management System (e.g., Itslearning, Canvas, Moodle, etc.) to allow students to engage in peer-to-peer or students-to-instructors communications to explore concepts, dis-

cuss the course material, ask questions and obtain advice. Students can participate anonymously or under their actual names (based on the setting selected by the course instructor).

However, students are identified as a risk population for addiction to the Internet (Kuss, Griffiths, & Binder, 2013), as they “typically have (i) free and unlimited access, (ii) flexible schedules, and (iii) freedom from parental interference” (p. 960). Social media provides space for a virtual life, and many opportunities to engage with other people located anywhere in the world. The list of social networking sites is long and everchanging: Facebook, YouTube, Instagram, TikTok, QQ, WhatsApp, Twitter, Pinterest, WeChat, Quora, and Discord, to name a few. Fleck, Richmond, and Hussey (2013) published a literature review, citing a list of research papers which determined that some instructors see a potential in using social media to promote students’ engagement with the material, build a sense of belonging to the learning community, and remove the impression of isolation. On the other hand, there are strong drawbacks reported by the authors. For example, when the social networks were accessed by students to study, two-thirds of the students reported being sidetracked into other online activities, not related to learning the intended material (such as posting updates to their statuses or reading tweets, blogs or irrelevant posts). Cain and PolICASTRI (2011) reported that not all students enjoy spending time on social media, or even know how to use it, so those students see no value in spending their time on such online activities. However, many students use social networks anonymously but potentially positively, when searching for solutions to calculus problems, or reviewing techniques that they did not understand from previous studying attempts. Often students post sample old midterm examinations or copies of their lecture notes. Due to the anonymity, the effects of this style of collaborative learning on students’ success are nearly impossible to analyze objectively.

### **2.4.8 Technology-enhanced Calculus lectures**

When enhancing calculus lectures, Miller (2011) employed digital ink and interactive figures and made pre-lecture-, post-lecture-slides, lecture-capture videos, and lecture notes available to the students via the course page. In the large lectures of 120-240 students in introductory calculus classes, the students performed slightly better when compared to the lectures before the enhancements had been implemented. The improvement in students' performance was particularly noticeable in the classes where the instructor was experienced with using the technology. The research also indicated that students who were slightly more prepared for calculus probably tried to register for the enhanced calculus lectures. The author commented that students' satisfaction with the lecture format improved, while the students' grades and the instructors' satisfaction levels remained nearly constant.

To assess students' understanding of the material, instructors often choose to use Clickers or smartphone-based educational applications for collecting students' responses to posed questions. While students might resent a requirement for additional purchases (Clickers), I have observed students sitting in classrooms with multiple Clickers in their hands, entering the same answer for their absent friends. This behaviour was observed in a classroom when a portion of the total course score included some participation marks from the use of Clickers during the lectures. On the other hand, instructors often shy away from using smartphone-based educational software, as smartphones carry other potentially distractive applications (text messaging, news, movies, games, etc., (Wangler & Ziliak, 2013)).

### **2.4.9 Technology-enhanced Calculus tutorials**

Ayub et al. (2010) used a quasi-experimental method to compare a traditional non-computerized style tutorial (using handouts and Microsoft PowerPoint presen-

tations) to two tutorial groups that used SAGE and Mastering Calculus Computer Courseware (MACCC). SAGE is a computer algebra system, which is an open-source alternative to commercial systems such as Maple, Mathematica, Magma and MATLAB. MACCC consists of modules such as a diagnostic test module, explanation module, exercise module, exploration module, reinforcement module and enrichment module. The authors found that the students' performance was significantly better in classes where SAGE or MACCC was used, compared to the classes with traditional tutorials. There was no statistical difference between the performance of students in the courses with computerized tutorials; however, these were both higher than the traditional courses (SAGE ( $M = 56.67$ ,  $SD = 15.65$ ,  $n = 24$ ), MACCC ( $M = 55.80$ ,  $SD = 11.11$ ,  $n = 22$ ), Traditional ( $M = 38.70$ ,  $SD = 13.23$ ,  $n = 23$ )). The authors did not indicate whether the students were self-selected in one of the three groups or randomly assigned. There is also no indication of how the preparation of the students for calculus differed between those three tutorial groups.

#### **2.4.10 Formative and summative computerized testing**

Rashad et al. (2008) introduced Electronic Assessment System (EAT), which is a web-based application of a Computer Assisted Assessment used in a Computer Programming Language course (Java) at Helwan University. A case study was based on a sample of twenty-one students. Instructors can use EAT to generate both formative and summative tests (Assignments, quizzes, Midterm and Final Exams) in a Multiple-Choice Questions (MCQ) format. The goal of computerized formative assessment is to obtain students' feedback, comments and performance statistics to modify the course material to better meet individual students' needs (Angelo & Cross, 1993). Having feedback about students' understanding or misunderstanding of content, the instructor might be able to address the topics that have not yet been mastered by

most of the students. EAT can be used to track individual students' responses, and design individualized homework assignments, based on the students' responses.

Roberts (2006) provided a literature review of the other three important types of assessment in e-learning: self-, group-, and peer-assessments. Self-assessment often requires guidance from the instructor in the form of the methods used to conduct assessment and detailed objectives for the upcoming formative assessment. Peer-assessment includes students looking through each other's work and learning about assessment rubrics, sharing success and failure stories (and learning from them), learning about other strengths and weaknesses. As shown by Jordan (2015), students do not like being evaluated (assigned grades) by their peers, resenting that the instructors delegate marking to less qualified members of the class. Group assessment involves each member of a group project describing and evaluating the contributions of the members of the group to the project (Roberts, 2006). Experience in cognitively communicating with other members and analyzing the individual impact of the project can assist students in learning. The negative aspects of peer evaluation include resentment towards the instructors and distrust of the fairness of the resulting grades.

#### **2.4.11 Effect of technology on Academic Integrity**

Technology is a tool that can and will be used in education for both positive and negative purposes. Cheating by students is changing its scope as the technological ability of society grows: for example, using smartphones and smartwatches allows the capture, transmission and display of examination papers as well as solutions produced by third parties; pens with embedded video cameras and wireless microphones allow for audio and video presence of a third party in proctored rooms during examinations or interviews; online companies offering help with questions/projects/writing of theses for modest fees (such as [freelancer.ca](http://freelancer.ca)) allow outsourcing of assigned projects to third

parties, also known as a “contract cheating”.

Nilsson (2016) proposed that the students’ behaviour is always influenced by the methods of assessment employed in the course. To succeed in a course, some students might focus on good cheating (i.e., training for the test by searching for the answers to the previous year’s questions and discussing solutions with peers or tutors), while other students might resort to bad cheating (i.e., presenting someone else’s work as their own such as plagiarizing a report or using unauthorized technology or aid material during the test) in hope of improving their chance of successful completion of the course. According to Nilsson (2016), “when there are large differences between how technology is used for learning and assessment, the Academy is likely to experience conflicts that cannot be resolved by technology alone” (p. 620).

In the current research in the in-person classes at the University of Victoria, electronic technology was used in the following ways:

- to provide students with individualized feedback (through emails);
- to engage students with the online practice Gateway Tests, actual Gateway Tests, weekly assignments, follow-up quizzes and pre-class assignments located on the publisher’s database MyLab Math (MyMath Lab or MML);
- to provide students with access to an online textbook (on MML);
- to determine if proctored online tests produce considerably different outcomes than non-proctored online tests;
- to post on the online course page tutorial worksheets before each tutorial, as well as solutions to the worksheets after the due date;
- to provide timely support through Forums available on the course page;
- to provide access to the old practice midterms (posted on the course page).

## 2.5 General Introduction to the Current Research

In this study, I focus on students' engagement and success in first-year mathematics courses at the University of Victoria (i.e., Calculus I and II) that were redeveloped using design-based research over a period starting from May 2015 and continuing through December 2020. Based upon the literature, to measure engagement and success in these classes, I focused my research on the following five factors: students grades in the prerequisite course, assessments (formative and summative), engagement (with the practice work and the feedback of instructors and students), format of the class (regular vs flipped classroom), and previous experience with calculus.

Due to the larger class sizes at the postsecondary level, when compared to mathematics classes in elementary and secondary schools, some behavioural and cognitive indicators of engagement provided by the instructor about each student are not possible or practical to consistently obtain (such as in-class and outside-of-class participation). The following behavioural and cognitive indicators were extracted from the coursework and post-course experience surveys:

- scores on the assignments, quizzes and tests (behavioral indicator);
- number of attempts / accesses of the not-for grades material (cognitive indicator);
- attendance of the tutorials (behavioral indicator);
- anonymized feedback through exit surveys (students' reflection on the implemented course modifications and instructor's support).

I aimed to develop tools that could be used to help students understand the reasons behind the courses' structure, and improve the level of students' engagement with different course elements with the intent to increase students' satisfaction and their

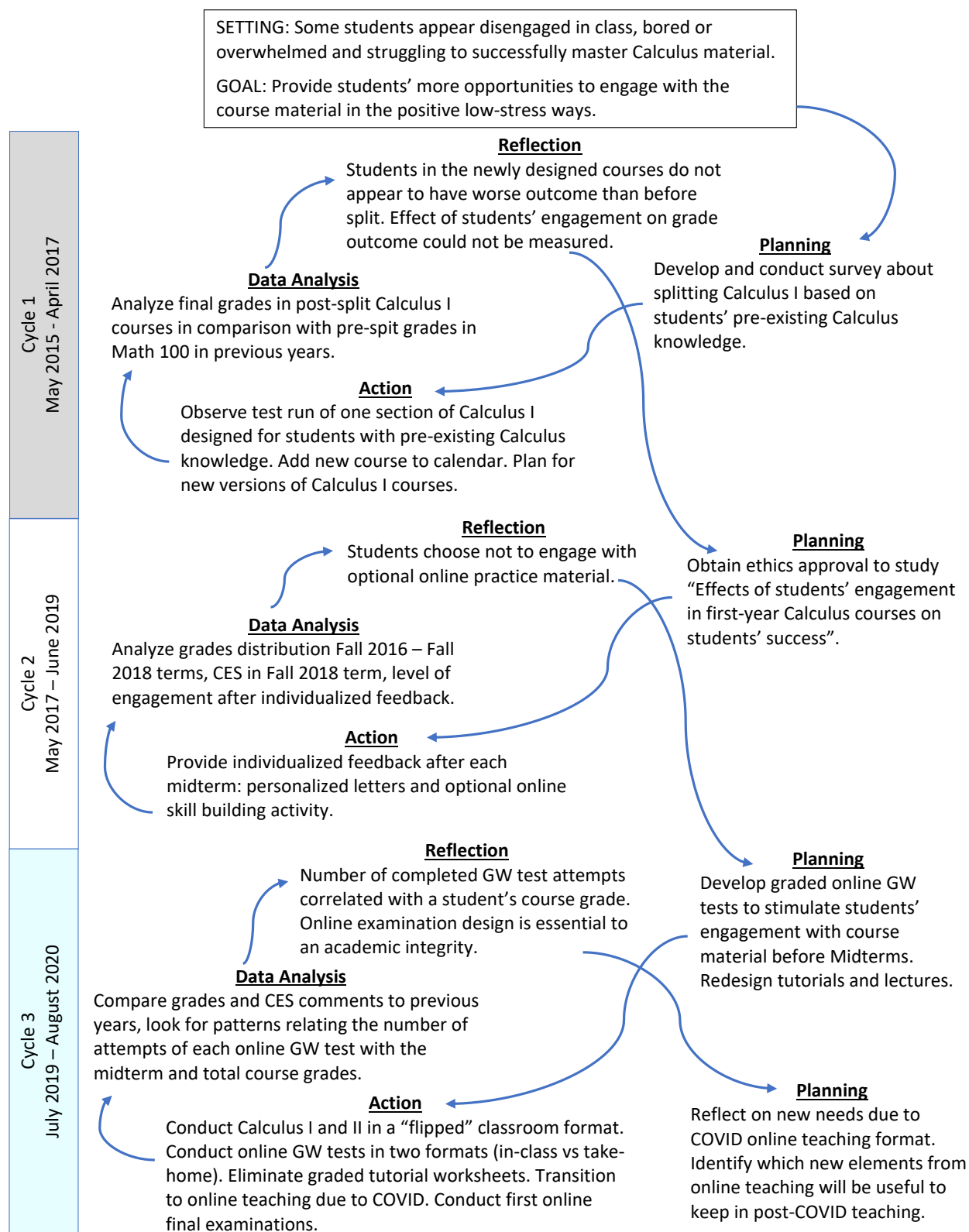
success in first-year University Calculus courses. Courses were gradually redesigned through three research cycles, by implementing changes to different elements of the course structures and analysis of the effect of the implemented changes on the students' success and satisfaction.

Figure 2.2 provides an overview of the Design-based research and is given in the form of a figure introducing planning, action, data analysis and reflection for each of the three research cycles. All the interventions were iteratively developed through the three research cycles, while analysis of and reflections on the outcomes of the intervention were employed via practicality, effectiveness and sustainability of the change in a specific course design.

Table 2.1 with the description of all courses included in this study includes information about dates when the courses were offered, the number of students registered for the course on the last day of the term, the number of instructors teaching the course, types and the number of the assessments used, as well as the formula for total course grade calculation.

Figure 2.2

## Complete Diagram of Three Research Cycles



**Table 2.1**

*Courses Structures Within Three Research Cycles*

Course	109	100*	101	109	100*	101	100*	101	100*	101	100	100	100	101	109*	101	100	101	109*	101	101	109*	101
Date (yyymm)	1609	1609	1701	1709	1709	1709	1709	1801	1801	1801	1809	1901	1809	1801	1809	1909	1901	1909	1909	1909	1909	1909	2001
Stud (#)	396	659	832	384	612	233	115	692	513	557	93	244	415	657									
Instr (#)	3	3	3	2	3	1	1	3	2	2	1	1	3	2									
WkA (#,%)	14-2,5	12-1,7	11-1,5	12-1,5	8,0#	10,0#	11,0#	10,0#	na, 6	10,0#	7,0#	9,0#	9,0#										
CRT (#, %)	1, 3	1, 2		1, 2					1, 2														
Quiz (#, %)	1, 12	1, 8			8-1,8	10-1,8	11-1,8	10-1,8	10-1,8	10-1,8	7-1,7	7-1,7	10-2,7	9-2,7									
Midts (#, %)	2, 30	2, 30	3, 45	3, 43	3, 39	3, 39	3, 39	3, 39	3, 39	3, 39	3, 39	3, 39	2, 30	2, 33									
TutA (#, %)	9-1,5	9-1,8	10-1,5	10-1,5	8-1,8	7-1,8	7-1,7	9-1,7	7-1,8	7-1,7	4-1,7												
FlipA (#, %)													24-4,5	34-6,5	24-4,5								
GWT (#, %)													2, 6	2, 12	2, 6								
Attends (%)							1	1		1	1+1	1	1	1									
FExam (%)	45	45	45	45	45	45	45	45	45	45	45	48	45	45	48								

Table 2.1 “Courses Structures Within Three Research Cycles” on page 53 has the following information:

- “Course” shows a Calculus course number offered at University of Victoria. For example, 109 corresponds to course Math 109. Star next to the number indicates that one of the sections was excluded from the analysis, because that section had a larger number of contact-hours with their instructor and had completely different course structure. Number 100\* refers to Math 100 in 2016\_09, 2017\_09, 2018\_01, while 109\* for Math 109 in 2018\_09 and 2019\_09. Excluded section contained 11, 7, 24, 7 and 12 students respectively.
- “Date (yymm)” shows the year and the first month of the term in which the course was offered. For example, the course Math 109 offered in the Fall term in 2019 started in September, so the date is recorded as 1609 using the last two digits of year 2016 and 09 representing September.
- “Stud (#)” shows how many students were registered in the course at the time when total course grades were assigned.
- “Instr (#)” shows how many instructors were involved in teaching a course.
- “WkA” = “Weekly Assignments”, “CRT” = “Calculus Readiness test”, “Quiz” = “Quizzes”, “Midts” = “Midterms”, “TutA” = “Tutorial Assignments”, “FlipA” = “Flipped Assignments”, “GWT” = “GateWay Tests”. Each cell in those rows consists of the two entries (#, %) indicating number of assessments of each type and the total percentage assessment contributed to the total course grade. Indicator 0# showed that the students had weekly homework assignments that did not directly contribute to the total course grade calculation. To access a quiz, which contributed to the total course grade, a corresponding homework

assignment needed to be completed before the due date with a score of at least 75%. In the cell indicating number of assessments of specific type a difference 14-2 (Math 109, 201609) indicates that 2 lowest grades of the 14 assigned were excluded for each student before the total course grade was calculated.

- “Attends (%)” contains information about how attendance was contributing to the total course grade calculation, if at all. In a case when there is a single number is entered in the cell, it corresponds to 1% of the grade given based on the attendance of the tutorials. In “1+1” case, students were contributing 1% to the total course grade by attending the lectures and 1% by attending the tutorials in that course.
- “FExam (%)” what percentage of the total course grade was based on the Final Examination grade.
- ‘na’ indicates that information about the number of weekly assignments in Fall 2018 in Math 109 was not available for analysis. This missing information did not affect analysis of the students’ course grades distribution.

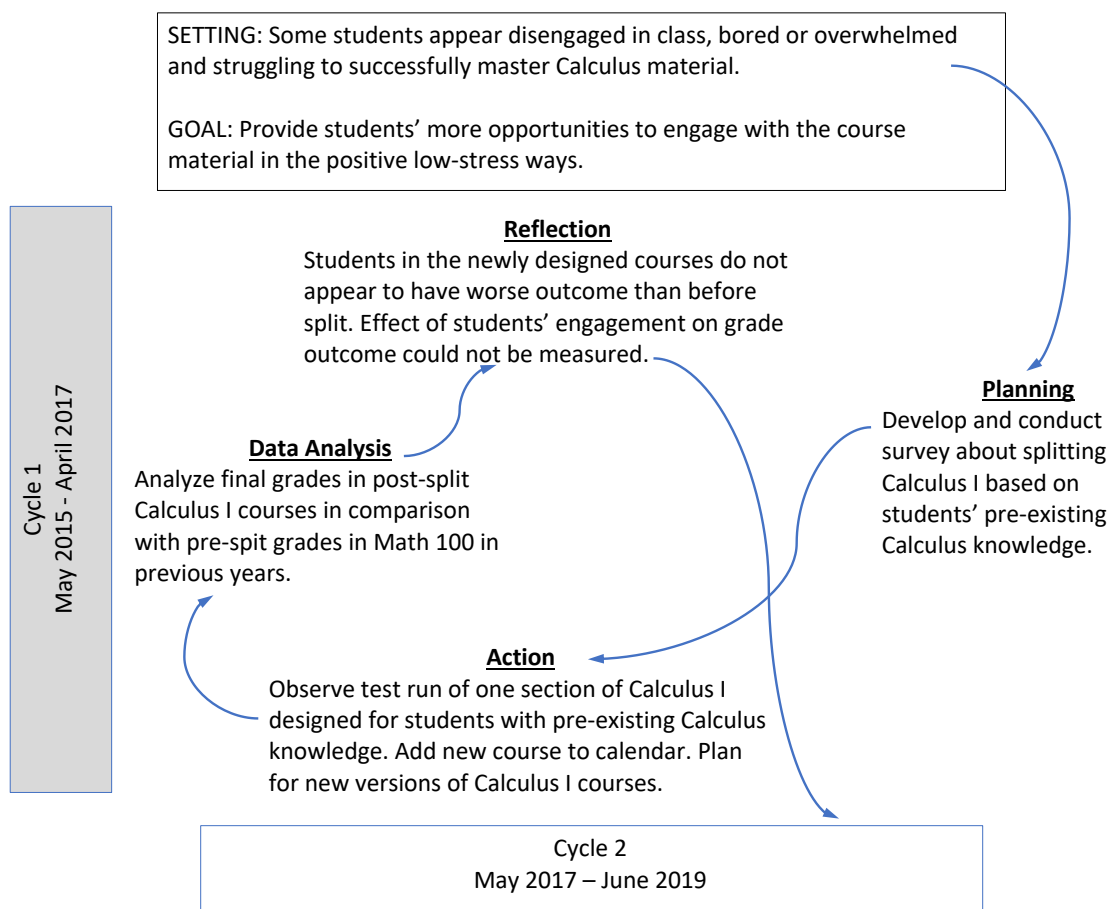
## Chapter 3

### Cycle 1 detailed information

In this Chapter, I detail the first step in redesigning the first-year calculus course (Math 100) to increase students' engagement and potentially improve their success. Students were self-placed in either Math 100 or Math 109 courses based on their previous experience with Calculus: students with little or no experience with Calculus were directed to register in Math 109, while students who were comfortable with basic knowledge of limits and calculation of derivatives were encouraged to register in Math 100. Figure 3.1 illustrates and details the four stages of Cycle 1: planning, action, data analysis, and reflection, which will be further detailed in this chapter.

#### **3.1 Cycle 1, Courses Structure.**

Table 3.1 is an extraction from Table 2.1 and contains a description of all courses corresponding to the research in Cycle 1. As mentioned in Chapter 2, coordinators worked closely to align the courses: offering a Calculus Readiness Test, two midterms, weekly assignments, a quiz, tutorial assignments, and a cumulative final examination. While the Math 100 and 109 course structures were similar, having two independent courses allowed coordinators to design their courses to better fit students' previous

**Figure 3.1***Research Cycle 1 - Planning, Action, Data Analysis, Reflection*

experience with Calculus topics. The main differences between the courses included the number of weekly assignments, the weight of course components in the total course grade calculations, and the timing of the assessments. The materials covered on the final exam and the midterm examinations, as well as their weights in the total course grade calculation, were identical.

To assess the impact of splitting Calculus I into two (Math 100 and 109) courses, it is important to continue observing and analyzing students' performance in their next

**Table 3.1***Cycle 1 Courses structures*

Course	109	100*	101
Date (yymm)	1609	1609	1701
Stud (#)	396	659	832
Instr (#)	3	3	3
WkA (#,%)	14-2,5	12-1,7	11-1,5
CRT (#, %)	1, 3	1, 2	
Quiz (#, %)	1, 12	1, 8	
Midts (#, %)	2, 30	2, 30	3, 45
TutA (#, %)	9-1,5	9-1,8	10-1,5
FlipA (#, %)			
GWT (#, %)			
Attends (%)			
FExam (%)	45	45	45

*Notes.* All three courses are colored grey to indicate that this is Cycle 1.

All listed courses have name “MATH” followed by Course number.

This table is an extraction from Table 2.1 “Courses Structures Within Three Research Cycles” located on the page 53, with the following two pages (p.53-54) containing the description of each item in the current table.

Calculus II course (Math 101). If student self-placement into one of two Calculus I courses would negatively affect the students’ success in the following Calculus II course, then the current implementation of the course split would have to be reviewed or even reversed.

In the 2017 spring term, the Math 101 course structure was very similar to Math 100 and 109 in the 2016 fall term: multiple midterms, weekly assignments, tutorial assignments, and the cumulative final examination. The difference with the Calculus I courses was that in Math 101 the Calculus Readiness Test and quiz were replaced by the third in-class midterm (see Table 3.1). Students in Math 101 in Cycle I could be viewed as belonging to one of two groups: they either completed the prerequisite Calculus I course (Math 100 or 109) in the 2016 fall term or satisfied their prerequisite requirement before the 2016 fall term.

## **3.2 Background information, coming into Cycle 1**

Before January 2015 University of Victoria (UVic) offered only two Calculus I courses' Math 100 Calculus I and Math 102 Calculus for Students in the Social and Biological Sciences. Traditionally, Math 100 was comprised mostly of first-year students working towards their Bachelor of Engineering, Software Engineering or Science. There was an expectation that upon completing Math 100, the students would enroll in other Calculus courses, such as Math 101, 200, 202 or 204.

Math 102 is comprised mostly of first-year students working towards their Bachelor of Science, Arts or Commerce. There is no expectation that the students in Math 102 would take any other Calculus courses. No Engineering students take Math 102, as it does not fit the requirements for the Engineering program. Math 100 is required in many programs at UVic and is offered in all three terms (spring, summer and fall) with over 1,400 students registered in 2014 (260, 53 and 1083 in each respective term).

Engineering students often exhibit a stronger background and more comfort with mathematics than students who intend to get a degree in Biology or Commerce. Often Engineering students take an introductory Calculus course in their last year of high

school, before enrolling in Math 100 at UVic.

From informal in-class surveys in Math 100 during 2013-2014, I learned that the course is approximately evenly split between students who have had some calculus before and others who have not seen any calculus before or cannot recall basic material presented in their first-year calculus course. Based on Course Experience Surveys over the same period, the following problems were identified by the students:

- students who have some basic knowledge of introductory calculus material become disengaged with the course: bored in class when familiar material is presented, get distracted and often miss important explanations;
- students who do not have a basic knowledge of introductory calculus material become intimidated by the quick and correct answers of their classmates to the questions posted by the lecturer and believe that it is not possible to pass the Math 100 course without taking some introductory calculus course before it. This group of students often chooses not to participate in the in-class discussions, and rarely asks the instructor for clarifications in class.

Based on the observations from the point of view of the course coordinator, the course was too large for the final examination to be scheduled in a single location. The largest examination room at UVic seated 800 students, while in the fall of 2014, Math 100 had 1083 students completing the course in seven sections, led by six instructors (2 faculty members and 4 sessional instructors). Writing an examination scheduled in multiple locations creates various problems:

- students often come to the incorrect location for their examination, creating a problem within the examinations when the seating is assigned;
- any announcements (such as information about errors) made in one examination

location had to be communicated and replicated in the other locations of the examination to preserve fairness;

- any problems observed by the examination personnel (invigilators) could not be verified by the course coordinator located at the other location and therefore, could not be immediately addressed.

A team of Mathematics and Statistics Department Faculty members created and surveyed Math 101 (Calculus II) students about the possibility of splitting a Calculus I course into two independent Calculus I courses separating students by previous calculus experience: students with no previous calculus experience would go to the Math 109 course; while students with some calculus experience would go to Math 100. The results showed that support for the split was strong, with all participants of the survey (over 120) unanimously agreeing with our proposed new course offering. Data indicated that about 60% of the students who responded would have self-selected to enroll in Math 100, while about 40% of the responders would have self-selected to enroll in Math 109.

After completing the Math 102 course, Calculus I for students in the Social and Biological Sciences, a majority of the students do not continue studying calculus as Math 101 (Calculus II) requires completion of Math 100 or 109 or permission of the department. Upon completion of Math 100 or 109 the students can choose to continue studying Calculus by taking Math 101 or, if the program of their choice does not require Calculus II, choose not to take Math 101. The majority of students who need Calculus I and II take corresponding courses immediately after another: Calculus I in the fall term, followed by Calculus II in the spring term. Math 101 in the spring term typically has approximately 800 - 850 students registered on the first day of the term, with approximately 20% of the students having completed the prerequisites more than one term ago (not in Math 100 or 109 in the previous term).

### 3.3 Cycle 1 Planning: Instructional Intent

In 2015, my goal was to create an engaging environment in the Calculus I courses for the students based on their previous existing knowledge of Calculus or a lack thereof. The Department of Mathematics and Statistics worked diligently to clearly communicate with the other Departments at UVic and the incoming students about the difference between the Math 100 and 109 courses, to provide students with the information about the courses to facilitate correct course selection.

Additional benefits from splitting the Calculus I course into two independent courses would result in having the course coordination position a more manageable job, as each course would have considerably fewer students registered. Furthermore, scheduling of the common final examinations within each of the new courses would allow for a single location.

In September 2015, with evidence of students' support of the split of the courses idea, the Department offered one of the Math 100 sections as a section for students with previous Calculus experience. All Math 100 students received an email about the special section, and 135 students registered and completed the term in that section.

Analysis of the students' results indicated that the performance of the students registered in the special section was not in any way worse when compared to the rest of the cohort of Math 100 students. The instructor of this special section indicated that it was hard to know exactly to what extent the students in the special section were familiar with the basics.

Over the 2015-2016 academic year, the Department of Mathematics and Statistics implemented a calendar change by adding a description of a new course, Math 109, worked with other Departments at UVic to clarify the difference between the Math 100 and Math 109 Calculus I courses, and distributed information to the incoming first-year students about the differences between the two first-year Calculus I courses

to allow for correct self-placement.

### **3.3.1 Participants and action plan in Cycle 1**

In the Fall of 2016, when Math 109 was offered for the first time, 396 students registered and completed the term in three lecture sections of the course. Two of the three instructors in Math 109 were sessional instructors, with the third instructor being a faculty member. The two courses had separate course coordinators, who were also the instructors for one of the sections of the course. At the same time, 660 students registered and completed the term in Math 100, also offered in three lecture sections. Each section of the Math 100 course was taught by a different faculty member. The two courses were completely independent of each other, such as different weights for the assignments and assessments, different exam dates and examination tests, and different homework and tutorial assignments. The course coordinators closely worked together to ensure that the difficulty of the assessments (including final examinations) and the materials covered in the two courses were comparable.

In the spring of 2017, the term immediately following the first offering of the split Calculus 1, the Math 101 (Calculus II) course had 832 students registered on the last day of classes. Out of 832 students, 462 students completed Math 100 and 200 students completed Math 109 in the previous term, while the remaining 170 students did not complete either Math 100 or Math 109 in 201609 and obtained a grade of 50 or higher in the prerequisite Calculus I course at some time before the previous term.

### **3.3.2 Literature review supporting Cycle 1**

In this section, I present a literature review supporting the separation of the students into distinct courses based on background.

Bressoud, Camp, and Teague (2016) identified that students without previous cal-

culus experience feel at a disadvantage when competing with students with previous knowledge. Furthermore, high school and university students had a perception that without completing calculus courses in high school it is not possible to succeed in calculus courses at the post-secondary institution. This negatively impacted the morale of the students in their studies and affected their choice of post-secondary programs. Comments in the Course Experience Survey in Math 100 at UVic before the separation of the students into Math 100 and 109 have supported the above-mentioned observations made by Bressoud et al. (2016).

Jones (2009) proposed MUSIC as a model for student academic motivation. The model is based on five components that contribute to increased students' motivation to learn: eMpowerment, Usefulness, Success, Interest and Caring (abbreviated as MUSIC). The MUSIC model is potentially applicable to the UVic division of Calculus into two sections. By providing students with the choice between Math 100 and 109 the Department of Mathematics and Statistics empowers students. Having a designated course for students with some basic Calculus knowledge should address the problem of the loss of interest exhibited by students who already have basic knowledge of Calculus. Students who would like to carefully work through the introduction of the basic calculus material would be able to choose the course where knowledge of any portion of calculus before beginning the course is not expected. Members of the Department of Mathematics and Statistics hoped that the separation of the students into two courses would allow for creation of the homework assignments specifically addressing the difference in the background and would be useful in helping students build their Calculus I skills. The effort of the Department of Mathematics and Statistics to increase students' likelihood of success and raise students' interest in the course material included instructors redesigning not only the assignments but also the delivery of the lecture material. Department members not only supported the

transition to two separate Calculus I courses by including separate course coordinators but actively shared the information about the difference between Math 100 and 109 courses with other Departments and all incoming students. This care given by the instructors and the Department in supporting students' interests is demonstrated through the implemented changes to the Calculus I courses.

The literature indicates that the strength of students' foundational knowledge increases their success rate in the course. For example, Pilgrim (2010) concluded that having an intervention course correlated positively with the highest students' success in the intervention group. As there is no required intervention course at UVic for the students who already satisfy the Calculus I course prerequisite, separating the students into two courses using self-selection and building the just-in-time reviews of algebra and trigonometry material in Math 109 could provide timely support needed for the students with weaker calculus foundational skills.

Carefully communicating to the students the reasons for splitting the Calculus I course to better fit previous experience, potentially created an elevated level of familiarity between the instructor and the students. This communication demonstrated to the students that the instructor cared about students' success. According to Christophel (1990), immediacy such as demonstrated here in the Calculus I class is one of the factors correlated to the students' positive behaviour and favourable attitude towards the instructor.

### **3.4 Cycle 1 Data Analysis: Hypothesis Testing**

In the Fall of 2016, Math 109 was offered for the first time, and the students were alerted that Math 100 would be taught under the assumption that all students in this course had seen some calculus material already.

Calculus I (i.e., 100 and 109) courses had a similar number of students. Math 100 in the Fall of 2014 had 1045 students, and the combined Math 109 and 100 courses in Fall 2016 had 1055 students. The number of lecture sections and the number of students per section remained the same in the above-mentioned courses: six sections in the Fall of 2014 with the number of students varying between 140 and 210 per section, and six sections in the Fall 2016 with the number of students varying between 115 and 240 per section.

**Figure 3.2**

*Math 100 grades in 201409 and Math 109 / 100 grades in 201609*

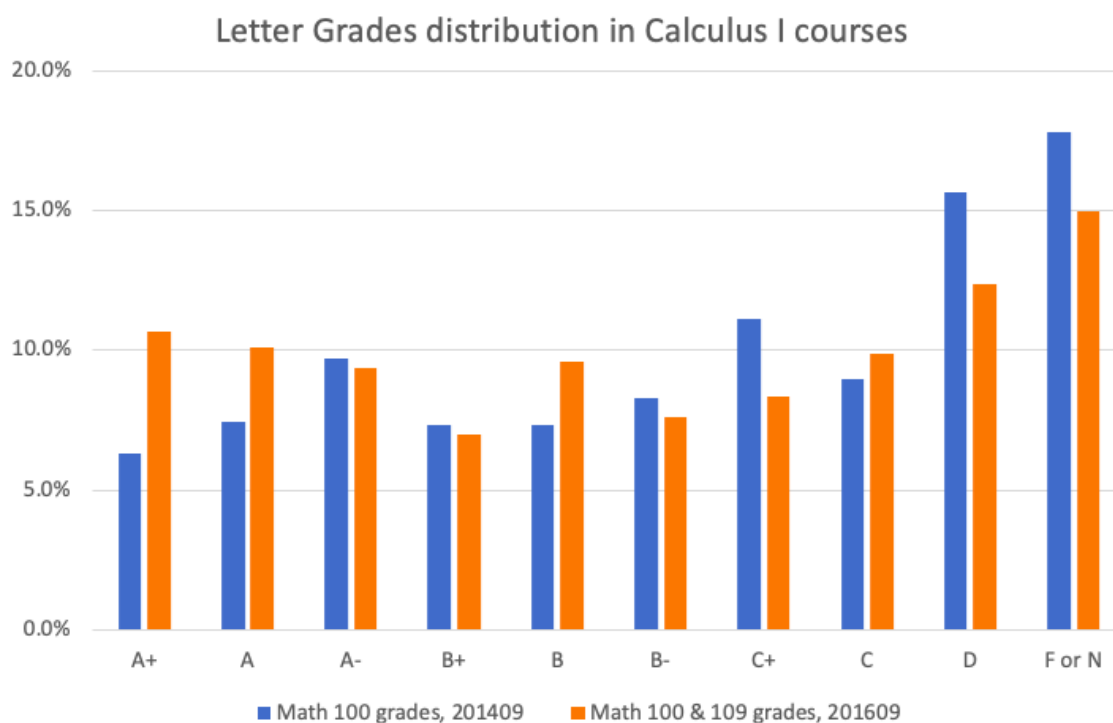


Figure 3.2 shows a spread of the course grades in Calculus 1 based on whether students were Math 100 graduates in 201409 or Math 109/100 graduates in 201609. Data shows that while grades in Calculus I in 201609 on average appear to be higher

**Table 3.2***Chi-square test of Math 100 grades before and after split*

Observed Frequency	100, 201409	109&100, 201609	Total	Expected Frequency	100, 201409	109&100, 201609	Total
A	249	325	574	A	285.1	288.9	574
B	244	260	504	B	250.3	253.7	504
C	213	196	409	C	203.2	205.8	409
D	166	133	299	D	148.5	150.5	299
F or N	189	161	350	F or N	173.9	176.1	350
Total	1061	1075	2136	Total	1061	1075	2136

$\chi^2$	17.07
df	4
p_value	0.0019

for the students before the Calculus I split, in the next sub-section I check if the observed difference is statistically significant.

### 3.4.1 Effect of Splitting the Calculus I Course on Students' Success in Calculus I.

#### Hypothesis 1 in Cycle 1:

Null: Students in Math 100 Fall term of 2014 and the students in combined Math 109 and Math 100 courses in the Fall term of 2016 performed at the same level.

Alternative: Students in Math 100 Fall term of 2014 and the students in combined Math 109 and Math 100 courses in the Fall term of 2016 performed at different levels.

The null hypothesis 1 in Cycle 1 states that splitting Math 100 into two courses Math 100 and 109 (based on the students' previous Calculus experience) did not have any effect on the course grades distribution. The Fall term in 2014 was the last in the pre-split offer of the Math 100 course; all offered sessions were taught under the assumption that all students had not seen any Calculus material yet.

To analyze the distribution of letter grades assigned in each of the terms in the

Calculus I courses in 2014 and 2016 I used a Chi-square test. Letter grades were grouped into the following 5 categories (“A”, “B”, “C”, “D”, failing grades “F or N”), for the two terms, which gives degrees of freedom equal to four. Table 3.2 shows the data used for the analysis. The Chi-square value is equal to 17.07. The resulting  $pvalue = 0.0019$  is smaller than 0.05, meaning that the null Hypothesis 1 is rejected in favour of the alternative. Based on this result, I can conclude that performance in the pre-split Calculus I course (Math 100) in the 2014 Fall term and post-split combined Calculus I courses (Math 109 and 100) in the 2016 Fall term did not have the same grade distribution. Figure 3.2 shows that the main difference in the grade distribution corresponds to grades “A+”, “A”, “B”, “C+”, “D” and “F or N”, with Math 100 & 109 grades in the 2016 Fall term (201609) having a larger proportion of the students with the higher overall course grades than Math 100 in the 2014 Fall term(201409). The split of Math 100 into Math 100 and 109 courses does not appear to result in a greater number of lower grades for Calculus I students.

### **3.4.2 Effect of Splitting the Calculus I Course on Students’ Readiness for Calculus II.**

#### **Hypothesis 2 in Cycle 1:**

The newly developed Math 109 course prepares Calculus I students for Math 101 (Calculus II course) well.

Students in the Math 101 2017 Spring term can be split into the following three categories:

- 1) Math 100 graduates - students who completed the Calculus I prerequisite through the Math 100 course in the 2016 Fall term;
- 2) Math 109 graduates – students who completed Calculus I prerequisite through

the Math 109 course in the 2016 Fall term;

3) Others\* – students who completed the Calculus I prerequisite earlier than the 2016 Fall term using any acceptable UVic prerequisite.

**Table 3.3**

*Descriptive Statistics of Math 101 grades*

Math 101 grades for	Math 100 graduates	Math 109 graduates	Others*
Mean	66.69	59.33	57.14
Standard Error	0.94	1.38	1.75
Median	67.5	60	61
Mode	81	73	69
Standard Deviation	20.14	19.52	22.80
Sample Variance	405.74	380.99	520.03
Kurtosis	0.14	-0.67	-0.23
Skewness	-0.63	-0.22	-0.65

**Figure 3.3**

*Math 101 grades in 201701 based on Calculus I grade from 201609*

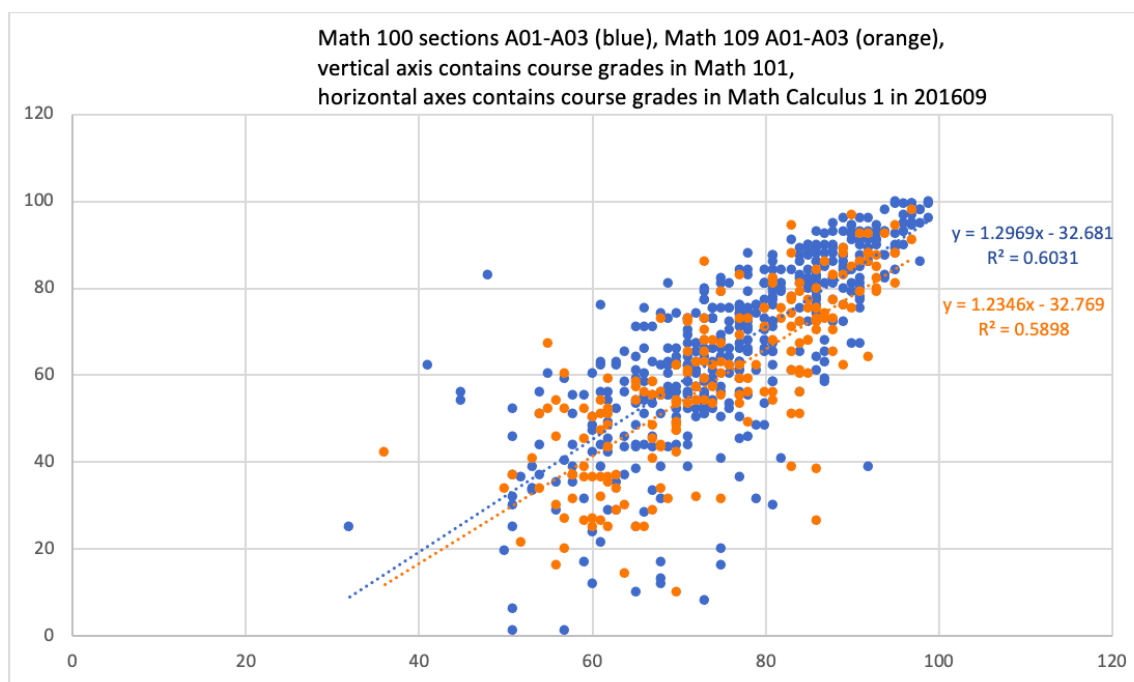


Table 3.3 shows descriptive statistics of the total course grades distributions for each of the three categories, with Math 100 graduates performing in the Math 101 course better on average by 7% than Math 109 graduates, and 9% better than Others\*.

To see if Math 109 prepares students for Math 101 as well as Math 100 we start by looking at Figure 3.3, which shows the spread of the course grades in Math 101 based on whether students were Math 100 graduates in the 2016 Fall term or Math 109 graduates. We can observe that while grades in Math 101 on average appear to be higher for the students with the Math 100 prerequisite, it is important to check if the difference is statistically significant.

An F-test as shown in Table 3.4 indicates that the variances of the Math 101 course grades for Math 100 graduates and Math 109 graduates are approximately equal, as  $p_{value} = 0.3063 > 0.05$ . Using t-Test for the two samples with equal variances, Table 3.5 analysis shows that Math 101 grades for Math 100 graduates are statistically different from Math 101 grades for Math 109 graduates ( $p_{value} = 1.5E-05 < 0.05$ ). Therefore, I conclude that Math 100 graduates are doing better in the Math 101 course than their peers who are Math 109 graduates.

**Table 3.4**

*F-Test Two-Sample for Variances*

Math 101 grades for	Math 100 graduates	Math 109 graduates
Mean	66.69	59.33
Variance	405.74	380.99
Observations	462	200
df	461	199
F	1.0650	
$P(F \leq f)$ one-tail	0.3063	
F Critical one-tail	1.2241	

To complete testing the hypothesis that the newly developed Math 109 course prepares students for Math 101 (Calculus II course) well, I compare Math 109 graduates'

**Table 3.5***t-test: Two-Sample Assuming Equal Variances*

Math 101 grades for	Math 100 graduates	Math 109 graduates
Mean	66.69	59.33
Variance	405.74	380.99
Observations	462	200
Pooled Variance	398.28	
Hypothesized Mean Difference	0	
df	660	
t Stat	4.3548	
$P(T \leq t)$ one-tail	7.7E-06	
t Critical one-tail	1.6472	
$P(T \leq t)$ two-tail	1.5E-05	
t Critical two-tail	1.9636	

**Table 3.6***F-Test Two-Sample for Variances for Math 109 graduates and Others\**

Math 101 grades for	Math 109 graduates	Others*
Mean	59.33	57.14
Variance	380.99	520.03
Observations	200	170
df	199	169
F	0.7326	
$P(F \leq f)$ one-tail	0.0175	
F Critical one-tail	0.7846	

**Table 3.7***t-Test: Two-Sample Assuming Unequal Variances for Math 109 & Others\**

Math 101 grades for	Math 109 graduates	Others*
Mean	59.33	57.14
Variance	380.99	520.03
Observations	200	170
Hypothesized Mean Difference	0	
df	335	
t Stat	0.9851	
$P(T \leq t)$ one-tail	0.1627	
t Critical one-tail	1.6494	
$P(T \leq t)$ two-tail	0.3253	
t Critical two-tail	1.9670	

performance in Math 101 with the performance of Others\*.

The F-test shown in Table 3.6 indicates that the variances of the Math 101 course grades for Math 109 graduates and Others\* are not approximately equal, as  $p_{value} = 0.0175 < 0.05$ . Using a t-Test for the two samples with unequal variances, shown in Table 3.7, it is clear that Math 101 grades for Math 109 graduates are statistically no different from Math 101 grades of Others\* ( $p_{value} = 0.1627 > 0.05$ ). Based upon this, I conclude that Math 109 graduates in the Math 101 course are doing as well as their peers who have completed prerequisites earlier than the 2016 Fall term.

Since Math 100 was designed for students with previous Calculus experience, while Math 109 was designed for students with no previous Calculus experience, the difference in students' performance in the Calculus II course might be attributed to Math 100 students, in general, having more time committed to learning Calculus. This difference might be attributed to their previous experience with some Calculus material before taking Math 100 at UVic. Furthermore, students having no previous calculus experience might be an indication of their lack of enjoyment in working on mathematics in general, having a fear of mathematics courses, or their lack of access to upper-level mathematics in high school.

### **3.4.3 Correlation Between Calculus I and Calculus II Grades.**

#### **Hypothesis 3 in Cycle 1:**

Students with the same letter grade in Math 109 and Math 100 will perform approximately at the same level in Math 101.

Figure 3.4

*Math 101 grades distribution in 201701 based on Calc I grade in 201609*

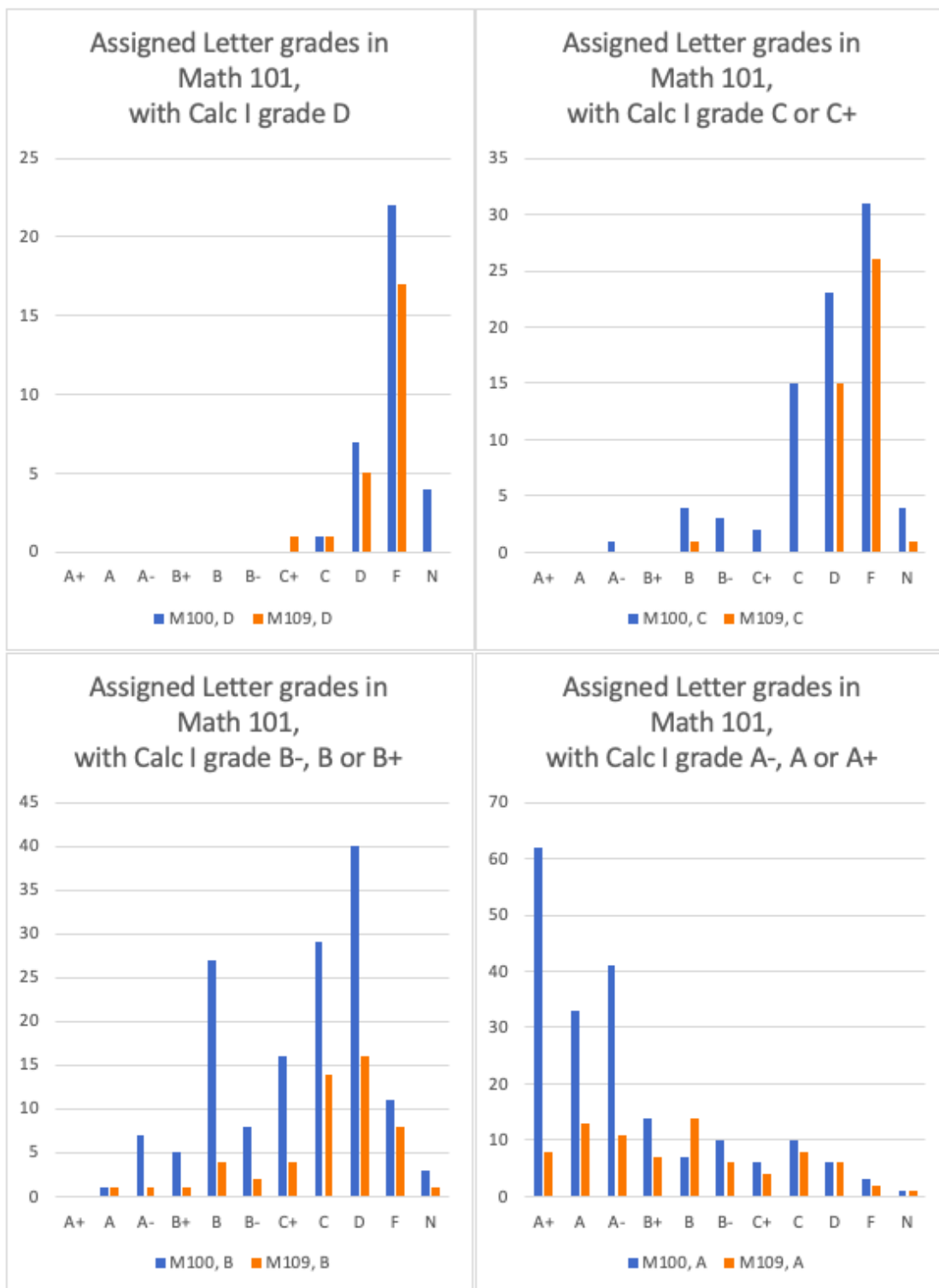


Figure 3.5

*Math 101 grades distribution in 201701 based on Calc I grade in 201609*

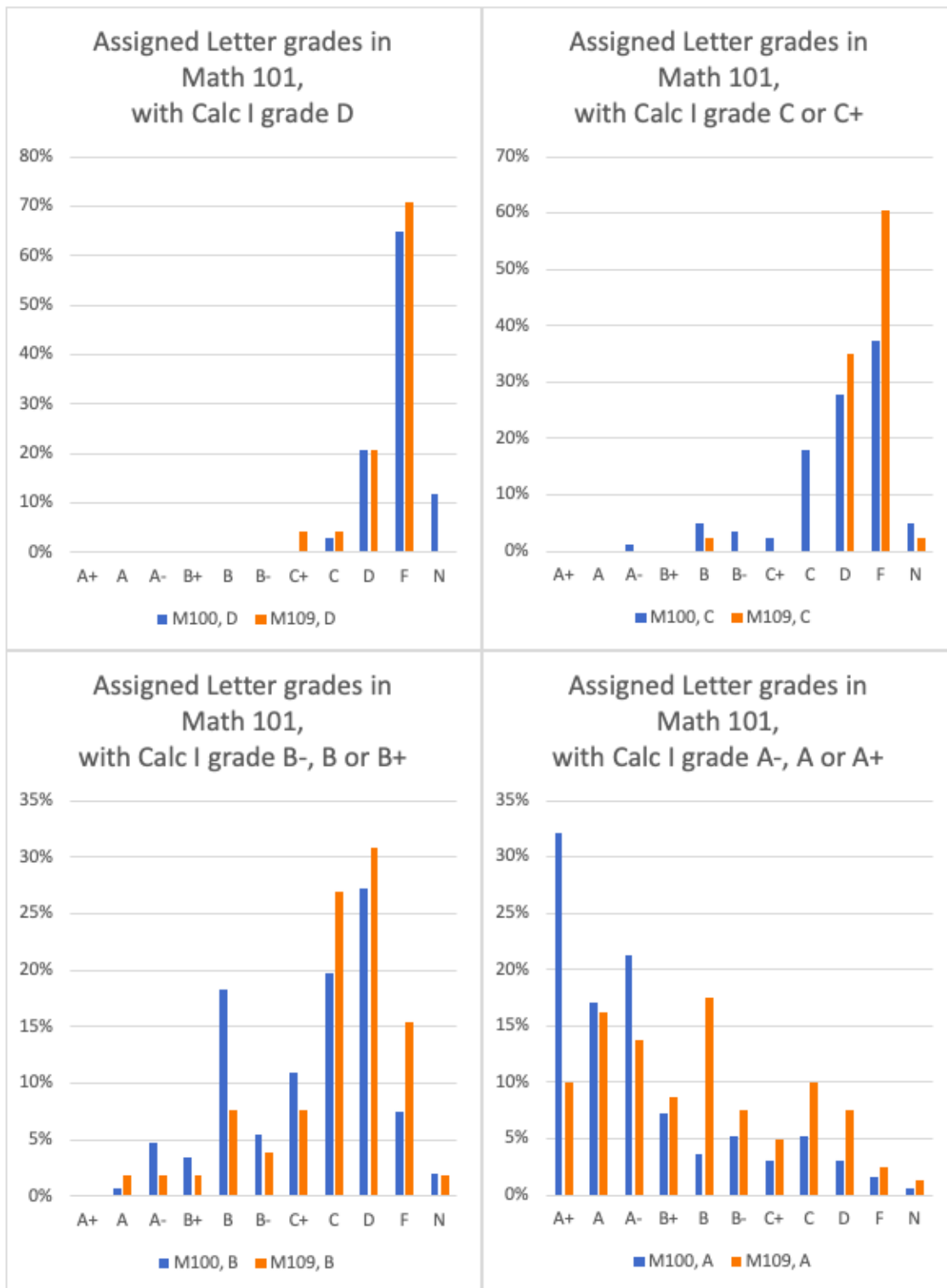


Figure 3.4 shows distributions of Math 101 grades in the 2017 Spring term based on the Calculus I grade earned in the 2016 Fall term. Since the number of Math 100 graduates taking the Math 101 course was more than double the number of Math 109 graduates, it is more appropriate to compare the shapes of the distribution by plotting data in percentages, and not by the number of students (see Figure 3.5).

It appears that students with grades A and C in Math 100 had a considerably better course grade distribution in Math 101 (Calculus II) than their peers with the same grades coming from Math 109 (see Table 3.8).

**Table 3.8**

*F-Test: Two-Sample for Variances Based on Letter Grades*

	M100,D	M109,D		M100,C	M109,C
Mean	36.38	39.38	Mean	49.96	42.37
Variance	226.05	170.85	Variance	250.18	169.72
Observations	34	24	Observations	83	43
df	33	23	df	82	42
F	1.32		F	1.47	
P( $F \leq f$ ) one-tail	0.24		P( $F \leq f$ ) one-tail	0.09	
F Critical one-tail	1.94		F Critical one-tail	1.59	

	M100,B	M109,B		M100,A	M109,A
Mean	62.71	58.96	Mean	82.52	74.89
Variance	162.50	164.51	Variance	145.21	187.04
Observations	147	52	Observations	193	80
df	146	51	df	192	79
F	0.99		F	0.781	
P( $F \leq f$ ) one-tail	0.46		P( $F \leq f$ ) one-tail	0.08	
F Critical one-tail	0.70		F Critical one-tail	0.74	

An analysis of the Math 100 and 109 letter grade distributions shown in Table 3.8 indicates that for all four groups of the letter grades (A, B, C and D) the variances within each letter grade are approximately the same in Math 100 and Math 109, based on the  $p_{value}$  being more than 0.05. Therefore, for the t-test analysis, I will

assume equal variances for the grade samples (see Table 3.9).

One of the main goals for Calculus instructors is to help students successfully navigate through their studies at the University. Communicating expectations and sharing observations from the previous terms can be very useful to the students.

**Table 3.9**

*t-Test: Two-Sample Assuming Equal Variances, Math 101 grades*

	M100,D	M109,D	M100,C	M109,C
Mean	36.38	39.38	49.96	42.37
Variance	226.06	170.85	250.18	169.72
Observations	34	24	83	43
Pooled Variance	203.39		222.93	
Hypothesized Mean Difference	0		0	
df	56		124	
t Stat	-0.79		2.71	
$P(T \leq t)$ one-tail	0.22		0.004	
t Critical one-tail	1.67		1.66	
$P(T \leq t)$ two-tail	0.43		0.008	
t Critical two-tail	2.00		1.98	
	M100,B	M109,B	M100,A	M109,A
Mean	62.71	58.96	82.52	74.89
Variance	162.50	164.51	145.21	187.04
Observations	147	52	193	80
Pooled Variance	163.02		157.40	
Hypothesized Mean Difference	0		0	
df	197		271	
t Stat	1.82		4.58	
$P(T \leq t)$ one-tail	0.04		3.6E-06	
t Critical one-tail	1.65		1.65	
$P(T \leq t)$ two-tail	0.07		7.2E-06	
t Critical two-tail	1.97		1.97	

Table 3.9 shows that students with a D grade in the 2016 Fall term Math 100 and 109 courses have no difference between the means of their grades in Math 101. Unfortunately, the students with a D grade in the prerequisite course typically fail

Math 101: in both cases the means for the Math 101 grades are below 40%.

Table 3.9 also shows that students with grades of C or C+ in the Math 100 and 109 courses in the 2016 Fall term do not have approximately the same means for their grades in Math 101. Unfortunately, the students with C or C+ in the Math 109 course typically fail Math 101 (the mean is below 43%). On the other hand, students with grades C or C+ in the Math 100 course are equally likely to pass or fail Math 101 (the mean is 49.96%).

Furthermore, Table 3.9 shows that students with grades of B-, B or B+ in the 2016 Fall term Math 100 and 109 courses have approximately the same means for their grades in Math 101. The students typically pass the Math 101 course with a score below 65%.

Finally, Table 3.9 shows that students with grades of A-, A or A+ in the 2016 Fall term Math 100 and 109 courses do not have approximately the same means for their grades in Math 101. The students with A-, A or A+ in the Math 109 course typically complete Math 101 with a grade of 75% or higher (mean is 74.89%). Typically, the students with A-, A or A+ in the Math 100 course complete Math 101 with a grade of 83% or higher (the mean is 82.52%).

Based on the analysis of Cycle 1 data, the beginning of the term and before the last date to drop the course I can share the following observations with the Calculus I students (both Math 100 and 109 courses):

1. Less than 26% of the students who completed Calculus I in the previous term with a grade of D passed the Math 101 course. Only one student out of 68 students with a D for the prerequisite course achieved a score of 65% in Math 101, the rest had lower scores. Completing the course with a grade above 65% might be a requirement for some university programs, such as Engineering.
2. Less than 9% of the students with a grade of C or C+ in Calculus I obtain 65%

or higher in Math 101. Only approximately 50% of the students with C or C+ in Calculus I pass the Math 101 course.

3. Approximately 90% of the students with a B grade (B-, B or B+) in the Calculus I course complete the Math 101 course. Only 40% of the students with B (B-, B or B+) in Calculus I complete Math 101 with a grade of 65% or higher. With 65% being a minimum score accepted by programs such as Engineering, it is important for the students needing a Math 101 grade of at least 65% to be aware of the risks involved in taking the Calculus II course without having a Calculus I grade of B or higher.
4. Only one out of 40 students with a grade of A (A-, A or A+) in the Calculus I course did not complete the Math 101 course (which was less than 3% of A students). Approximately 90% of the students with a grade of A (A-, A or A+) in Calculus I obtain a grade over 65% in Math 101.

Based on the above-described analysis, my recommendations to the Calculus I students are as follows:

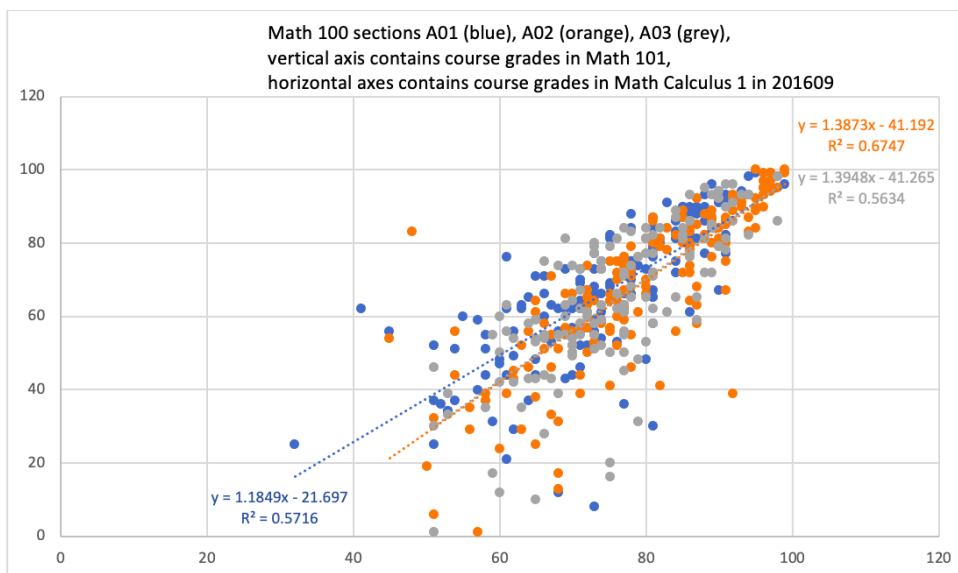
1. If you need to complete Math 101, strive to master the Calculus I material at the level of A (A-, A or A+).
2. If you are fighting for a low passing grade in Calculus 1, but intend to take Math 101, consider dropping Calculus I before the last day allowed to withdraw from the class without consequence of failure and use the remaining time in the term to build up your precalculus skills. Then take Calculus I in the next term with the intent of getting an A in the course.

While sometimes students might prefer one instructor's lecturing method to another instructor's lecturing method, the final Math 101 grade distribution based on

both the Calculus I grade obtained and the lecture section appears to be similar across all sections of the same course. See Figures 3.6 and 3.7 for the total course grade distribution in the Calculus II course based on the Calculus I lecture section.

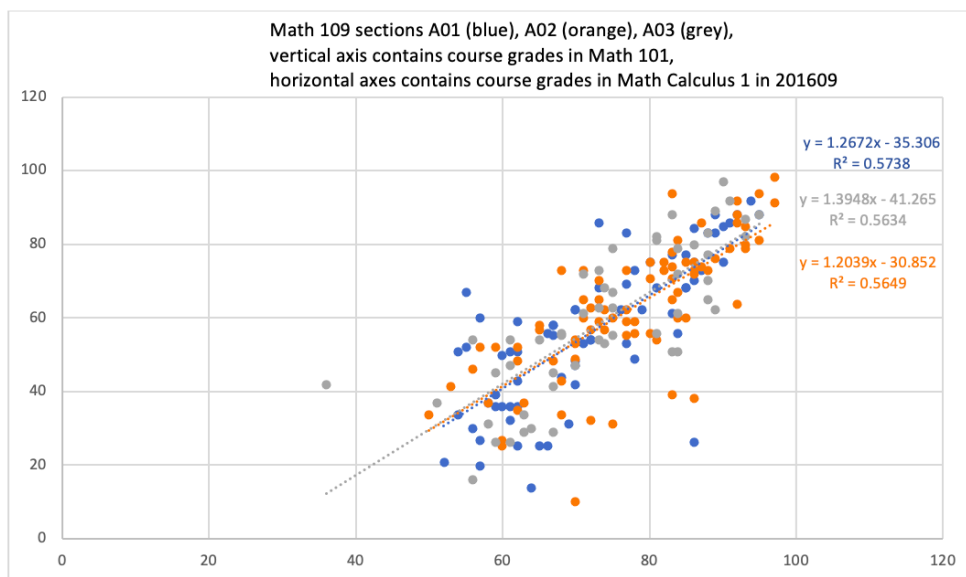
**Figure 3.6**

*Math 101 grades in 201701 based on Math 100 grade from 201609*



**Figure 3.7**

*Math 101 grades in 201701 based on Math 109 grade from 201609*



### 3.5 Reflections at the end of Cycle 1

Detailed course grades for Math 100 and 109 at the end of the Fall 2016 term were reviewed and compared to the Math 100 Fall 2014 grades.

At the end of each term, when the course grades have been assigned by the course instructor and approved by the Chair of the Department, the Course Experience Surveys (CES) are reviewed by the Chair of the Department and made available for the instructors for their review. Due to my study leave, I did not teach in the Fall of 2016 and Spring of 2017. So I had no access to detailed CES data for those terms, but common feedback was provided by the members of the project team.

It appeared that the grade distribution showed more higher grades in the Calculus I courses (Math 109 and 100) than before Calculus I was split into two courses. As expected, due to the large number of parameters affecting the final course grades, it was not possible to measure the effect of students' engagement on the resulting course

grade.

Based on the comments of the instructors teaching the new Math 100 and 109 courses, not all students were able to or chose to place themselves in the correct course (based on their previous level of exposure to Calculus) and often students without a basic knowledge of any Calculus topics still chose to register in Math 100, not in the recommended Math 109.

Course coordination became more manageable as the over 1000 students were now split between two Calculus I courses, with each course size dropping below 800. Reduction of the class size made it possible to better address logistic questions of scheduling common midterms and final examinations.

### **3.6 Problems to be addressed in Cycle 2**

The detailed explanations of differences between the first-year Calculus courses posted on the Department's course page and announcements made in classes by the instructors are not sufficient to help students correctly place themselves in the correct Calculus course (Math 100, 109 or 102). Instructors need to develop additional tools to clearly illustrate to the students the difference in the expectations related to the preliminary Calculus knowledge levels.

To help students to correctly interpret their progress through the course, course instructors should:

1. develop a tool that allows for meaningful engagement of the students in mastering the course material without increasing the number of high-stress assessments such as the midterms;
2. provide students with individualized feedback after each large milestone such as a midterm. The feedback could be based on the student's grades on the

midterms, as well as on the information about the study habits observed through completed to-date online assignments and quizzes.

An application for an ethics approval of the study “Effects of Students’ Engagement in First-year Calculus Courses on Students’ Successes” needed to be completed to allow for the search for the underlying reasons for the students’ successes and failures in the first-year calculus courses.

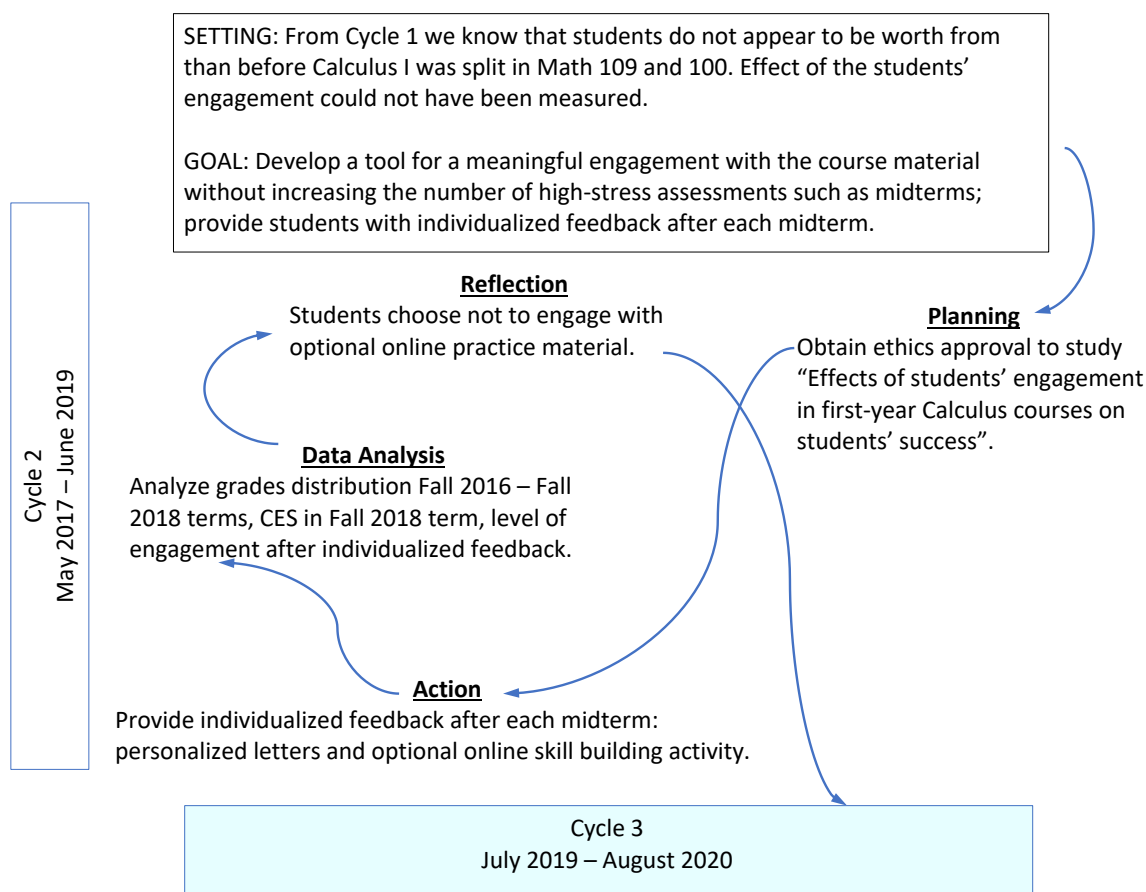
## Chapter 4

### Cycle 2 detailed information

In this Chapter, I introduce the second of the three cycles of the research. In Cycle 2, which ran from May 2017 to June 2019, I continued my work on modifying the design of the first-year calculus course by redesigning the tutorials, providing students with individualized feedback, and adding the low-stress not-for-grades practice tests to increase students' engagement and improve on their success. Figure 4.1 illustrates the four stages of Cycle 2: planning, action, data analysis, and reflection, and will be further detailed in this chapter.

#### 4.1 Cycle 2, Course Structure.

Table 4.1, an extraction from Table 2.1, contains a description of all courses corresponding to the research in Cycle 2. While the Calculus I (Math 100 and 109) course structures were similar, having two independent courses allowed course coordinators to design their course to better fit students' previous experience or lack of experience with Calculus topics. The main difference between the courses included the number of weekly assignments and the weight of course components in the total course grade calculations. In Math 100 students were required to complete assign-



**Figure 4.1**

*Research Cycle 2 - Planning, Action, Data Analysis, Reflection*

ments in preparation for the weekly quiz, but the scores from weekly assignments were not included in the total course grade calculations. However, in Math 109 the weekly assignments were included in the total course grade calculation.

The timing, material coverage on the final exam and the midterm examinations, as well as their weights in the total course grade calculation, were identical in Math 100 and 109. The Math 101 course (Calculus II) had similar structure and weights to the Math 100 and 109 courses (Calculus I), which gave students a feeling of familiarity with the course structure and expectations concerning the due dates.

**Table 4.1***Cycle 2 Courses structures*

Course	109	100*	101	100*	101	109*	100	100
Date (yymm)	1709	1709	1709	1801	1801	1809	1809	1901
Stud (#)	384	612	233	115	692	513	557	93
Instr (#)	2	3	1	1	3	2	2	1
WkA (#,%)	12-1,5	8, 0**	10, 0**	11, 0**	10, 0**	NA, 6	10, 0**	7, 0**
CRT (#,%)	1, 2					1, 2		
Quiz (#,%)		8-1,8	10-1,8	11-1,8	10-1,8		10-1,8	7-1,7
Midts (#,%)	3, 43	3, 39	3, 39	3, 39	3, 39	3, 39	3, 39	3, 39
TutA (#,%)	10-1,5	8-1,8	7-1,8	7-1,7	9-1,7	7-1,8	7-1,7	4-1,7
FlipA (#,%)								
GWT (#,%)								
Attends (%)				1	1		1	1+1
FExam (%)	45	45	45	45	45	45	45	45

*Notes.* All courses are colored white to indicate that this is Cycle 2.

All listed courses have name “MATH” followed by Course number.

This table is an extraction from Table 2.1 “Courses Structures Within Three Research Cycles” located on the page 53, with the following two pages (p.53-54) containing the description of each item in the current table.

## 4.2 Background information: coming into Cycle 2

The Calculus I courses (Math 100 and 109) starting from Cycle 1 separate first-year students based on their previous calculus experience. Math 100 is a course for students who have some experience and basic knowledge of limits and derivatives

calculations, while Math 109 is designed for students who have not seen calculus previously. Math 102 is the first-year calculus course that existed before Cycle 1 and is designed for students in Social and Biological Sciences.

With the historical offering of only two courses (Math 100 and 102), first-year calculus students need help to correctly place themselves in one of the correct courses (Math 100, 109 or 102). After Cycle 1, students in Math 100 who misplaced themselves commented on how they were expected to know some calculus material, while the prerequisites did not require any calculus background. While the detailed explanation of differences between the three Calculus I courses was posted on the Mathematics and Statistics Department webpage, the students without basic calculus knowledge mostly relied on the word-of-mouth of the students who had taken the pre-split Calculus Math 100 course and followed their peers' recommendation to enroll into Math 100, instead of the Math 109 course recommended by the Department.

From the comments in class and the course experience survey, some students appeared surprised about the difference between their grades on the at-home home coursework and the in-class midterm examinations. The comments indicated that during the term students often believe that the higher grades achieved on the homework assignments and short quizzes are a better representation of their mastery level of the course material when compared to their lower midterm grades. Students often brushed off the low score on the midterm examination as an accidental mishap on their part or an unfair or difficult examination created by the instructors.

To help students correctly interpret their progress through the course, there was a need to:

1. develop tools that allow for meaningful engagement of the students in mastering the course material without increasing the number of high-stress assessments such as the midterms, and

2. provide students with individualized feedback after each large milestone such as a midterm.

Feedback was based on the students' grades on the midterms, as well as the information about useful study tools and habits successful students exhibit in the Calculus courses.

### **4.3 Cycle 2 Planning: Instructional Intent**

As a part of the planning process, I obtained Ethics approval to study the effects of students' engagement in the first-year Calculus course on students' success. I used the first part of Cycle 2 to develop my Application for Research Ethics Approval for Human Participant Research in consultation with the Human Research Department at UVic. This allowed me to collect data about students' grades in the Calculus courses before and after the changes were implemented in Cycles 1 through 3.

As a part of the redesign, tutorial worksheets were redeveloped to encourage students' active, meaningful engagement in the tutorial classroom, as well as after the tutorials. In the tutorial classrooms, I planned for the students to spend time working in small groups on worksheets related to the previous week's lectures. Their tutorial leaders were asked to facilitate small group discussion by inviting students to break into groups, asking probing questions, giving hints, occasionally answering questions (sometimes with another question), and encouraging students in the groups to explain their ideas on how to solve worksheet problems.

Each student would submit complete solutions to the distributed worksheets the following week, so active participation in the tutorials could maximize the amount of assistance with solving the worksheet questions in the classroom. The detailed solutions were uploaded by the students to CourseSpaces and were marked online,

providing students with detailed feedback on the selected subset of the problems.

The goals of redesigning the tutorials' structure were:

1. to move away from the passive classroom where the students are observers, to a more active one, where the students are engaged in peer teaching,
2. to offer enough atypical (not like the textbook) questions in each of the tutorial worksheets to promote discussion and collaboration in the tutorials and stimulate creation by students of study groups for the work outside of the classroom,
3. to engage students with practicing writing out the detailed solutions, as the other homework assignments and quizzes were marked by the computer, and as such, did not require practice writing out detailed justifications in support of the solutions,
4. to use technology (CourseSpaces) for submission and grading of the tutorial worksheets, in so guaranteeing that each student will have access to the marker's feedback of their detailed solutions promptly. Without online grading, many students fail to pick up their graded tutorial worksheet solutions and therefore do not receive feedback about their solved questions.

Individualized feedback was provided to the students in the Math 100 course after the first and second midterm examinations in hopes of increasing students' engagement in the course, and possibly improving the following midterms and the total course grade results. The creation of two low-stress not-for-grades practice tests on the topics of Derivatives and Limits initially were made available to the students before midterm 3 and upon the students' request re-opened for practice before the final examination.

### 4.3.1 Participants and action plan in Cycle 2

In Fall 2018, 557 students registered and completed the term in Math 100, which was offered in three lecture sections. At the same time, in the third year when Math 109 was offered, 513 students registered and completed the term also in three lecture sections of the course.

Two of the three sections in Math 100 were taught by a faculty member, who was also a course coordinator. The third section was taught by a sessional instructor. Both instructors in Math 109 were sessionals. The course coordinator in Math 109 was a faculty member, who did not teach any sections of the course. The two courses had separate course coordinators. The Math 100 and 109 courses were completely independent of each other: had a different weight distribution for the assignments and assessments, different exam dates and examination tests, different homework, and different tutorial assignments. Instructors closely worked together to ensure that the tests' difficulty was comparable across the two courses.

Instructors in Math 100 created a short not-for-grades quiz and posted it on the course page allowing students to self-assess their existing knowledge of Calculus before committing to taking the course. The quiz consisted of basic calculation questions on the topics of limits and derivatives. Questions were simple and did not require a pen or paper. Providing correct answers on the bottom of the same page allowed students to immediately confirm if their answers were correct. A short explanation that followed the answers to the quiz guided the students on how to interpret their results on the quiz: all students registered in Math 100 should immediately know the correct answers to those basic questions; all students who do not know the answers to any of those questions at this time should be registering in Math 109.

Instructors planned to create engaging tutorial worksheets to be posted on the course page at least one day before each tutorial together with a detailed grading

rubric. Instructors planned to meet weekly with the tutorial leaders to discuss the focus of the upcoming weekly tutorial and discuss typical difficulties, errors, and misconceptions that are to be anticipated during the upcoming tutorial. Online assignment boxes were activated on the day of the tutorial for the students to upload images of their detailed solutions to the weekly worksheets. I worked with the Learning and Teaching Center at UVic to organize training for the markers of the online assignments of the digitally submitted solutions using a preprogrammed rubric.

Instructors intended to develop a student-specific feedback mechanism as a debriefing after each of the three midterms. After midterm 1, the feedback was based on the overall grade achieved by the student on the given midterm, as well as on the grade achieved on each learning outcome tested. Recommendations included a list of the specific practice questions aimed at improving the specific learning outcome, as well as general recommendations on learning strategies and self-assessment techniques. (Sample letters can be found in Appendix A.) After midterm 2, the feedback was in the form of an online practice set of questions called Gateway tests focused on antiderivatives and integration techniques. The Gateway tests were not used for the final course grades calculation and are designed to assist students with improving their foundational calculation skills in the last portion of the course material. Each student can attempt the gateway tests as many times as desired, with the questions graded immediately, incorrect answers identified, and correct answers given for comparison. On each attempt at the Gateway test, a new set of questions was generated, and the order of questions was randomized. It is unlikely for any student to get an identical set of questions to the set they already worked on.

### 4.3.2 Literature review supporting Cycle 2

Ambrose et al. (2010) discuss the importance of feedback focused on specific goals and in providing sufficient targeted practice opportunities. Providing students with sufficient practice opportunities to allow for mastery of the material in combination with timely and detail-oriented feedback leads to improved performance during the assessment. Researchers underline the importance that practice questions provide “an appropriate level of challenge relative to students’ current performance” (p. 127). The practice-feedback-practice cycle is similar to the test-teach-test cycle that lies at the core of the Adaptive Dynamic Assessment (Ting & Kuo, 2016). Engaging in the cycle where guided mindful practice alternates with timely feedback provided through an assessment requires time commitments from the students as well as the instructors.

Another type of feedback that can be effectively used by students to guide their learning process comes via a rubric (description of the graded criteria) because the rubric distributed together with the assignment communicates instructors’ expectations in advance of students beginning their work on an assignment. Ericsson, Krampe, and Tesch-Rmer (1993) observed significant performance improvements when students were 1) provided practice with well-defined objectives, 2) determined to improve, 3) guided by the instructors with feedback, and 4) given sufficient opportunities for improvements through practice. Andrade (2001) described the effect of distributing a rubric together with the assignment, which improves the quality of work produced by the students. This author states that the description could have been used to guide the learning process. Students find assignments that promote deliberate practice challenging yet perceive them as reasonable and therefore can complete them. A detailed rubric accompanying an assignment communicates the instructor’s expectations.

Sofroniou and Poutos (2016) highlight the positive effects of the collaborative work

conducted by students in Calculus classes. Some of the positive changes observed within the experimental group included a deeper understanding of the course material, improved performance on the assessments, reduced stress when tackling mathematical problems in class, and a reported increased self-esteem. Among the reported negative effects of the group work was the slow tempo of the work completed in class and the work being perceived by the students as non-productive when only one of the members of the group was doing the work assigned. Despite the negative aspects mentioned above, collaborative learning is often identified as an excellent learning method due to extensive positive outcomes (Koak, Bozan, & Ik, 2009; Pewewardy, 2002; Tarmizi & Bayat, 2012).

## **4.4 Cycle 2 Data Analysis: Hypothesis Testing**

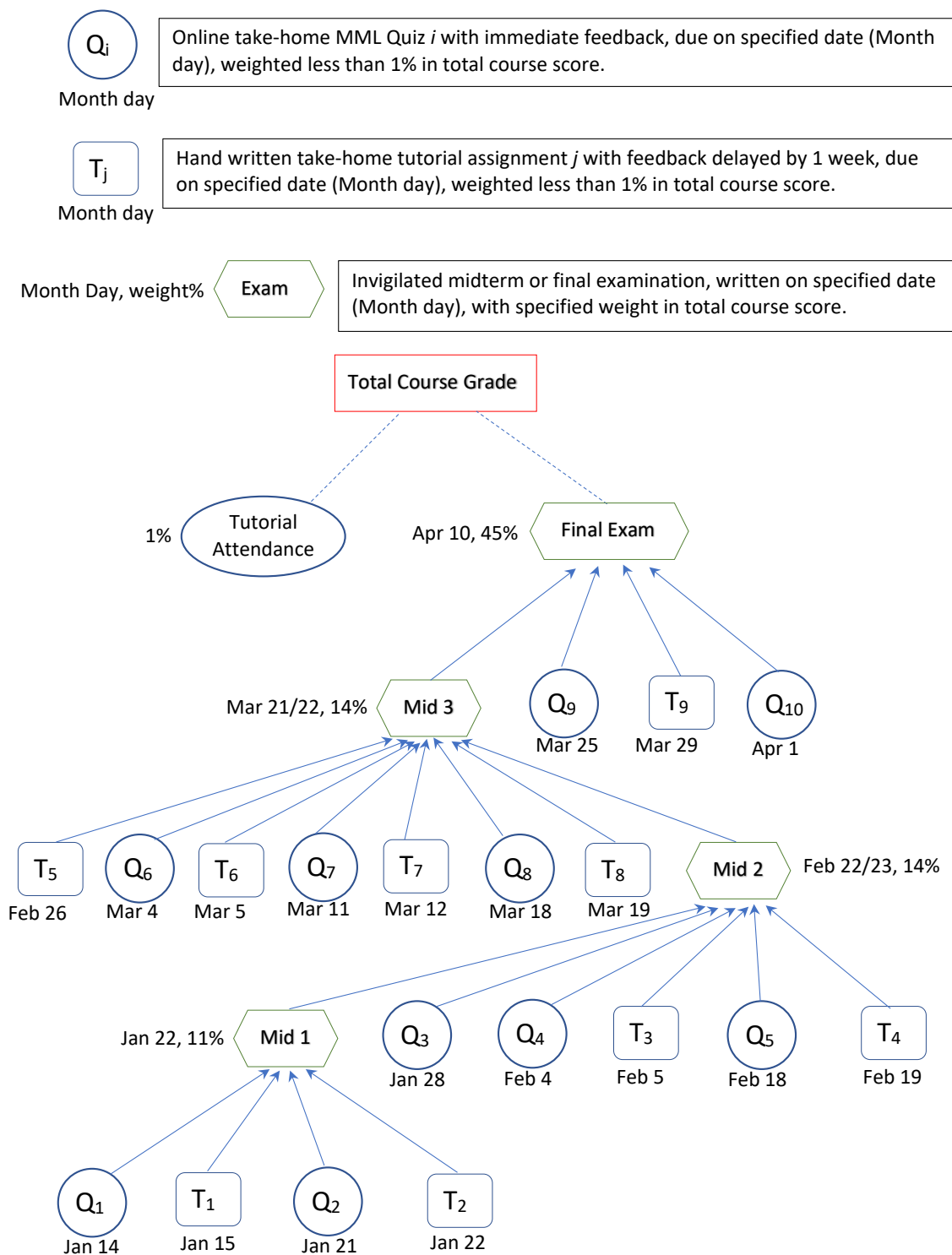
In this section, I provide a detailed description of the types of engagements and the date of the assignments and assessments students were expected to complete in the Math 101 course in the 2018 Spring term. Figure 4.2 illustrates the structure of the Math 101 course in the 2018 Spring term.

### **4.4.1 Quizzes and Homework**

There are approximately 10 quizzes in each course (one per week), contributing a total of 8% to the total course score. The lowest quiz grade is dropped before the overall grade calculation. The remaining grades on the nine quizzes are equally weighted. Each quiz is not proctored and has a time limit of 30 minutes. To gain access to each of the quizzes, the student needs to complete the corresponding homework assignment with a grade of 75% or higher. Each homework assignment is available to the students at least one week before the deadline and contains between 20 and 30

Figure 4.2

*Calculus II Course Structure, Spring 2018*



questions. Each corresponding quiz consists of similar questions to the homework assignment questions and contains between three and five questions.

#### **4.4.2 Tutorials**

There are approximately nine tutorials in each course (one per week), contributing up to 8% to the total course score. The students were given their weekly tutorial worksheet assignments in the tutorials and were encouraged to start working on the worksheets in groups, while tutorial leaders guided the discussions. The lowest grade on the tutorial worksheets was dropped before the overall grade calculation. The remaining grades on the eight tutorials were equally weighted. The tutorial worksheets were due a week from when they were assigned. Each worksheet contained between four and five questions, often with multiple parts. Students were encouraged to discuss their solutions with their peers but were told that they should only submit their own solutions. Any duplication of another student's solution was viewed as cheating and was immediately brought to the attention of the Department Chair.

#### **4.4.3 Midterms**

There are three midterms in each course (one per month), contributing approximately 13% each to the total course score. In the Fall 2017 Calculus I class, the midterms were scheduled outside of the class time and were 120 minutes long. The midterms consisted of two types of questions: multiple choice (correct/incorrect marking done by computer) and long answer (partial marks, with the marking done by people). In the Spring 2018 Calculus II class, the midterms were scheduled inside of the regular lecture time and were 50 minutes long. Each exam consisted of only multiple-choice questions (correct/incorrect marking done by computer). In both terms, the midterms were proctored and had multiple versions of the examination

papers, so any two neighbouring students had a different set of examination questions. Students who wrote the midterms at different times were writing different versions of the exams.

#### **4.4.4 Tutorials in Course Experience Surveys (CESs)**

In the current section, I analyze students' reflections on the tutorials offered in the Calculus I and II courses at the University of Victoria. In particular, I looked for information about students' likes and dislikes in the tutorials as a class (structure and Tutorial Leader) and tutorial worksheets (sets of questions that Tutorial Leaders use to guide each tutorial and which questions were given as a take-home tutorial assignment).

##### **CES on Tutorials in Calculus I (Math 100)**

##### **Hypothesis 1 in Cycle 2:**

Students in Math 100 are more likely to “like” than “dislike” engaging with the tutorials.

This hypothesis is tested using anonymized feedback provided by students through the Course Experience Surveys (CES) in the last two weeks of the Math 100 course, sections A01 and A02 in the Fall of 2018 term. The anonymized feedback was accessible only from the sections that were taught by the researcher themselves.

During the Calculus I Fall 2018 course, as a course coordinator, I provided individualized feedback to the students at three points in time immediately after the grades for each midterm were posted on CourseSpaces (protected course webpage). Using the CES, I intended to determine if the students found individualized feedback useful. I also analyzed students' comments on the other elements of the course, such as the

MyMath Lab (MML) database of questions, textbook, handbook, tutorial worksheets and the way the tutorials were run.

**Figure 4.3**

*Math 100 A01 & A02 Proportions of Likes to Dislikes in CES comments*

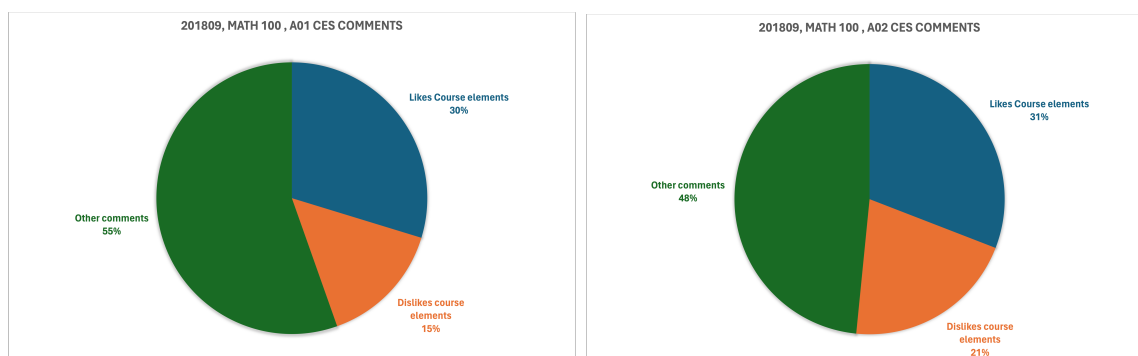


Figure 4.3 shows that in the A01 and A02 sections proportions of comments related to the course structure are similar (approximately half). Positive comments (“likes”) about the course structure outweigh the negative comments (“dislikes”) at the rate of approximately 2:1 in section A01 and 3:2 in section A02.

Figure 4.4 shows that in two sections of the Fall 2018 Math 100 course where CES were available for analysis, most comments are related to topics other than the course elements. The other comments included midterms (difficulty, length, marking), lecturer, material difficulty and precalculus material. Course elements that we separated for the analysis included tutorials, old midterms posted on the course page for practice, tutorial worksheets assigned for grades, textbook, MML database and handbook with additional questions. Figure 4.4 also shows the proportions of the liked and disliked elements of the course structure in the A01 and A02 sections. The comments indicated that the most popular “liked” course element was MML, while the most common “disliked” course element was Tutorials. Individualized feedback

Figure 4.4

Math 100 A01 & A02 CES comments

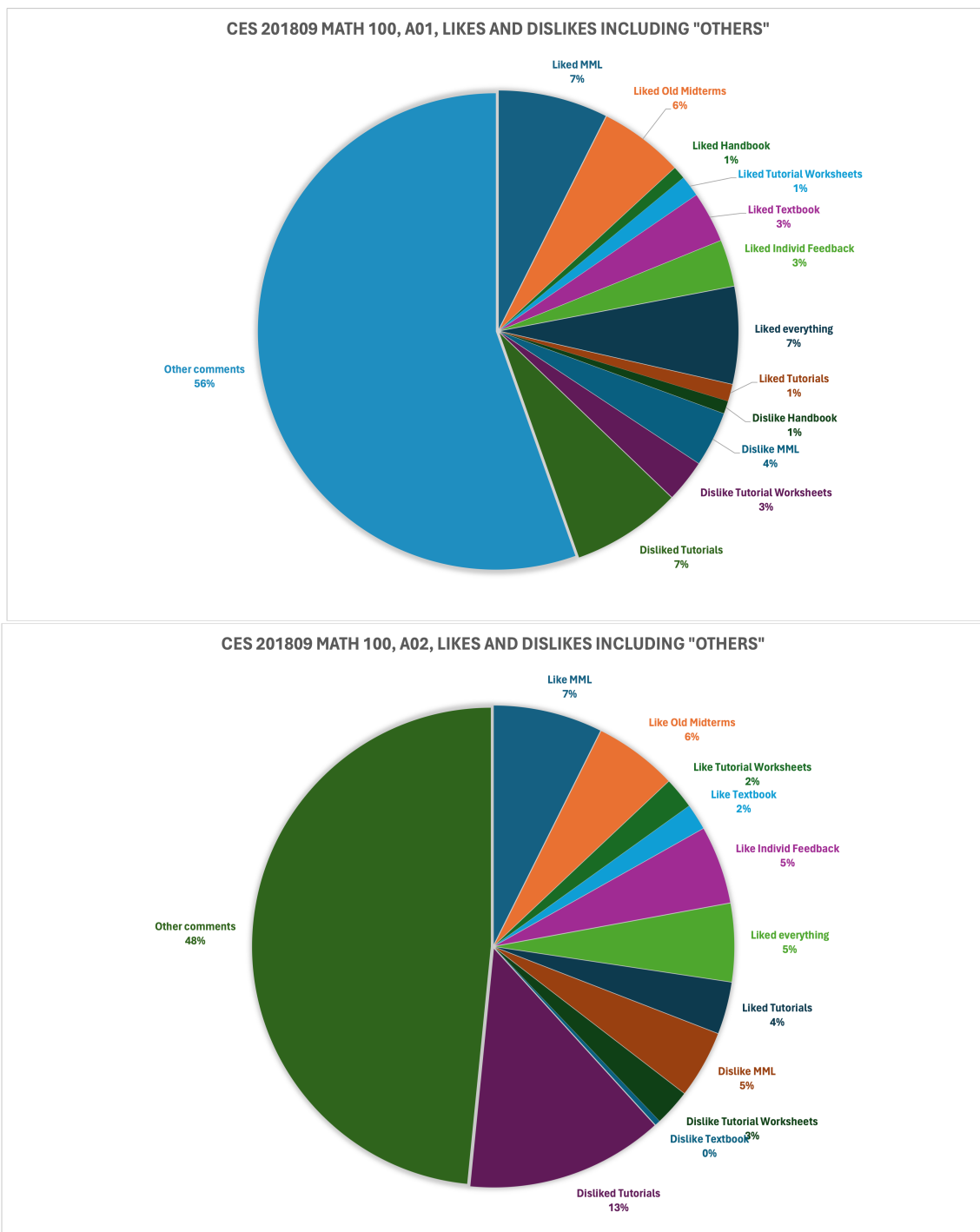
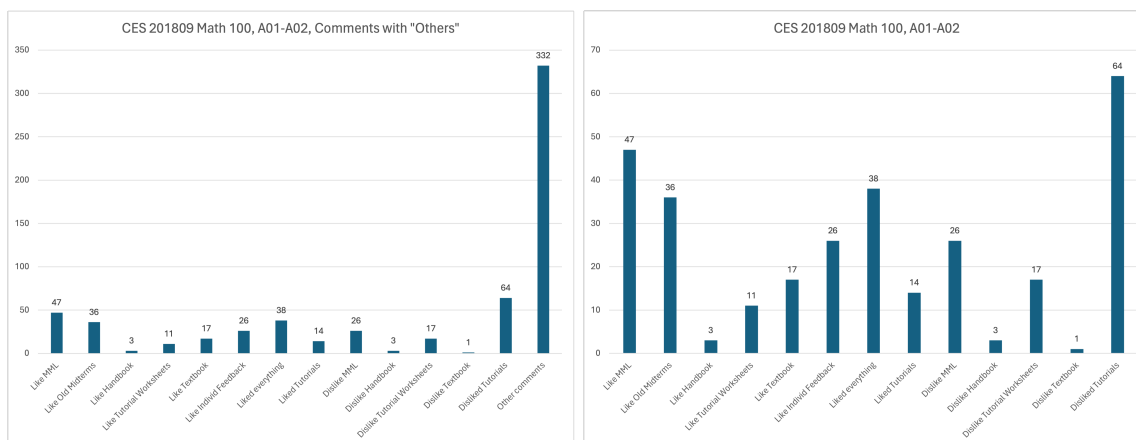
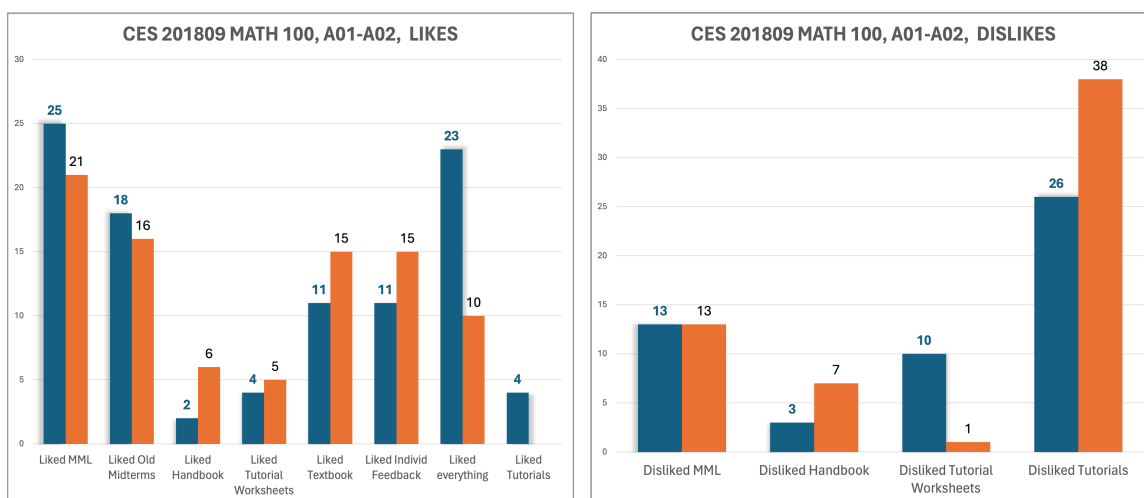


Figure 4.5

*Math 100 A01-A02 Combined Likes to Dislikes in CES comments*

(a) *Likes, Dislikes and Other responses*(b) *Likes and Dislikes only*(c) *Likes as presented in A01 vs A02*(d) *Dislikes as presented in A01 vs A02*

was mentioned among other liked elements of the course, however, it was not the most commented on as being a useful element of the course. It is clear from the comments that tutorials and tutorial worksheets are still disliked more than liked. Comments indicated that there are different reasons why students disliked the tutorials and the tutorial worksheets: weekly assignments and tutorial worksheets used two independent systems, and students wanted tutorials to be integrated with MML; having two

due dates in a week (one for weekly assignments and one for the tutorial worksheets) added stress and appeared as an unnecessary increased workload; students wanted to have tutorials more closely connected to the current week's lectures; students disliked group work in the tutorials; they wanted more interactive tutorials; and the students wanted "better TAs" in general and complained about having difficulty understanding the TA's explanations. Figure 4.2 illustrates the typical course structure in Cycle 2, showing that indeed, the students had multiple due dates within a typical week.

Figure 4.5 allows us to see the scale of the positive and negative responses within the A01 and A02 sections. It also allows us to conclude that while students overall appear satisfied with the course elements, improving the structure of the tutorials and the tutorial worksheets or improving students' understanding of the reason why the tutorials and worksheets are offered in a specific way, could improve the students' satisfaction with this element of the course.

### **CES on Tutorials in Calculus II (Math 101)**

Typically, an instructor only has access to the CES comments from the students registered in the section that they are teaching. Therefore, each instructor has limited information related to the students' likes or dislikes about a particular course. On the Departmental level, the office of the Chair is in a better position to have a complete overview and observe any changes in the students' comments over time. The Collective Agreement between the Faculty Association and UVic describes the extent to which the Department Chair has access to the CES. As of July 2022, student comments are no longer available to the Chair of the Department, unless Faculty Members choose to include them in the biannual Faculty Member evaluation of their teaching performance. However, comments left in sections taught by sessional instructors are available to the Chair of the Department.

At the beginning of this research, the University of Victoria moved from an in-class paper-based CES to an online CES system. This move correlated with a swift decrease in student participation in CESs for the Calculus courses that I teach. While participation was near and sometimes above 100% for the paper-based CES, the participation dropped below 30% in the online CESs in my courses. Starting from 2018, I have used the following approaches to increase student participation in the CESs:

- ask students to complete CES at the beginning of the first lecture after the University of Victoria gives students access to the surveys;
- explain to students why completing CES will be done now in class and not left to be completed later outside of class (referring to the low level of participation in the 2016-2017 school year CES);
- explain to students why CESs are important to the Department, to the course instructor and to students who will take this course in the following terms;
- explain to students the course elements before this term and what changes were made for this term based on CES feedback;
- ask students to specifically comment on which course elements they found to be most useful in preparation for the midterm examinations;
- give students sufficient time to complete the CES and leave the classroom, telling the students that you will return in 10-12 minutes to allow them space and time to complete the CES without pressure;
- after returning to the classroom, ask students if they are still working on the CSE, and start the lecture when less than 5% of the students are still engaged with the CESS.

In the Math 101 courses, the use of the approach I describe above for conducting CESs in class resulted in an increase in participation during Cycle II from 29.2% to 78.0% and allowed me to identify students' impressions of the tutorials and changes implemented within the tutorials.

**Table 4.2**

*Frequency of tutorial-related comments in Math 101*

Term; Sections	# of respondents (% of expected)	TTs, likes	WSheets, likes	TTs, dislikes	WSheets, dislikes
201601; A02, A04	120 (29.2%)	0.8%	0.0%	0.8%	5.0%
201709; A01, A02	88 (37.1%)	3.4%	1.1%	4.5%	6.8%
201801; A04, A05	255 (71.6%)	2.4%	6.7%	5.5%	20.4%
201901; A03, A04	277 (78.0%)	19.9%	5.4%	21.3%	15.9%

*Notes.* “# of respondents (% of expected)” = number of respondents (percent of the expected participants); “TTs” = Tutorials; “WSheets” = Tutorial Worksheets

The most common message related to the tutorials for each Math 101 CES survey from Table 4.2 could be summarized as follows:

- 2016 Spring term (201601) and 2017 Fall term (201709) students perceived tutorial worksheets as irrelevant to midterm questions.
- 2018 Spring term (201801) students particularly disliked that tutorial worksheets had only 2 questions graded out of a set that contains between 8 and 10 questions.
- 2019 Spring term (201901) students disliked worksheets mostly because of the amount of work required to solve the set of worksheet problems. The majority of the students liked the form of the tutorial where TAs first gave a mini-lecture and then solved some of the examples from the worksheet on the board, and then left the rest of the questions for the students to work through on their own. A small portion of the students preferred to not have a mini-lecture before

working on the tutorial worksheet and would prefer to immediately focus on the worksheets. A common dislike of the tutorials included having TAs introduce new material in the tutorials. Students expressed a strong preference for having a lecturer to introduce material, and for tutorials to focus on practicing only.

While the percentage of comments for the Fall 2018 Math 100 class term is not the same as in the Spring 2019 Math 101 class the numbers indicate that tutorials in Math 101 as well as the tutorial worksheets were still mostly disliked rather than liked by the students.

#### **4.4.5 Students' Action After Individualized Feedback.**

After students received individualized feedback following the midterms 1 and 2 in the Fall of 2018 Math 100 course, it was impossible to determine if students had taken any action upon receiving the feedback, as the feedback consisted of a student-specific list of textbook questions, which was created based on the errors they made on the recent midterm, as well as study tips for preparation for the following test.

I decided to change the type of feedback to trackable, so after midterm 3, the feedback included not-for-grades Practice Gateway Tests (PGWTs) offered on MML. Those PGWTs were designed to be used in preparation for the Final examination. PGWTs could be tracked using reports created on MML. The PGWTs were designed as two sets of questions selected from the pool of textbook questions that students could take at any time and as many times as desired. The questions were randomly selected from a large pool, with numbers within each question parameterized. To any student, each PGWT appeared to consist of different questions for each attempt on the quiz. The results of PGWTs were not included in the total course grades calculation, as those practice tests were only recommended.

### Hypothesis 2 in Cycle 2:

Most students in Math 100 would follow the recommendation of the instructor and engage with the practice material provided after each midterm.

**Table 4.3**

*Engagement with PGWTs in Math 100 term 201809*

Number of attempts	more than 10 times	3 to 10 times	1 or 2 times	0 times
Median Course grade	69	75.5	72	71
Number of students	7	50	134	368
Percent of students	1.3%	8.9%	24.0%	65.8%

After the completion of the Fall 2018 Math 100 class, I analyzed the data and observed that only one out of three students followed the recommendation of the instructor and accessed PGWTs in preparation for the final examination (see Table 4.3).

Unfortunately, the data failed to support Hypothesis 2 in Cycle 2, as most of the students in the course (65.8%) did not engage with the recommended practice activity suggested by the instructor.

### Hypothesis 3 in Cycle 2:

Stronger students are more likely to follow the instructor's recommendations than the weaker students in the Math 100 course.

To determine if hypothesis 3 is supported by my data, Fall of 2018 Math 100 students were separated into the following categories based on their total course grade:

between 80% and 100% - category "A",

between 70% and 79% - category "B",

between 60% and 69% - category "C",

between 50% and 59% - category "D",

between 0% and 49% - category “F” or “N”.

To calculate the average number of attempts per person in each category, the total number of attempts by all students in the category is divided by the total number of students in the category, see Table 4.4.

**Table 4.4**

*Engagement with PGWTs based on students’ total course grade*

Course grade category	“A”	“B”	“C”	“D”	“F” or “N”
Number of attempts	188	139	89	69	57
Number of students	174	138	111	59	77
Aver number of attempts	1.08	1.01	0.80	1.17	0.74

As Table 4.4 shows, the average number in each category is approximately 1 per person. Students in category “D on average had as many attempts on the PGWTs as students in category “A. Therefore, the data does not support hypothesis 3 in Cycle 2 that the stronger students are more likely to follow the instructor’s recommendations.

## 4.5 Reflections at the End of Cycle 2

With Ethics approval for the “Effects of Students’ Engagement in First-year Calculus Courses on Students’ Success” research, the detailed course grades for the Fall of 2018 Math 100 were reviewed and compared to the Fall 2016 Math 100 and Fall 2017 Math 100 grades. To determine the grade distribution in all calculus courses at UVic, I collected and analyzed detailed grades for all students in the first-year Calculus courses for terms starting Fall 2016 up to and including the Fall 2018 term. At the end of this three-year cycle, I observed that the students were actively switching between three Calculus I courses (Math 100, 109, and 102) in the first couple of weeks of the term. The biggest difference with the previous cycle is that not as many students as before chose to remain in the “wrong” Math 100 course and trying to

succeed, choose instead to switch either to Math 109 or Math 102 (the courses that were designed for the students without some prior experience in Calculus). This is clear progress. Students in Cycle 1 who tried to work through Math 100 without having previous experience with calculus clearly struggled with the course, and most often either dropped out of the course by the end of the second month of the term or failed the Math 100 course.

Students' responses to the individualized feedback through the emails after midterms 1 and 2 have been very positive, with the students replying to the feedback and expressing their gratitude for the provided resources and tips. Letters sent to the students following the completion of the grading of the midterms contained student-specific comments and recommendations based on the student's performance on each question in the examination. For every question where the student did not achieve a perfect score, information was provided identifying a textbook question that is identical or similar to the examination question. Specific suggestions on the preparation for the upcoming examination were provided, including a description of a self-assessment technique.

Students who chose to engage with the online practice Gateway tests commented on the practice test being very useful. The Gateway test covered the antiderivatives and integration portion of the course, which is the material most of the students were not familiar with before taking the course. The Gateway test was made available before midterm 3 and the final examinations as a not-for-grades practice item. Only a small portion of the students chose to engage with a non-graded Gateway test. Providing students with meaningful individualized feedback proved to be a time-consuming process for the instructor. The most time-consuming processes were: 1) preparing lists of suggested practice questions for each incorrectly answered question, 2) preparing explanations about the difference between the technical and conceptual

errors, and 3) programming the Excel file for automated emailing of feedback to each of the students. There was an unanticipated benefit from the format of the provided feedback: instructors did not hear from the students that the midterm questions were unfair. One of the typical reactions I observe after the midterm grades are released to the students is students commenting that some of the questions on the exam were unfair because there were no similar questions covered in class or the textbook. Goodboy (2011) identified “unfair testing” as the most common reason for students’ unhappiness in the classroom. With the individualized feedback providing a list of the similar (if not identical) questions in the textbook, lecture notes and tutorial worksheets for each question incorrectly solved on the midterm, the students were able to see that each question was indeed available for their examination preparation. Being able to see where questions came from allowed students to reflect on their actions as an alternative to shifting blame on the instructor. Instead of “We never were shown how to do a question like that” the comments were “I missed that one”, “I hoped that you would not ask that question”, “I did not know how to do that question”, and “I should have been better prepared”.

At the end of each term, when the course grades are assigned by the course instructor and approved by the Chair of the Department, the CES are reviewed by the Chair of the Department and made available for the instructors. Students’ responses to the CES for Fall 2018 Math 100 were analyzed for comments on implemented changes in the course in that term, and any request or suggestions for the future terms. While some students were happy with the tutorial format and content, some students still were not happy with the tutorial structure during the classroom, commenting on the work in groups as a waste of time, and asking for the TA to just tell us how to do those questions. All questions given in the worksheet were expected to be completed, only a subset of the worksheet questions was graded. Detailed solutions for all questions

were posted on the course page after the tutorial worksheet due date. Some students expressed their desire that all questions on the tutorial worksheets be graded, not a selected subset of questions. From the student comments after the lectures and in the course experience survey, it became clear that many students either did not notice the rubric given for each tutorial worksheet or did not pay them any attention. At the beginning of the term, the students were told in class that they would be able to see the feedback left by the marker on each graded question. At the end of the term, in preparation for the final examination, the instructor recommended students review the comments left by the markers in the graded papers. Many students appeared to be surprised to hear that they could read the comments left by the marker on their graded tutorial worksheet solution pages. Such a discrepancy could be an indication of the students' lack of familiarity with the online system for uploading and grading the handwritten solutions.

Feedback from the CES about the lectures can be divided into three categories: the first group was happy with the format of the lectures as is, the second group wanted to have more theory presented in class before going into the examples, and group three wanted to have less theory presented in class and have more examples presented in lectures.

Based on MyMath Lab data, the majority of the students chose to complete the questions assigned for grades but did not engage in the recommended activities that are not for grades (such as Gateway tests). It appeared that the students who have engaged with the not-for-grades practice tests sufficiently by repeatedly solving the practice tests have achieved higher than average class scores.

In the CES students commented on feeling grateful about the individualized feedback received after the midterms, mentioning the general study tips as well as the specific individual information.

The total number of students registered in the Fall 2016 Math 100 and 109 was 1056, and in the Fall 2018 was a very comparable 1070 students. After registration was settled in the first couple of weeks of the term, the Fall of 2016 Math 100 was chosen by 62.5% of the students, while the remaining 37.5% chose Math 109. The Fall 2018 Math 100 was chosen by 52% of the students, with the remaining 48% choosing Math 109. It appears that the students are now more comfortable registering in the new Math 109 course, and are now almost equally distributed between Math 100 and 109.

## 4.6 Problems to be Addressed in Cycle 3

Students as a group could be better prepared for their Calculus examinations. As an instructor, I need to find a way to increase students' engagement with the practicing of basic Calculus skills (i.e., limit calculation, differentiation, and integration) in preparation for the midterm and final examinations.

The amount of time needed to provide individualized feedback to the large body of students makes the currently employed mechanism unsustainable for big first-year courses. My goal is to develop a sustainable mechanism for providing feedback to the students after the examination that is less strenuous for the instructor while ensuring that the feedback is still useful to the students.

Students, in general, chose not to engage with the work that was recommended but was not directly affecting a total course grade calculation, as it was not for grades. Since having basic calculation skills is very important in Calculus, I need to find an alternative to the recommended activities (such as a not-for-grades Gateway Test) that would stimulate student engagement in the regular practice of limits, derivatives, and integrals calculation.

Students, in general, appear not to review lecture notes or read the textbook before coming to class. A reference to an example solved in the last class appears to the students useless, as the students do not remember the earlier solved examples. It could be useful to develop a method of increasing student engagement with the course material before, during, and after their lectures.

Students, who commented on the tutorial format, in general, find the format of the tutorials unsatisfactory. A restructure of tutorial classroom activities and tutorial worksheets to provide students with better engagement with the material might be worthwhile exploring. Considering what aspects of the tutorials need adjustment (TA training, tutorials format, grade assignment format) and implementing desired changes.

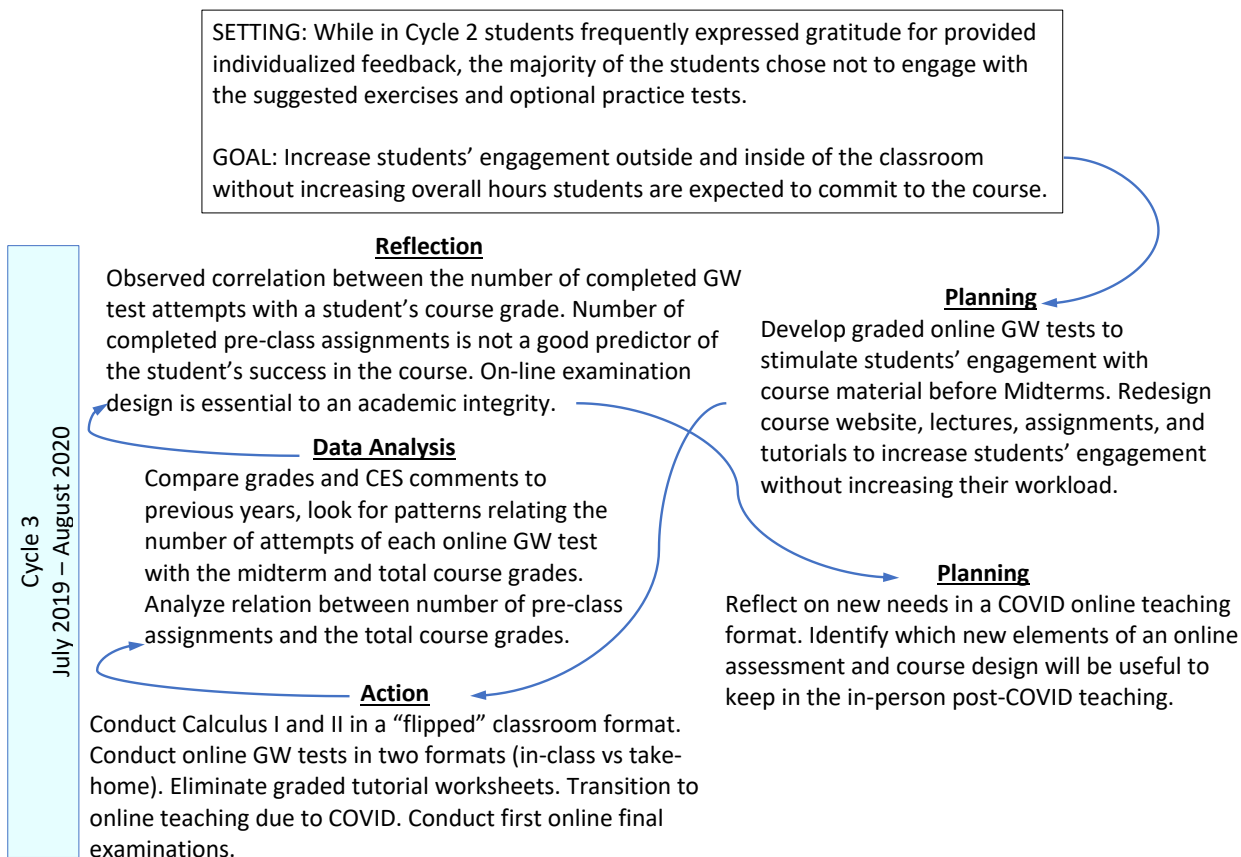
# Chapter 5

## Cycle 3 detailed information

In this Chapter, I introduce the last cycle (third out of the three cycles) of the research. In Cycle 3, which ran from July 2019 to August 2020, I attempted to increase students' engagement with the Math 109 (Calculus I) and Math 101 (Calculus II) courses by further modifying the design. I adopted a flipped classroom approach, incorporated graded online gateway tests before each midterm and final examination, introduced a special tutorial section designed specifically for the students who failed the Math 101 course in a previous term and continued to focus on improving the training for the tutorial leaders to improve students' experience with the tutorials and the tutorial worksheets. Figure 5.1 illustrates the four stages of Cycle 3: planning, action, data analysis, and reflection, and will be further detailed in this chapter.

### **5.1 Cycle 3, Courses Structure.**

The main difference between course structures in Cycle 2 and Cycle 3 was the pre-class assignments associated with a flipped classroom lecture style that was introduced in Cycle 3. The Math 101 (Calculus II) course had a similar structure and weighting to the Math 109 (Calculus I) course, which was intended to give the students a



**Figure 5.1**

*Research Cycle 3 - Planning, Action, Data Analysis, Reflection*

feeling of familiarity with the course structure and expectations concerning due dates.

## 5.2 Background information: coming into Cycle 3

The Fall of 2019 was the last term in Cycle 3 where courses were offered completely in a face-to-face format. On March 16, 2020, the University of Victoria made a transition to online learning due to the COVID-19 pandemic.

This cycle included Math 109 (Calculus I, designed for students without previous calculus experience) in the 2019 Fall term and Math 101 (Calculus II) in the 2019

**Table 5.1***Cycle 3 Courses structures*

Course	101	109*	101
Date (yymm)	19_09	19_09	20_01
Stud (#)	244	415	657
Instr (#)	1	3	2
WkA (#, %)	9, 0**	9, 0**	9, 0**
CRT (#, %)			
Quiz (#, %)	9-2,7	10-2,7	9-2,7
Midts (#, %)	2, 33	2, 30	2, 33
TutA (#, %)			
FlipA (#, %)	24-4, 5	34-6, 5	24-4, 5
GWT (#, %)	2, 6	2, 12	2, 6
Attends (%)	1	1	1
FExam (%)	48	45	48

*Notes.* All three courses are colored light cyan to indicate that this is Cycle 3.

All listed courses have name “MATH” followed by Course number.

This table is an extraction from Table 2.1 “Courses Structures Within Three Research Cycles” located on the page 53, with the following two pages (p.53-54) containing the description of each item in the current table.

Fall and 2020 Spring terms.

Table 5.1 is an extraction from table 2.1. It contains a description of all courses that were included for this research in Cycle 3. As detailed in Table 5.1, in Cycle 3 there were only three courses included:

Math 109 2019 Fall – 427 students, 3 instructors and 6 tutorial leaders;

Math 101 2019 Fall – 244 students, 1 instructor and 3 tutorial leaders;

Math 101 2020 Fall – 657 students, 2 instructors and 11 tutorial leaders.

While Math 100 continued to be offered at UVic every term of the year in Cycle 3, I was not teaching it during that period and did not include any data collected in Math 100 in Cycle 3 in my research.

Traditionally, Calculus courses are offered at the University of Victoria in a “face-to-face” format. The students come to the in-person lectures, get introduced to new topics in class, and work on mastering the course material in tutorials and at home (through the weekly assignments and assessments). Some material, such as the course outline, samples of old midterms and final examinations, and printouts given in class are posted online on the course Learning Management System (known as CourseSpaces). Some courses also offer discussion forums to facilitate engagement with the exercises. Overall, engagement with the online material posted in CourseSpaces was not required to complete a first-year Calculus course at UVic.

In a typical 2019 and 2020 term, the weekly assignments were based on the questions from the data set developed by the publisher company of the course textbook. MyMath Lab (aka MLM or MML) is an online learning system created by Pearson. Questions in their database correspond to questions published in the course textbook, with a variety of different types (static questions with fixed values of the parameters, algorithmically generated values that regenerate for every new attempt of a student on that question). While many students come to UVic knowing how to answer multiple-choice questions or how to enter a numerical answer to an online question, many first-year students are not familiar with entering functions or expressions when an answer requires symbolic mathematical expression.

None of the instructors teaching the course had ever created or been a part of a “flipped” classroom. Additionally, the majority of students coming into the first-year

Calculus course at UVic had not experienced a “flipped” classroom approach before. Through informal in-class conversation, it became clear that the students were not sure that the new format of the courses would be beneficial to their learning. The existing online course page was not designed to support a “flipped” classroom model, as it only contained the course outline, learning outcomes for each section of the textbook, samples of old examination papers, and discussion forums..

### **5.3 Cycle 3 Planning: Instructional Intent**

In Cycle 3 our (i.e., the course instructors) goal was to convince students that the new format of the course called a flipped classroom is beneficial to their learning and will improve their experience with Calculus. We intended to clearly identify the differences between the “traditional” format of the course (where the students learn about the new material for the first time in class from the lecturer, and then attempt to solve assignment questions using new information) from a “flipped” course (where the students need to do some work before the lecture such as reading or watching a video and solving some questions, and will continue exploration of the material together with a class instructor, and then work some more on solving questions in the assignment).

We needed to develop course material to support a flipped classroom course structure and expand the course site in CourseSpaces to include a video library as an alternative to the pre-class review, and calculus introductory material given in the textbook. Our goal was to make engaging with the review and new material as easy as watching a 10-minute video. We also developed pre-class assignments consisting of one to two basic questions related to each of the course topics. The pre-class assignment was intended to be solved after reading assigned pages from the textbook

or after watching the corresponding videos, but before the topic was discussed by an instructor in class.

We wanted to increase engagement by the Teaching Assistants (TAs) in creating tutorial worksheets. The goal was to improve TAs' understanding of how to determine which questions should be included in the worksheets. We hoped that increasing the tutorial leaders' ownership of the course could result in a deeper commitment to the course and produce further professional development of the tutorial teaching team.

We needed to be careful to avoid creating a course structure with a heavy workload that resulted from adding the pre-class reading assignment and pre-class questions needed to support a "flipped" classroom format. To mediate the increase in the workload due to the required pre-class coursework, we removed the graded tutorial component. The purpose of the graded tutorial component was to encourage students' active participation in tutorials. We needed to find an alternative way to encourage students to actively participate in problem-solving during the tutorials without requiring the students to submit some of the questions from the tutorial worksheets for marks.

To directly support the students who were repeating the course, I created and taught a special section of the tutorials that was offered only to the students who had taken Math 101 in 2019 Fall and were retaking the course to improve their grades. Often students fail the Math 101 course because they did not master a sorting technique: with over a dozen possible integration techniques learned throughout the course, they do not know which integration technique is appropriate to use when questions do not specify the technique. The goal of the special tutorial was to help students further practice their sorting skills under active guidance from the instructor.

The Gateway Tests used as a recommended practice from Cycle 2 were used in Cycle 3 as a required introductory activity before each midterm and final exami-

nation to stimulate students' engagement with procedural questions and to improve memorization of the basic calculus rules and techniques. Our goal was to help students recognize the value of using the Gateway Tests that we created in Cycle 2 in a low-stress environment.

### **5.3.1 Participants and action plan in Cycle 3**

In the 2019 Fall term, two sections of the Math 109 course were taught by two faculty members, one of whom was also the course coordinator. The third section was taught by a sessional instructor. Instructors agreed to hold weekly meetings to discuss pre-class assignments, expectations from the students, and outstanding issues, and to plan for the upcoming week and future examinations. A separate weekly meeting was held with the Head Teaching Assistant (Head TA) to discuss upcoming tutorial preparation and any unresolved issues with the tutorials. After this meeting, the Head TA was to meet with the TAs to discuss their concerns and to help them in preparation for the upcoming tutorials. The course had pre-class reading assignments and short pre-class assignments consisting of one or two problems. The pre-class assignment problems were based on a mixture of the related precalculus material (if deemed necessary) and the new calculus material related to the pre-class reading assignment. A set of short YouTube videos (each between four and 10 minutes long) was posted on the course page to support every reading assignment and to help students with solving the assigned pre-class problems.

In the 2019 Fall term, the Calculus II course (Math 101) had a similar course structure as described above with Math 109. This included a flipped classroom approach and preparatory weekly meetings with the tutorial TAs. The difference between the Math 109 and 101 courses during this term was that the preparatory weekly meetings were conducted by the course instructor directly, without a Head TA. Also, since

there was only one instructor in Math 101, there were no weekly meetings for the instructors. Students were almost evenly distributed between the two lecture sections taught by the same instructor, with 250 students registered in the course at the end of the term. Within the 11 tutorial sections, the number of students registered in each tutorial varied between 24 and 31. Both courses (Math 109 and Math 101) had the following assessments: weekly online assignments paired with follow-up quizzes, pre-class assignments, and two online Gateway tests conducted one week before the corresponding midterm examination and the final examination. Tutorial worksheets did not contribute to the student's grade. However, to encourage students' engagement in the tutorials, each student was given one percent of the total course grade for attending at least 80% of the scheduled tutorials.

In the 2020 Spring term, the Calculus II course (Math 101) had the same course structure as in the 2019 Fall. Three of five sections of the Math 101 were taught by a faculty member who was also the course coordinator. The other two sections were taught by a sessional instructor. The plan was to analyze the correlation between solving pre-class assignments and the resulting performance in the midterms and final exams for students from the 2019 Fall term. Similarly, we (Math 101 instructors) analyzed the correlation between the number of attempts on the practice Gateway tests and the resulting performance in the midterms and final exams in the 2019 Fall term. We repeatedly communicated these findings to the students in the 2020 Spring term to offer evidence of the value of different elements of the course structure.

### **5.3.2 Literature review supporting Cycle 3**

In this section, I review the literature related to using a flipped classroom approach. In addition to reviewing what a flipped classroom might look like, I will focus on issues and the possible concerns related to the effect of a flipped classroom

on students' grades, to using YouTube videos as an alternative to "read-only" or "videos made by an instructor" approaches, and a perceived workload increase on the students as a result of the expectation of working on the course material on their own, without first having it discussed in class.

Starting from early 1990, the rapid development of technology allowed for an extensive integration of online exercises, assignments, and videos in post-secondary education. One of the earliest mentions of the idea of a "classroom flip" was presented by Baker (2000). The implemented "flip" constituted moving the presentation of the material by the instructor together with the quizzes and facilitated discussion outside of the classroom into an online environment, while using in-class time for clarification of questions students have, practice solving the assigned questions, working on applications under active guidance from the instructor, and inviting students to expand on the assigned material based on their personal life experience. In 2000, a flipped classroom structure was implemented by Baker in two courses (Graphic Design for Interactive Multimedia and Communications in the Information Age). Findings highlighted the positive students' reaction to the new course structure. The number of participants in classes, nor the effects of the new course structure on the student's grade were not mentioned.

Since 2000 many more instructors have implemented some form of a flipped classroom format in their courses. Analysis by Cheng, Ritzhaupt, and Antonenko (2018) of the papers published between 2013 and 2016 shows that a "flipped classroom" technique is often not described in sufficient detail to allow for replication or analysis. Additionally, a comparison to the traditional classroom technique is not always given, which contributes to questioning the effectiveness of a flipped classroom. In 55 analyzed publications, small and medium-sized classes of K-12 students and university undergraduate students showed that using a flipped classroom resulted in

slightly better course outcomes when compared to regular lecture classes. Classes with graduate students showed that flipped classrooms resulted in worse course outcomes compared to the regular classes, but the difference was determined to be not statistically significant. Among the 55 analyzed publications only 14 showed a statistically significant preference for a flipped classroom setting based on the students' outcomes. The largest positive effect of flipped classrooms was determined to be in Arts and Humanities. Areas such as Sciences, Social Sciences, and Mathematics showed a small to medium positive effect of a flipped classroom. Health and Business did not show a statistically significant difference between the traditional lecture and flipped classroom course structure. Based on five publications included in the analysis, Engineering showed negative effects of a flipped classroom, but it was not statistically significant. No large-size university undergraduate courses were included in the analysis due to a lack of publications that included details necessary for the analysis conducted by Cheng et al. (2018).

Flipped classrooms can be implemented for some topics covered in the course, instead of the entire course material. Bastiaens and Marks (2014) used a "flipped" classroom approach for some (five) topics presented in their face-to-face classroom consisting of 60 preservice teachers (39 undergraduate and 21 graduate students) in a technology integration course.

Kadry and El Hami (2014) in their research had four lecture sections (two male and two female), where one male and one female section were taught in a traditional lecture format, while the other two sections were part of a flipped classroom teaching method. While statistically there was no significant difference between the grade distributions in a traditional and flipped classroom, a flipped classroom in the female section had somewhat better results than the male section of a flipped classroom.

EL Kemma (2024) observed that the effective implementation of a flipped

classroom depends on students willingness to engage in autonomic activities (such as learning new course materials at home) and actively participating in the learning process in class. Unfortunately, many students today do not have the academic skills needed to support the active role that a flipped classroom requires. Additional hurdles when engaging with online material are created by the proximity of the internet (social media) on the students stationary and mobile devices.

In the research conducted by Sosa Daz, Guerra Antequera, and Cerezo Pizarro (2021), collaborative learning and teamwork were identified as the strengths of a flipped classroom methodology. Some students identified an interaction between the learners and the instructor as more active in a flipped classroom than in the regular lecture-based classes. However, another group of students viewed the instructor as not attentive to the students needs. The same split in opinions was identified as related to the students motivation and emotions in a flipped classroom.

Awidi and Paynter (2019) in their first cycle of the action-based research on the impact of a flipped classroom approach on the learning experience of students observed in general an overall positive effect on student confidence, motivation and engagement. This observation is in alignment with the other researchers findings (Heyborne & Perrett, 2016; Moravec, Williams, Aguilar-Roca, O'Dowd, & Wakimoto, 2010).

## **5.4 Cycle 3 Data Analysis: Hypothesis Testing**

In Cycle 3, the research about "flipped classroom" was based on three courses: Math 109 2019 Fall term, Math 101 2019 Fall, and Math 101 2020 Spring term. Compared to Cycle 2 and in all three courses, a flipped classroom approach was integrated and pre-class assignments that students completed for grades were added.

### 5.4.1 Engagement via Flipped Classroom Course Structure.

#### Hypothesis 1 in Cycle 3:

Students who actively engage in flipped classroom activities in first-year Calculus courses do better overall than the students who do not actively engage with the course activities.

**Table 5.2**

*Total Course grade calculation in Math 109 term 201909*

Components	Dates	Weights
Weekly MML HW assignments/ follow up Quizzes	Most Weeks	7%
Pre-class assignments	before most lectures	5%
MML Gateway test #1, in COMP LABS	Mon 23/09	6%
MML Gateway test #2, in COMP LABS	Mon 28/10	6%
Tutorial “exit tickets”	Most Tutorials	1%
Midterm 1	Saturday 19/10	15 %
Midterm 2	Saturday 16/11	15 %
Final Examination	TBA	45%

Table 5.2 contains the details for the total course grade calculation for Math 109. Preliminary regression analysis conducted for predicting total course grade based on Quizzes, pre-class assignments, GWTs, tutorial attendance based on exit tickets, and midterms 1 and 2 shows that changes in grades on the pre-class assignments ( $p_{value} = 0.4948 > 0.05$ ) are not likely to largely impact the total course grade changes in the prediction model. Interestingly, the tutorial contribution based on the exit tickets ( $p_{value} = 0.0091 < 0.05$ ) that only represents 1% of the total course grade formula is likely to be a meaningful predictor since changes in total course grade are related to the changes in tutorial attendance. See Tables 5.3 and 5.4 for complete information on the coefficients for the model. This regression analysis was conducted with students who completed both midterm examinations. The model was run on this student data because including incomplete data with zeros for the missed tests

was negatively affecting the quality of the resulting formula for the regression.

**Table 5.3**

*Preliminary Regression Analysis of the Course Grades, Math 109 201909*

Math 109, 201909	Coef	SE	t Stat	P-value	Lower 95%	Upper 95%
Intercept	-0.70	1.48	-0.47	0.641	-3.62	2.22
Quizzes	10.31	2.11	4.88	1.5E-06	6.16	14.46
Tutorials “exit tickets”	3.36	1.28	2.62	0.01	0.84	5.89
Midt 1	34.03	2.37	14.39	6.7E-38	29.38	38.68
Midt 2	51.79	2.72	19.04	1.5E-57	46.44	57.14
GWTs	14.91	1.68	8.88	2.5E-17	11.61	18.21
Pre-class	-1.27	1.86	-0.68	0.49	-4.92	2.38

Notes: Coef = Coefficients, SE = Standard Error, Pre-class = Pre-class assignments

**Table 5.4**

*Regression Analysis of the Course Grade, Math 109 201909*

Math 109, 201909	Coef	SE	t Stat	P-value	Lower 95%	Upper 95%
Intercept	-1.10	1.36	-0.81	0.42	-3.78	1.58
Quizzes	9.55	1.79	5.33	1.7E-07	6.02	13.07
Tutorials “exit tickets”	3.18	1.25	2.53	0.01	0.71	5.64
Midt 1	34.15	2.36	14.48	2.6E-38	29.51	38.78
Midt 2	51.62	2.71	19.07	1.07E-57	46.30	56.94
GWTs	14.95	1.68	8.92	1.9E-17	11.65	18.24

Notes: Coef = Coefficients, SE = Standard Error

The regression model for the total course grade calculation indicates that the coefficient for midterm 2 is the strongest predictor among all included assessments when correlated with the total course grade. This should not be a surprise, as midterm 2 takes place approximately three weeks before the end of the term and includes some

of the most difficult material of the Calculus I course, which is also present in the final examination. Material that the students see as difficult includes word problems for optimization and related rates topics, as well as a complete analysis of a function that includes identifying asymptotes, local extrema, concavity, and graphing of a function. Historically, in the Calculus I courses I taught, the comprehensive final examination grades have a similar median to the median on the last midterm.

**Table 5.5**

*Total Course grade calculation in Math 101 term 202001*

<b>Components</b>	<b>Dates</b>	<b>Weights</b>
Weekly MML Quizzes, online, 30-mins-long	Most Weeks	7%
MML Pre-class assignments, online	before most lectures	5%
MML Gateway test #1, online, 30-mins-long	due Mon Jan 27	3%
MML Gateway test #2, online, 30-mins-long	due Mon March 02	3%
MML Gateway test #3, online, 30-mins-long	due Mon Apr 06	3%
Tutorial “exit tickets”	first 10 weeks	1%
Tutorial Assignments	last three weeks	3%
Midterm 1, 90-mins-long	Saturday 08/02	20 %
Midterm 2, 90-mins-long	Saturday 21/03	15 %
Final Exam, part 1, 60-mins-long, Short Answer	April 17	20%
Final Exam, part 2, 90-mins-long, Long Answers	April 17	20%

The detailed formula used to assign the total course grade in Math 101 in the 2020 Spring term is provided in Table 5.5. Table 5.6 shows a preliminary regression analysis of the Math 101 assigned total course grades in the 2020 Spring term. The table shows that pre-class assignments related to a flipped classroom engagement ( $p_{value} = 0.6509 > 0.05$ ) and tutorial attendance ( $p_{value} = 0.1928 > 0.05$ ) are not likely to be strong predictors for the total course grade changes in the regression model. A trimmed regression model with those variables excluded is detailed in Table 5.7.

As previously noted, this regression analysis was conducted on the student data for those who completed both midterm examinations. This was done because an

incomplete data set was negatively affecting the quality of the resulting formula for the regression. Preliminary regression statistics with incomplete data has  $R^2 = 0.2637$ . Regression statistics with removed incomplete data has  $R^2 = 0.8280$ .

High scores on the quizzes, homework, tutorial worksheets or attendance should be viewed as an indicator of the student's weekly effort and desire to succeed in the course, and high marks on those activities completed in a non-invigilated environment are not an indicator of their performance in the course. While it is great to have a better fitting model projecting total course grade before the final examination is written, for students it will be impractical to look up all their grades for the tutorial assignments, quizzes, gateway tests and the midterms to estimate a total course grade.

It might be more effective to share with students a simplified model for the total course grade projection based only on two midterm scores. It appears that 74% of the total course grade variation is attributed to the midterm scores alone. A corresponding regression analysis of the total course grades based on Midterm examinations 1 and 2 only, can be found in Table 5.8. Instead of looking up all students' up-to-date grades, the students can estimate their total course grade even before the final examination by the model based on two midterms only:

$$\text{Total Course grade} \approx 0.2 + 0.4 * (\text{Midt \#1}) + 0.4 * (\text{Midt \#2}).$$

This simple formula can be useful for the students as it illustrates the importance of preparation for the midterm examinations, as the total course grade is approximately equal to the average of two midterms, with the constant 0.2 representing high course grades on the rest of the assessments and assignments.

Understanding that midterm scores are great predictors of the final exam score and the total course score might help students address a common illusion that the high scores on the homework assignments and the quizzes are better indicators of what

**Table 5.6***Preliminary Regression Analysis of Total Course grade*

Math 101, 202001	Coef	SE	t Stat	P-value	Lower 95%	Upper 95%
Intercept	4.33	1.10	3.93	9.5E-05	2.17	6.50
Tut Att %	1.11	0.85	1.30	0.19	-0.56	2.78
Pre-class %	0.58	1.29	0.45	0.65	-1.96	3.13
Quiz %	8.26	1.74	4.74	2.5E-06	4.84	11.68
TW %	8.04	0.95	8.46	1.6E-16	6.18	9.91
GWTs %	14.80	1.48	9.96	6.0E-22	11.885	17.71
Midt 1 %	31.42	1.27	24.79	1.4E-97	28.93	33.91
Midt 2 %	21.72	1.44	15.05	1.7E-44	18.89	24.56

**Notes:** Coef = Coefficients; SE = Standard Error; TW = Tutorial Assignments**Table 5.7***Regression Analysis of Total Course grade*

Math 101, 202001	Coef	SE	t Stat	P-value	Lower 95%	Upper 95%
Intercept	4.72	1.05	4.48	8.7E-06	2.65	6.79
Quiz %	9.16	1.51	6.07	2.1E-09	6.20	12.13
TW %	8.13	0.95	8.57	6.8E-17	6.27	9.99
GWTs %	14.98	1.48	10.12	1.45E-22	12.08	17.89
Midt 1 %	31.55	1.26	25.02	6.4E-99	29.07	34.02
Midt 2 %	21.73	1.44	15.06	1.6E-44	18.90	24.56

**Notes:** Coef = Coefficients; SE = Standard Error; TW = Tutorial Assignments

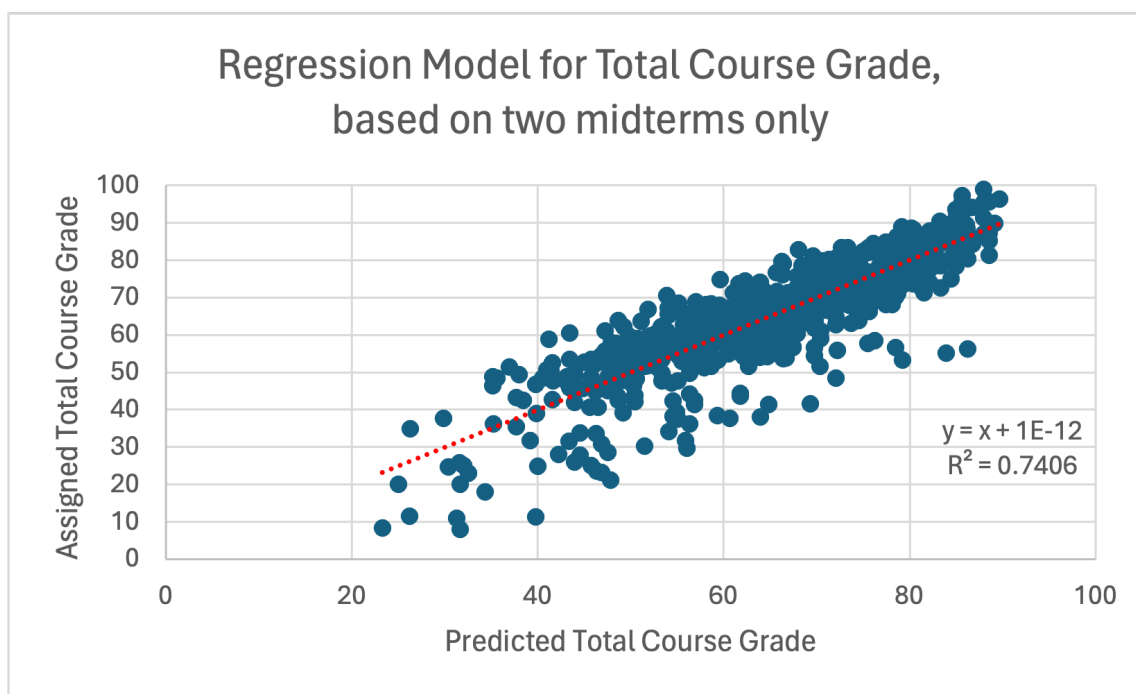
the total course grade will be, and that a low midterm score is a “fluke” accident and should be ignored.

High scores on quizzes, homework, tutorial worksheets, or attendance should be viewed as an indicator of a student’s weekly effort and desire to succeed in the course, and those high grades are not an indicator of their performance in the course. Instead,

**Table 5.8***Simplified Regression Model for Total Course grade*

Math 101, 202001	Coef	SE	t Stat	<i>p</i> value	Lower 95%	Upper 95%
Intercept	15.64	1.20	13.07	4.7E-35	13.29	17.99
Midt 1 %	38.28	1.68	22.76	4.0E-86	34.98	41.59
Midt 2 %	35.76	1.81	19.73	3.4E-69	32.20	39.32

**Notes:** Coef = Coefficients; SE = Standard Error; TW = Tutorial Assignments

**Figure 5.2***Formula for Forecasting Math 101 Course Grade in 202001*

the students can estimate their total course grade even before the final examination by the modification of the earlier proposed formula, which communicates the importance of practice offered through the Gateway Tests:

$$\text{Total Course grade} \approx 0.2 * (\text{average GWTs}) + 0.4 * (\text{Midt \#1}) + 0.4 * (\text{Midt \#2}).$$

While the proposed coefficients 20, 40 and 40 out of 100 for the total course grade prediction model, correspond to GWTs and Midterms 1 and 2 respectively,

they are different from the ones used in the actual formula for the total course grade calculation (9, 20 and 15 out of 100). This simple formula can be useful to the students to illustrate the importance of preparation for the GWTs and the midterm examinations. The detailed formula used to assign the total course grade in Math 101 2020 Spring term is given in Table 5.5.

We reject hypothesis 1 in Cycle 3, as regression analysis in Math 109 2019 Fall term and Math 101 2020 Spring term courses showed that grades for the formative activities (pre-class assignments) in a flipped classroom first-year Calculus courses do not significantly predict the total course grade assigned.

#### **5.4.2 Do Not-For-Grades Practice Gateway Tests Matter?**

##### **Hypothesis 2 in Cycle 3:**

Students who repeatedly use the Practice Gateway Tests in preparation for the upcoming examination, on average achieve a higher total course grade than the students who do not repeatedly engage with the not-for-grades Practice Gateway Tests.

Detailed analysis of the data collected in the Math 101 2022 Fall term shows that less than half of the students (65 out of 153, or 42%) engaged with each not-for-grades Practice Gateway Test at least one time. This observation is consistent with the observation I made in Cycle 2 that most of the students choose not to engage with the not-for-grades online practice material. Lack of engagement also might be related to the lack of time (as each Practice GWT requires approximately 30 minutes to complete, just as an actual GWT), so if the student has delayed completing the GWT until its due date, they might have run out of time. The students have access to the Practice GWTs for at least one week before the actual GWTs are due. From the conversations overheard in the classroom, the students do share their experience with

the practice tests and how similar the practice questions were to the actual GWT questions. The discussion in the classroom between the students about the optional practice online sets given one week before the midterms is very rare.

A “B” student (with a course grade in the [70, 79] range) has on average 19% fewer practice attempts than an “A” student (with a course grade in the [80, 100] range). A “C” or “D” student (with a course grade in the [50, 69] range) has on average 40% fewer practice attempts than an “A” student. An “F” or “N” (with a course grade in the [0, 49] range) student has on average 82% fewer practice attempts than an “A” student. While there are some “A” students with a low number of attempts given to the practice questions, on average “A” students have attempted different practice sets 24 times per course. It is important to highlight that we are not able to measure all other types of engagement each student had with the course material (such as working on the practice questions using the printed textbook, or solving old examination questions posted online).

In the class of 153 students, we analyzed several groups of students on their level of engagement with the optional practice sets and the resulting course grades:

Group 1 – included students who attempted no more than one Practice GWT before each examination (midterms and the final exam);

Group 2 – included students who attempted one Practice GWT more than once and possibly either or both of the other Practice GWTs only once before exams (midterms and the final exam);

Group 3 – included students who attempted at least two different Practice GWTs more than once before each examination (midterms and the final exam).

Some programs at UVic have a minimum grade requirement for completed courses: “All courses required in the program must be completed with a grade of “C+” or

**Table 5.9***Number of attempts on Practice GWTs in Math 101, 202209*

Name of the group	# of students in the group	average total course grade in the course	# of students with course grade at least 50% (% of group)	# of students with course grade at least 65% (% of group)
Group 1	29	32%	6 (20.7%)	2 (6.9%)
Group 2	59	60%	48 (81.4%)	25 (42.4%)
Group 3	65	69%	59 (91.8%)	37 (56.7%)

above.” Grade above “C+” corresponds to the numerical score equal to at least 65%.

Because students’ success in Group 1 is considerably less likely when compared to the success of students in Groups 2 and 3, we fail to reject Hypothesis 2 in Cycle 3. Students who repeatedly use Practice GWTs in preparation for the upcoming examination on average achieve higher grades than the students who do not repeatedly engage with the not-for-grades Practice GWTs.

### 5.4.3 Benefits of the Practice Gateway Tests

Table 5.9 shows that Math 101 2022 Spring term students who engage with practice gateway tests repeatedly are doing considerably better in the course than the students who use not-for-grades practice GWTs at most one time before each graded GWT. The current record holder of the maximum number of attempts is a student with 78 fully completed attempts on a specific practice GWT in Math 101. Coincidentally, the student received the top mark in the course. Should all students make as many attempts as possible in the hope of obtaining a top course grade? In this section, I will discuss how many attempts on the Practice Gateway Tests are beneficial.

#### **Hypothesis 3 in Cycle 3:**

Students who repeatedly use Practice Gateway Tests in preparation for the upcoming examination on average get a higher grade than the students who do not

repeatedly engage with the not-for-grades Practice Gateway Tests.

Looking at the subgroups with the increased minimum number of attempts before each examination (midterms or a final exam) when compared to group 3, shows that the average course grades remain similar to the averages of course grades in group 3. I considered four subgroups where students had at least 3, 4, 5 or 10 attempts before each examination. I call those subgroups  $3_3$ ,  $3_4$ ,  $3_5$  and  $3_{10}$ , as they all belong to group 3. The average course grades within the subgroups are 69%, 72%, 75% and 73% respectively.

In subgroup  $3_3$  out of 44 students only three have a failing course grade; furthermore, 24 of the 44 students (54.5% of the subgroup) have a course grade greater or equal to 65%.

In subgroup  $3_4$  out of 25 students, only one has a failing course grade; furthermore, 17 of the 25 students (68% of the group) have a course grade greater or equal to 65%.

Subgroup  $3_5$  has only 18 students, and no students have a failing course grade; furthermore, 14 of the 18 students (77.8% of the group) have a course grade greater or equal to 65%.

Subgroup  $3_{10}$  has only four students, and no students have a failing course grade, and three of the four students (75% of the group) have a course grade greater or equal to 65%. When the size of the group is small (below 25), we hesitate to draw conclusions extendable to general large classes.

However, we can observe that the average grade in subgroup  $3_{10}$  is not higher than in the group  $3_5$ .

As a recommendation to future students, we can generalize that having at least 5 attempts on the not-for-grades practice gateway tests before each test (midterm or a final exam) will place the student in a group with the most successful students, who complete the course with a grade of 65% or higher.

#### 5.4.4 Invigilated vs Non-invigilated Gateway Tests.

Graded Gateway Tests were for the first time incorporated in Math 109 during the 2019 Fall term as a component of the total course grade. While the Practice Gateway Tests had an unlimited number of attempts and the students were able to practice them in the comfort of their homes, the actual graded Gateway Tests were completed by the students in the computer laboratory at the University of Victoria, under the invigilation of the instructors and the TAs. With the COVID lockdown in the Spring and Fall of 2020, all in-person testing moved online. While in-person testing allowed invigilators to identify a student, who used disallowed technology (such as a cell phone) during the exam, online testing made observing whether the students used disallowed technology impossible. Even with the screen lockdown technology that does not allow the use of any other window on the same machine, and a camera showing some portion of the student's workplace, it is easy to have a secondary machine (a tablet or a cell phone) to communicate with a hired helper or a friend, or to search online for a solution to a Calculus question. Away from the invigilator's eyes students can use many online tools, such as <http://wolframalpha.com>, <https://www.intmath.com/> and <https://mathsolver.microsoft.com/>, to solve any first-year calculus question promptly. Students do not need to engage in PGWTs at all to achieve 100% scores on the GWTs if they choose to use online tools to answer GWT questions. Without proper invigilation, questions of academic integrity repeatedly were voiced by some instructors and students. Would the results of the non-invigilated Gateway Tests be drastically different from the results of the invigilated Gateway Tests due to the opportunity for academic misconduct?

#### **Hypothesis 4 in Cycle 3:**

Students in non-invigilated GWTs who did not complete PGWTs on average will

outperform the students who completed PGWTs with a score of at least 80%.

**Table 5.10**

*Invigilated Gateway Tests in Math 109 2019 Fall term*

Course, Term, GWT	Groups PGWT, highest scores	Median score in Lab	People in group, #	Group proportion
#1	below 50%	na	0	0.0%
	between 50% and 79%	50.0%	21	4.4%
	between 80% and 99%	66.7%	181	38.2%
	exactly 100%	<b>83.3%</b>	272	<b>57.4%</b>
	did not write practice GWT	na	0	0.0%
	across all groups	<b>83.3%</b>	474	100.0%
#2	below 50%	20.0%	37	9.6%
	between 50% and 79%	40.0%	123	<b>31.9%</b>
	between 80% and 99%	60.0%	96	24.9%
	exactly 100%	<b>80.0%</b>	104	27.0%
	did not write practice GWT	60.0%	25	6.5%
	across all groups	60.0%	385	100.0%

We (the instructors of the Calculus courses at UVic) hope that the majority of students are taking GWTs without outside help. To confirm that hypothesis, we compared the results of the graded GWTs in Math 109 2019 Fall term that had invigilated Gateway tests with the results of the graded GWTs in Math 100 2020 Fall and 2022 Spring terms that had non-invigilated tests. All three first-year courses had hundreds of students registered in them and had the same Gateway Tests 1 and 2. In Math 100, students in both terms had the third Gateway test, which was not available in the Math 109 2019 Fall term.

In the Fall of 2019, to qualify for the invigilated Gateway Test 1 in Math 109, a student had to first achieve a score of 50% or higher on the non-invigilated Practice Gateway Test 1. Practice Gateway Tests could be taken an unlimited number of times, with each attempt having questions pulled from the large pool of questions.

On Gateway Test 2, there was no prerequisite for completing a Practice Gateway Test 2 with a set minimum required score. Therefore, students were allowed to take GWT 2 even if they did not attempt to complete PGWT 2.

In addition to having non-invigilated GWTs, Math 100 (in both terms, 2020 Fall and 2022 Spring) had no prerequisites for any of the Gateway tests. While information about the importance of the PGWT was shared with the students, they still could choose to not attempt any of the PGWTs before taking the actual GWT.

From Cycle 1 we know that Math 100 students typically have better total course grades than Math 109 students. Therefore, while comparing results on the invigilated GWTs in Math 109 with non-invigilated GWTs in Math 100, we should observe higher GWTs' medians in Math 100, when compared to the grades in Math 109.

Tables 5.10 and 5.11 show students' performance on GWTs grouped by students' highest grades on PGWTs. I grouped students into five groups, based on the highest grade achieved on PGWTs:

- (1) below 50%,
- (2) between 50% and 79%,
- (3) between 80% and 99%,
- (4) exactly 100%, and
- (5) students who did not write PGWTs at all.

In Tables 5.10 and 5.11 we see that the median scores on GWTs among the students in groups (3) and (4) are always the highest among all five groups. We also observe that the second GWT is hardest for the students, as the median scores are lower than the first GWT.

On the invigilated GWT 2 in Math 109 we see that the number of participating students has dropped to 81.2% of the total number of students who wrote GWT 1 earlier in the term.

This is contrary to what I expected when we removed the requirement of achieving a passing grade on the Practice Gateway Test that could have prevented some students from coming to write GWT 1.

Having GWTs not invigilated in Math 100 at the later terms also showed the decrease in participation in the last GWT when compared with the first and second GWTs by between 9% and 30%. Having GWTs more accessible did not make them more enticing.

**Table 5.11***Non-Invigilated Gateway Tests in Math 100 2020 Fall and 2022 Spring terms*

Term, GWT	Groups PGWT, highest scores	Median score on GWT, Lab	People in group, #	Group proportion
202009, GWT 1	below 50%	70.1%	24	4.8%
	between 50% and 79%	83.3%	39	7.8%
	between 80% and 99%	83.3%	117	23.3%
	exactly 100%	<b>91.7%</b>	241	<b>48.0%</b>
	did not write practice GWT	83.3%	81	16.1%
	across all groups	83.3%	502	100.0%
GWT 2	below 50%	66.7%	36	7.0%
	between 50% and 79%	66.7%	129	25.0%
	between 80% and 99%	83.3%	125	24.3%
	exactly 100%	<b>100.0%</b>	88	17.1%
	did not write practice GWT	66.7%	137	<b>26.6%</b>
	across all groups	81.0%	515	100.0%
GWT 3	below 50%	82.1%	53	11.1%
	between 50% and 79%	83.3%	106	22.2%
	between 80% and 99%	87.5%	111	23.2%
	exactly 100%	<b>93.5%</b>	75	15.7%
	did not write practice GWT	81.0%	133	<b>27.8%</b>
	across all groups	85.7%	478	100.0%
202201, GWT 1	below 50%	65.3%	10	9.0%
	between 50% and 79%	83.3%	27	24.3%
	between 80% and 99%	91.7%	25	22.5%
	exactly 100%	<b>93.1%</b>	34	<b>30.6%</b>
	did not write practice GWT	72.2%	15	13.5%
	across all groups	86.1%	111	100.0%
GWT 2	below 50%	75.0%	20	22.7%
	between 50% and 79%	75.0%	25	<b>28.4%</b>
	between 80% and 99%	<b>87.5%</b>	21	23.9%
	exactly 100%	<b>87.5%</b>	11	12.5%
	did not write practice GWT	75.0%	11	12.5%
	across all groups	82.9%	88	100.0%
GWT 3	below 50%	78.6%	14	15.2%
	between 50% and 79%	69.6%	29	<b>31.5%</b>
	between 80% and 99%	<b>100.0%</b>	24	26.1%
	exactly 100%	96.4%	11	12.0%
	did not write practice GWT	85.7%	14	15.2%
	across all groups	85.7%	92	100.0%

In the invigilated and non-invigilated GWT 1, we observe the highest median falls on the students who achieved exactly 100% on the Practice Gateway Test. This is also the largest portion of students in each of the three courses. This was probably due to the novelty of the GWTs for the students, so the students did not know what to expect and were worried about not doing well on their first Gateway test. Approximately between 13% and 16% of the students did not write PGWT 1 in the non-invigilated courses before writing the corresponding GWT 1.

The proportion of students who achieved exactly 100% as the highest score on PGWT 2 was less than half of PGWT 1. Most likely, students decided that the GWTs were not as scary as they originally thought, and instead of striving to master the material to a 100% score on PGWT 2 were satisfied with a passing grade on PGWT 2. The results on GWT 2 were lower than on GWT 1 for all three courses. While the material on GWT 2 is a little more difficult than on GWT 1, it is not sufficiently more difficult, therefore the increased difficulty cannot be an explanation for the observed performance difference in the invigilated Gateway tests.

Observing that the best performing groups for the non-invigilated first-year calculus courses are always the students who completed PGWTs with a score of at least 80% allows us, just as for the invigilated GWTs, to reject Hypothesis 4 in Cycle 3, and conclude that the students are completing non-invigilated GWTs without outside help.

In the future we should share with the students' the following observations:  
the students who completed PGWTs with a score of at least 80% typically outperformed the rest of the class on the actual GWTs, and the students who chose not to engage with the PGWTs typically showed the worst performance in the class.

### 5.4.5 Special Tutorial: Engaging students repeating the course.

In the Math 101 Spring 2020 term I had 49 registered students, who were not satisfied with their Math 101 Fall 2019 course grade and were determined to improve their grade. All 49 students who were repeating the course were contacted by email and invited to join a Special Tutorial Section run by the Course Coordinator instead of a regular tutorial section the students were already registered in. While the majority of the students in Math 101 achieve high grades on the weekly assignments and corresponding quizzes (around 80%), the grades on the midterm and final examinations barely pass (around 50%). After the midterms, some students voiced complaints that the questions on the midterm were “not familiar” and, therefore, “unfair”, while in actuality, the questions came directly from the textbook and weekly assignments. In my opinion, the students did not recognize which technique could be used to approach solving such “unfamiliar” questions. They were not able to identify, or “sort” the given midterm questions, before applying a plausible solution technique. The focus of the Special Tutorial was to engage in the practice of “sorting” through random questions identifying a possible appropriate technique that could simplify the original question. Twelve out of 49 students expressed interest in participating in the Special Tutorial section instead of a Regular Tutorial.

**Table 5.12**

*Special Tutorial Section - Participants*

Total number of students (% of the group)	Retake with Regular Tutorials	Retake with Special Tutorial	Entire course
originally registered	37 (4.8%)	12 (1.6%)	771 (100%)
dropped the course	4 (10.8%)	0 (0%)	37 (4.8%)
did not pass, “F”	8 (21.6%)	1 (8.3%)	78 (10.1%)
did not pass, “N”	1 (2.7%)	0 (0%)	45 (5.8%)

In Table 5.12 In Table 5.12 we see that only a quarter of the students who

**Table 5.13***Special Tutorial Section - Medians of the grades*

Medians within each group	Retake with Regular Tutorials	Retake with Special Tutorial	Entire course
Midterm 1 (in-person)	53%	62%	59%
Midterm 2 (online)	66%	73%	75%
Course grade in 202001	57%	61%	66%
Course grade in 201909	42%	44.5%	–

**Notes:** “–” indicates not all students registered in 2020 Spring in Math 101 already had a grade for Math 101 from 2019 Fall or any earlier term. “Entire course” column contains data that is based on the results of every registered student.

were repeating the Math 101 course in the Spring of 2020 term after receiving an unsatisfactory grade in the Fall of 2019 term chose to join the Special Tutorial section. Some students stated that they have a conflict with other courses but would like to be a part of that section if it were not for the time conflict. Some students stated that they preferred to stay in a regular tutorial, as they would like more practice on each of the specific techniques in class. The rest of the students did not reply to the invitation. Out of 37 repeating students taking Regular Tutorials (constituting 4.8% of the entire class) only 24 students (or 64.9% of the group) have completed the course with a passing grade. Out of the 12 repeating students taking the Special Tutorials (constituting 1.6% of the entire class) almost the entire group but for one (or 91.7% of the group) have completed the course with a passing grade. To compare completion rates in the entire course, out of 771 students we see 611 students (or 79.2%) pass the course. The students in the Special Tutorial had a better success rate in Math 101 than the repeating students in the Regular Tutorial, or generally in the course.

Table 5.13 illustrates the difference between the median grades on both midterms and in the overall course performance of the students retaking Math 101 within Regular Tutorial vs Special Tutorial and compares the entire course results. An important

distinction between midterms 1 and 2 is the fact that midterm 1 was conducted in person with the invigilators and no access to phones, lecture notes, programmable calculators or the internet, while midterm 2 was conducted during COVID lockdown, where students could not be invigilated, and students could have access to any desired tools, including another person online or in the same room. Historically, midterm 2 scores on average are lower than the score on midterm 1. Adhering to the Academic Integrity policy during online COVID examinations is questionable. Because of this, I focus more on the results related to midterm 1, and not as much on midterm 2 and the overall course grades. We see that median grades on midterm 1 for the students in the Special Tutorial are 9% higher than the median grades for the repeating students in the Regular Tutorial. The difference is noticeable especially when the course grades for the Math 101 Fall 2019 term between those two groups of students were compared (median 42% and 44.5% respectively). We can take this result as an indication that since the only difference in the course experience for students retaking the course is the type of tutorial (Regular vs Special Tutorial), the format of the Special Tutorial might be beneficial and should be further investigated while implemented for the entire course.

## 5.5 Reflections at the end of Cycle 3

Detailed analysis of the course experience survey collected in Math 101 Fall 2019 and Spring 2020 terms shows that a flipped classroom introduced in the course was not uniformly viewed by the students as a useful tool. Some students believed that they were forced to teach themselves, while some students celebrated this as a greater engagement mechanism. Using regression analysis on the grades students achieved through the Spring 2020 term, we were able to identify that tutorial attendance,

completion of the pre-class assignments, and quizzes were weak predictors of students' performance on the final exam. Completion of the tutorial worksheets also appears to be negligible when predicting the final examination grade. If a student missed one or more midterm, the quality of the prediction suffered greatly.

As a recommendation, students should not take their grades on quizzes, homework, tutorial worksheets, or attendance as a strong indicator of their potential total course grade. On the other hand, grades on the Gateway Tests and midterms are good indicators of their total course grade, provided the student did not miss any of the midterm examinations.

Unfortunately, one regression model for predicting total course grades based on the midterms and Gateway tests scores might not be appropriate for the Calculus course that historically has large grade variation from term to term. The difference between the average scores on midterm 1 in the Fall and Spring Math 101 courses varies by over 10%, with the students performing better in the Spring term. While the final examination grade variations are smaller when compared to midterm 1, the Spring term has, on average scores 7% higher. The resulting total course grades are also different by 7% between the Fall and Spring terms, with Fall grades being lower. While the difference in average grades might be due to many factors (such as course instructors and course structure), I believe it is due to the proportion of students repeating the course in the Fall and Summer terms, when compared to the Spring term with a large number of students taking the course for the first time.

Students who consistently and repeatedly (at least twice) engaged with each not-for-grades Practice GWTs were more likely to pass the course (91.8%) and were more likely (56.7%) to achieve a total course grade above 65% than the students who did not solve each Practice GWTs at least two times. None of the students who solved each Practice GWT at least five times failed the course. The students with at least

five Practice GWTs attempts had a 77.8% chance of completing the course with a total course grade above 65%.

Students who consistently and repeatedly (at least twice) engaged with each not-for-grades Practice GWTs were more likely to pass the course (91.8%) and were more likely (56.7%) to achieve a total course grade above 65% than the students who did not solve each Practice GWTs at least two times. None of the students who solved each Practice GWT at least five times failed the course. The students with at least five Practice GWTs attempts had a 77.8% chance of completing the course with a total course grade above 65%.

Communicating to the students typical expectations and outcomes associated with different levels of engagement and providing a variety of engaging practice sets with immediate feedback might be more beneficial and better received by the students than a flipped classroom course structure.

Teaching Assistants (TAs) supported the idea of sharing the responsibility of creating the tutorial worksheets. The course coordinator conducted a group meeting with all course TAs, where the TAs distributed responsibility for the tutorial worksheet development equally among themselves, respecting each other's needs and already made commitments. The TAs discussed the details of the process and timeline to produce the worksheets and corresponding solutions. The course coordinator shared the plan for what should be the topic and the learning outcome for each of the tutorial worksheets and distributed old tutorial worksheets from the previous terms. The TAs were to produce a first draft of the worksheet one week before it was to be distributed to the students and submit it, together with the detailed solutions, to the course coordinator for approval. The final version of the tutorial worksheet, together with the detailed solutions, was distributed to the other TAs at least three days before the tutorials. All TAs in Cycle 3 courses showed a great level of professional

responsibility by creating well-developed worksheets and producing the worksheets together with detailed solutions within the agreed timelines.

## 5.6 Unresolved problems remaining after Cycle 3

### 5.6.1 Variability in examinations

Cycle 3 took place from July 2019 to August 2020. On March 13, 2020, the President of UVic announced that in response to the pandemic (COVID-19) starting from Monday, March 16 all classes and examinations would be conducted in an online format. Midterm 2 in Math 101 was scheduled to take place on Saturday, March 21. This term was the first time when Math 101 experienced an online midterm and final examination. We observed inflated grades on midterm 2 when compared to the scores on the midterm in other terms before the final exam. The final examination was also in an online format, but the scores appeared to be considerably lower when compared to the previous final exam scores in the corresponding terms. The difference in grades, I believe, should be attributed to the specifics of the implementation of online examinations. Midterm 2 allowed students to access the entire examination at the same time and move through the questions in any desired order, while the final examination was a one-directional test, meaning that after a student left a question, they were not able to return to the same question.

In the face-to-face format, the midterms in Math 101 would be written in person in an invigilated room, without access to phones, computers, peers or tutors, with only paper, pen, and a basic scientific calculator model Sharp EL-510R\*\* available. In an online environment, midterm 2 questions were answered without invigilation, with the students having access to all books, notes, friends, computers, calculators and any desired internet site (such as <https://www.wolframalpha.com/>

and <https://www.chegg.com/> ). The midterm 2 questions were programmed or selected from the database of questions familiar to the students. This database was used in the course for all weekly assignments, quizzes and Gateway tests. Proof of the work in form of the detailed handwritten solutions for every question was required to be uploaded in a timely manner to the drop-off box on CourseSpaces (a web-based environment used at UVic in 2020). The final examination had a format similar to midterm 2. However, there was also a difference. The first portion of the final examination consisted of 11 questions, that had to be accessed and completed within a familiar software which students used for the weekly assignments, quizzes, Gateway tests and midterm 2. The second portion consisted of four questions created by course instructors in CourseSpaces. Each question in the second portion of the final examination was open within specified 15-minute time slots, and could not be accessed outside of the specified time. Students needed to submit detailed solutions after each question was solved.

### **5.6.2 Academic Integrity Violations**

After midterm 2, there was evidence of communication between the students writing the examination and the people within an online community that was not taking the course. Some midterm questions were posted by the students online during the exam, and solutions like the ones provided by online “tutors” appeared to be submitted for grades. The time between posting the question and the original solution appearing online was under 15 minutes. This is why on the final examination instructors chose to have a second portion of the exam with a time limit for access to each question. While engaging students using online tools has been instructors’ goal throughout the first-year calculus courses, the use of online tools by the students during the examination times proved to be a pitfall of the online course delivery.

“Academic integrity” and related violations were an object of active discussion in the academic community during mandatory online learning due to COVID-19. With multiple potential tools (phones, computers, laptops) students have unrestricted access to the entire internet community and therefore can outsource problem-solving if desired.

### **5.6.3 Inconclusive outcome of the “flipped classroom”**

Another unresolved question is an uncertainty on whether a “flipped classroom” is an effective learning tool.

While students in Math 101 Fall 2019 seem to have had one of the better performances on the first midterm, their performance on the last midterm was affected by the lack of in-person invigilation. It becomes impossible to determine if higher medians on the midterms correspond to the positive effect of the flipped classroom, a stronger group of students or a lack of in-person invigilation.

Some students expressed fatigue from being “forced to teach themselves”, indicating that they would prefer a standard lecture format. A “flipped classroom” can potentially remain in the course only for some topics, where the instructor foresees difficulties and would like the students to start working on the topic before class. However, this research has seen through the experience with optional Gateway tests, that most of the students do not complete assigned work, if there is no percentage of the course grade associated with the assignment. Therefore, a flipped classroom needs to have some portion of the grade associated with the assigned activity for the students to engage with it.

#### 5.6.4 Format of Tutorials in Calculus I and II

Upon conclusion of the three cycles of this research, the format of the tutorials in the first-year Calculus courses is still not settled to the students' satisfaction. From the research in Cycles 2 and 3, we know that the students' preference to have a Teaching Assistant (aka Tutorial Leader) start each tutorial with an introduction, review or a "mini-lecture" of the course material that will be useful during the current tutorial. Some of the students indicated that they feel confident with the course material, do not want a review at the beginning of the tutorial classes, and would prefer to directly move to solving worksheet questions.

From Cycle 3 we observed that focusing on practicing sorting (or identifying which techniques might be useful as a first step in solving any of the worksheet questions) correlated with a higher Calculus course grade than in the tutorial sections that were not practicing sorting in their tutorials.

Students relayed information about a heavy workload associated with solving the tutorial worksheet questions and the importance of the Teaching Assistants' guidance in completing solutions to the tutorials. The quality of the feedback on the solutions and constant delays by some markers in providing the feedback through grading of the tutorials remains a question about the usefulness of the tutorial worksheets in Calculus courses.

The format of the tutorials, focus and role of the tutorial worksheets will remain an important aspect of future research.

In Chapter 6 of this thesis, I discuss my observations, recommendations and unresolved issues remaining in Calculus I and II courses after this research has been completed.

# Chapter 6

## Conclusions

In this section I briefly outline the conclusions of the current study, describing which data that is readily available for the course instructor was the most useful as a tool for the data analysis; describe the results, observations and recommendations for the Calculus instructors to be shared with the students and the recommendations to the Math and Stats Department; and summarise the limitations of the current study and possible directions for future research.

### 6.1 Data Used to Analyze Students' Engagement

This section contains information about what data was used in this research from the information that is readily available to an instructor at the University of Victoria for an analysis of the effectiveness of strategies to promote students' engagement.

In the case of automated grading (multiple choice questions marked using a computer program), obtaining detailed grades did not require extensive effort. If questions are graded manually, then record keeping requires additional effort from the grader. Providing individualized feedback for a large course (with hundreds of students) was time-consuming and required knowing how to automate generation of the personal-

ized emails based on the extensive Excel file. I determined that it was not an effective use of an instructor's time, especially since the students did not choose to engage in an optional activity recommended by the instructor. Having a detailed record of the grades on each midterm is useful for an instructor/course coordinator even when the instructor does not provide personalized feedback to the students, as it allows the instructor to determine which topics the class has already mastered well and which topics will be problematic for the students. Armed with such knowledge, the instructor can provide general feedback to the class through in-class practice or discussion, or by setting an additional activity to support students' further learning.

To determine how well students in Calculus I courses were prepared for the Calculus II course, I used overall course grades for these courses in the two consecutive terms. Unless the course instructor/course coordinator was the same person for all Calculus I and II courses, this information can only be obtained through a Department lead inquiry, collaboration among the course instructors, or by obtaining research Ethics approval to conduct the intended analysis. Such a study on the effectiveness of a prerequisite course, I believe, is essential when the Department is reviewing prerequisite conditions. Making students aware that a lower passing grade in the prerequisite course does not correlate to a passing grade in Calculus II can be done directly by sharing the findings on the course statistics with students in the earlier completed classes.

To study if there is a correlation between the levels of engagement with the not-for-grades practice tests, I used information on the number of student attempts on the practice tests and the highest score achieved on the practice tests. Such information can be obtained from the online software instructors use for conducting practice tests. If practice is completed without using the online software, it is impossible to track the level of students' engagement with the practice material, unless requesting students

keep a journal of their practice attempts and report data to the instructor.

While grades for the majority of the course work (weekly assignments, quizzes, tests) are collected as a result of grading, attendance can be collected in a variety of ways. In a small class (e.g., less than 30 students), calling names to take attendance at the beginning or end of the class is sufficient. However, in a large class (e.g., with 80 to 250 students) taking attendance by calling out the names would be a waste of instructional time. Alternatively, students can be asked to complete an online questionnaire, solve a question, or participate in a survey (online or paper-based). For this study, I chose to use the last 5 minutes of the class to invite students to solve a question based on the day's class material, or to write a comment on what the most difficult or most useful part of the class was, and to include their student number as an identifier. The students' responses would be handed to their instructor on the way out of the classroom. This allowed instructors to determine whether the students were able to solve the problem, to identify where the most common error occurred, and to hear students' concerns or feedback. Instructors could then use this information to adjust the next class, create discussions on the course forum, or contact the student to provide support if requested. When instructors collect the information personally from each student, the process ensures as true an account of the attendance as possible, since each student can only submit one piece of paper. Using technology allows for the possibility of an inflated attendance, with students remotely "participating" in class by getting instructions directly from their classmates on time. However, with the in-person paper-based collection of attendance, it is still possible for someone to impersonate a student and submit attendance on their behalf. Recording the attendance in an Excel file can be done either by an instructor or TA. The use of anonymized Course Experience Surveys (CES) for data collection and analysis has both positive and negative effects. My experience shows

that leaving students to complete CES at their convenience (not in class) results in low participation rates (below 30%). To achieve higher participation rates, I provide 15 minutes at the beginning of the first class after the CES becomes available, and explain how important the students' feedback is, and how it has been used in the past to redesign the course over time. I invite students to write about how they feel about different elements of the course (e.g., their "likes" and "dislikes"). Since CES is anonymous, the students can feel confident that none of their comments can be used to their disadvantage. However, since the CES are anonymous, there is no chance of following up on the feedback for clarification or providing support to the specific student. Coding information for the CES written responses is a time-consuming process that can also be emotionally draining when coding the "critical" or "negative" feedback. Maybe, outsourcing the coding process to an arm-length Research Assistant (RA) could be an effective solution, as an RA does not have an emotional investment in the course and will not take critical feedback personally.

## 6.2 Results

This section contains a summary of the observations and conclusions made in the current study.

The Cycle 1 analysis showed that it is a good idea to offer students a choice between Calculus I courses based on the students' previous experience with calculus. My research supports observations identified in the literature that students without previous calculus experience feel at a disadvantage when competing with students with previous knowledge of calculus (Bressoud et al., 2016). Having a first-year Calculus course (e.g., Math 109) designed for students with no previous calculus experience and an alternative course (e.g., Math 100) for students with some previous calcu-

lus experience allowed for a better engagement of students in the classroom without negatively impacting students' performance (based on the over-all course grades). Communicating with students about the importance of correctly self-selecting the Calculus I course created a learning environment where the students were mostly satisfied with their course experience. This observation is supported by Jones (2009), who commented on students feeling empowered about the opportunities to make decisions about their learning, the usefulness of mastered material, feeling interested in course content and instructional activities, and instructors caring about the students and their learning and feeling that the students have a real chance for success in a course.

Undergraduate students having two courses to choose from (Math 100 and 109) instead of a single course, redistributed the previous 1,200 students registered in Math 100 into approximately 600 in each of Math 100 and 109. This redistribution of the students made each course not only more manageable by the course coordinator and allowed all students to write a common final examination at the same location, but also gave course coordinators the ability to adjust assignments based on the students' previous experience with calculus (including Precalculus review). Literature supports that successful Calculus programs provide "proactive student support services, including the fostering of student academic and social integration" (Bressoud & Rasmussen, 2015, p. 145). Offering the alternative Calculus I course with the teaching material (in-class examples and assignments) tailored specifically to the students without previous Calculus experience allows the University to proactively support students in their academic needs.

Results obtained in Cycles 2 and 3 confirm the importance of immediacy and usefulness of feedback through online practice quizzes or communications between students and instructors highlighted in the literature (Ambrose et al., 2010; Andrade,

2001; Christophel, 1990; Ting & Kuo, 2016).

While some students appeared to appreciate personalized feedback provided in Cycle 2, there was little to no follow-up action taken by the students based on the instructor's recommendation. If solving recommended questions did not directly affect the total course grade (had weight equal to zero), students perceived the recommendation as optional (unnecessary) and did not dedicate the time needed to solve such questions. There was a positive outcome from the personalized feedback: when the students received a list of the textbook questions similar to the questions they solved incorrectly during the midterm examination, they did not complain to the instructor about the examination being "unfair" or the examination having the "questions that we have never seen before". Individualized feedback takes considerable effort on the part of the course coordinator. Having little buy-in from the students (i.e. the majority did not follow the given recommendations) makes a strong argument against trying to sustain individualized feedback in the future for large first-year courses. To capitalize on the observation that students see the examination as "fair" if they see questions on the midterm like those they see in the textbook, a list of such questions can be posted on the course page after grading of the midterm is completed and the papers are returned to the students.

Analysis of the data in Cycle 3 showed that students' high scores on the quizzes, weekly homework assignments, pre-class assignments associated with the flipped classroom, tutorial worksheets, or students' attendance do not positively correlate with the students' success in Calculus I courses. This information should be viewed as students' weekly effort and desire to complete the course. Analysis of the correlation between total course grades and the number of attempts on not-for-grades PGWTs shows that stronger students were attempting PGWTs most often. So, practice makes perfect is not necessarily true for all students all the time, but high engagement rates

with the PGWTs did correlate with the high total course grade. My analysis shows that the recommended number of attempts on PGWTs is at least 5. From the instructor's point of view, non-invigilated GWTs did not appear to be a subject of academic misconduct when compared to invigilated GWTs. This is good news to all involved, as having non-invigilated GWTs allows some flexibility to the students on when and where to take them while removing the stress of invigilation and having to deal with the student's accommodations. Since the "flipped classroom" was not well received by all students, did not produce measurable improvement in the students' success rate, and was strenuous on the course instructors, I do not intend to use it in future terms.

Johnson (2006) observed a correlation between completion of the optional non-for-grades quizzes and students' scores on the related graded tests (three proctored in-class midterm examinations and one final examination) in an undergraduate course in educational psychology. In their study, approximately 2/3 of the students engaged in any of 14 optional not-for-grades quizzes, and the "high-use students", who engaged with the quizzes the most were the best performing group. My research is supported by this finding, where over 70% of the students engaged with PGWTs, and the students who used PGWTs until their highest score on the practice test was "A" (80% or higher) had the top performance on the graded GWTs when compared to their peers' scores. Engagement with the PGWTs only happened after graded GWTs associated with each of the PGWTs were introduced in the courses. When optional practice tests were not visibly connected to the graded tests, the level of engagement with the PGWTs was extremely low. Out of 559 students, only 191 (or 34.2% of the class) attempted at least one of the optional tests, while 65.8% chose not to engage in the optional practice.

As supported in the literature (Koak et al., 2009; Pewewardy, 2002; Tarmizi &

Bayat, 2012), some students in my research also acknowledged collaborative work within tutorials as a positive experience. Unfortunately, almost as frequently, other students disliked the format of collaborative work and viewed it as increasing needless stress and as adding to the time it took to solve the problem. Students not liking collaborative work was also observed by Sofroniou and Poutos (2016).

The anonymous Course Experience Surveys (CES) in Cycle II showed that, in general, students liked the course structure. Unfortunately, changes made to the tutorials did not make them a well-liked part of the course, and more students “disliked” than “liked” both the tutorials and the tutorial worksheets. Throughout Cycles II and III tutorials went through multiple modifications:

- tutorial worksheets were designed with the direct involvement of the tutorial leaders,
- discussions of the upcoming tutorials took place in the weekly meetings under the guidance of the Head TA, course instructor or course coordinator,
- changes in the format of the engagement with the worksheets went from solving part of it at home for grades to having no graded portion of the worksheets at all,
- attendance of the tutorials was changed to contributing 1% to the total course grade.

Bagley (2014), when comparing four calculus courses, also observed similarly that students were dissatisfied when working on solving practice questions with TAs. In their research students claimed that TAs did not appear knowledgeable about material, could not solve questions on the first attempt, and were not able to answer questions from students related to the course content. Furthermore, the questions

on practice worksheets appeared to the students as being selected at random, too difficult, and unrelated to the midterm examination questions.

### 6.3 Limitations of the Research

My observations apply to the specific implementations of the course design aimed to improve students' engagement and success in their first-year Calculus courses. The Calculus courses used in this research had typical material coverage. Both Calculus I courses (Math 100 and 109) covered differentiation of the single variable functions, introduction to integration (antiderivatives, indefinite and definite integrals, Fundamental Theorem of Calculus) and applications of the differential calculus (graphing, optimization, related rates and calculation of the area between curves). The Calculus II course covered integration techniques of the single variable functions, complex numbers, sequences and series, and applications of integral calculus (separable differential equations, volumes, arc length, parametric curves, curves in polar coordinates). Success in the course, or overall course grade, heavily depended on students' grades on the invigilated in-person midterm and final examinations, and when combined, accounted for between 75% and 88% of the overall course grade. I observed that students' success strongly correlates with the following factors: student engagement with the not-for-grades practice tests; student grades on the midterm examinations, and the overall grade in a prerequisite course completed immediately before the current course. In a course where there are no not-for-grades tests that are directly connected with the graded course work, no heavily weighted midterm examinations, or no prerequisite courses, student success would most likely not be related to the factors listed above. Tracking students' engagement with not-for-grades practice tests requires having access to an online database of questions, setting up practice tests

and retrieving collected data, which might not be an available or a familiar tool to an instructor interested in tracking their students' course engagement.

My specific limitations from this research include the following:

- The grade distribution on non-invigilated GWTs was not different from the invigilated GWT. This cannot be generalized to a non-invigilated GWT that has a higher contribution towards the final grade value.
- During Cycle 3, the COVID pandemic forced learning (lectures and tutorials) and assessments (midterm and final examinations) to be conducted online instead of intended in-person interactions, which visibly affected students' behaviour in preparation for and during the online examinations.
- Engagement in the course was only measured via PGWTs and GWTs in the online environment. There was no attempt made to measure any other type of students' engagement with the course material (i.e., working on the recommended questions not online, but on paper, engagement with the tutors through the Math and Stats Assistance Centre, or working with peers in study groups).
- Each term a new group of students was exposed to the different learning and assessment environments, with different members of the teaching team (instructors, TAs), different lecture lengths (50 minutes 3 times per week vs 80 minutes 2 times per week), different midterm length (in lecture 50-min, in tutorial 45-min, or outside of the class 90-min or 120-min), different number of midterms (2 or 3 per term), different tutorial formats (group work vs lecture style), and at homework with different types of graded assignments.
- Typically, the University instructors do not have access to information about their students' previous calculus experience; time from completion of the prerequisite course and the final grade. It is possible to obtain a part of that

information related to the Calculus II course by getting ethics approval to conduct the data analysis. Then by sifting through the total course grades from the previous courses, it is possible to identify if the student took Calculus I through Math 100 or 109, how long ago, and what was the total course grade. The same procedure is impossible to do for the Calculus I course. Requesting prerequisite information about Calculus I courses results in incomplete data, where dates and grades are missing.

- Instructors might request a specific teaching assignment, but typically instructors do not have control of which courses they get assigned to teach and coordinate. This makes it difficult to plan the suggested changes in a course structure that requires time stretching over several terms. Instructors, typically, do not choose their teaching team (i.e., other course instructors, tutorial leaders or markers).
- The formula used to calculate total course grade not only varies from term to term but can also be adjusted within a term, as happened during the COVID-19 pandemic.
- In Cycle 3 (Math 101 Spring 2020 term) it is possible to view all students who repeated the course but self-selected not to be a part of the Special Tutorial section, as a control group. However, in all three research cycles, in all other courses, none of the sections were offered as a control group due to ethics. All implemented changes were done based on my belief that the students would benefit from the implemented changes. Under this belief, it would be unethical not to offer the changes to all students.

All the above limitations are the reasons why the findings in my research are not universally generalizable.

Design-based research (DBR) allowed me to use mixed types of interventions: changing the instructional method, strategy or technology used. DBR allowed me to encompass a variety of students' preferred teaching methods. The conclusions in this study are based on the complete first-year calculus student body, as none of the students could opt out or choose to be excluded from the research.

The current study lacked control group comparisons as there was no randomization, and the study was conducted within one university with the same instructor involved in teaching courses included in the study. Often DBR does not result in a measurable output that “proves” that an implemented measure or modification in instructional method “works” but offers recommendations for what might work under certain conditions.

## **6.4 Suggestions for Future Research**

### **6.4.1 Multi-institutional Course Experience Survey**

In the future, it could be useful to complete a multi-institutional survey among BC institutions that offer similar first-year Calculus courses, identifying which elements of the course structure students find most useful in achieving success in the course.

### **6.4.2 Tutorials and tutorial worksheets**

With 25% of the in-class work conducted through tutorials, it is essential to seek ways to improve students' engagement within the tutorials. Another consideration would be how to structure TAs' professional development, increase their ownership of the tutorials and communicate the importance of the tutorials in the eyes of the TAs and students. One of the possible ways to convey the importance of the tutorials is to position tutorials as a special weekly practice for the upcoming midterms.

Specifically, dedicate tutorials for practicing the “sorting” technique: identifying which solution approach would be appropriate for each question on the tutorial worksheet. For example, instead of practicing specific techniques, TAs could guide the students through the sorting exercise, where for the questions related to the limit calculations, the students would argue which question can be simplified by applying one of the listed techniques: factoring out numerator/denominator, completing a perfect square, factoring out the unknown raised to the highest given power, trigonometric formula, L’Hospital Rule, simple substitution, approximation or multiplication by the conjugate. The students should be alerted to where the questions on the worksheet are coming from (i.e., the practice questions given in lectures, in homework assignments, the textbook, or old midterm papers available to students). To better set up the sorting practice, the order of the questions should be mixed and not be in the order in which the topics were introduced to the students in the course. The goal of “sorting” tutorials is to help students develop a clear map of how to approach identifying a possible method of finding a first step in simplifying an original question.

Another example of a typical problematic Calculus activity is related to the graphing of a function. Students often can correctly complete an analysis of function behaviour (intervals where the function is increasing, decreasing, concave up, concave down, points of discontinuity, points of inflection, asymptotes, etc.), however, the sketch does not reflect the student’s findings or is completely missing. Dedicating tutorials to only sketching functions with the already predetermined (given in the worksheet) specific behaviour would help students determine if a described function can even exist, and how differently it might look based on the same description.

It would be essential to include TAs in designing worksheets and have preparatory group discussions with the teaching team, including the course coordinator or an instructor/lecturer of each upcoming tutorial. Determining and appropriately assigning

working hours to the TAs is important in allowing sufficient time to prepare the TAs for their engagement with the students, and to plan the possible in-class scenarios and potential complicated questions from the students. TAs need to have sufficient time to develop a sense of the importance of their work and to find reasons why their presence in the course is important to the students and the team.

## 6.5 Recommendations for Departments

Based on the current research, we know that if students complete the Calculus I course with a grade below “C”, they are most likely to fail the Calculus II course in the next term. The Department of Mathematics and Statistics has an opportunity to either set a minimum grade required in the Calculus I course as a prerequisite for the Calculus II course or communicate with Calculus I students about the likelihood of their success with low Calculus I grades in the following Calculus course. The communication with Calculus I students should happen three times in the term:

- 1) for the first time, at the beginning of the term, to help students set correct expectations about their desirable total course grade, and required mastery level on the course material,

- 2) the second time, before the last day to drop the course without consequences of failure, when the majority of the course work is already completed, including all or most of the midterms. This would help students project their overall course grade based on the regression model developed in this research, and determine if it is in the student’s interests to continue with the course, or drop it before the due date, and

- 3) the third time, before the end of the term, to help students with the projected low passing Calculus I overall course grade to determine if they need to drastically change their approach to learning to improve their chances to succeed in Calculus

II, retake the Calculus I course, or change their major so it might no longer be necessary for the students to complete the Calculus II course to satisfy their program requirements.

Another important consideration is the reallocation of the TA budget from marking to training tutorial leaders in course material development. Such training will allow tutorial leaders to become more invested in Calculus courses and get a feeling of ownership. Tutorial leaders' confidence and extended knowledge of the importance of the tutorials in the Calculus course would be transferred to the students and could improve students' experience in tutorials and the course overall.

## 6.6 Conclusion

The goal of this study was to determine the effect of students' engagement with calculus courses on the students' success in those courses. In particular, I asked does offering calculus courses based on students' previous calculus experience improve students' success in Calculus I and II; do high grades on the weekly online homework assignments, tutorial worksheets, online weekly quizzes, gateway tests, and midterms act as good predictors for the student's total course grade; do students complete not-for-grades practice questions recommended by an instructor if there is no corresponding graded course component; does student's active engagement with the frequent assignments associated with the flipped classroom course structure correlate with a high total course grade; do students benefit from actively practicing sorting in the weekly tutorials as opposed to solving more questions under the guidance of Tutorial Leaders; and are low stake online non-invigilated quizzes prone to inflated grades when compared to low stake online invigilated quizzes.

I found that there are benefits to the students and the instructors/course coordina-

tors in offering calculus courses based on the students' previous calculus experience. Students with previous calculus experience in general do better in the Calculus II course if the course is taken immediately following Math 100, when compared to the students who did not have previous calculus experience and are taking Math 109 immediately before completing Calculus II. High grades on weekly assignments, quizzes, and tutorials should not be viewed by the students as predictors of a high total course score, while high grades on the gateway tests and the midterms can be used as a predictor of the total course grade. Most students do not complete the recommended practice questions unless there is a directly associated graded test. Flipped classrooms were not well-received tools by the students and were mostly viewed as an additional burden by the students. There was no indication that the high scores on the flipped assignments could be used as a predictor of the total course grade. Despite the effort put in by the teaching team in the redesign of the tutorials to improve students' experience and engagement, it is still one of the most disliked elements of the course structure and requires more attention. Students do benefit from practicing sorting within their weekly tutorials, and my recommendation is to incorporate the practice of selecting the right technique in every tutorial.

# Appendix A

## Sample Letters:

### Individualized feedback in Cycle 2

**Letter sample of a feedback provided to the students after the midterm #1 for the student with the strong performance:**

Dear (Students name),

We have finished grading Math 100 Midterm #1 papers, posted the grades on CourseSpaces page and returned the papers this Thursday in lectures. The grade you have achieved on the midterm #1 79% is the reason why I am personally contacting you today.

The unclaimed midterm #1 papers can be found in the box in front of DTB A551 until the day of the final examination. Research shows that reviewing your work as soon as possible after the work is done is the most beneficial for your learning, so make sure that you work through your midterm paper now.

I believe that you have good studying skills, that are reflected by your grade on the midterm #1. Based on your answers to the midterm #1, I recommend to review the following sections using the textbook or MyMathLab Study Plan:

Q4 from Sect.2.2 (#33-41); Q12 from Sect.2.5 (#41-50); Q13 from Sect.2.6 (#75-85, 93-97, 105-109), see limit definitions of slant and vertical asymptotes given in class that were needed to be calculated for your specific function  $f(x)$  ;

To ensure that you continue to do well as the difficulty level of the material increases, take a couple of minutes to review the learning strategies useful in Calculus course:

- If you have not already done so, pick up your midterm paper and work through it to find every error in it. Make sure not to alter any pages of your midterm paper, in case you will need to apply for a grade review. If in a particular question your approach was incorrect (so it could not lead to the correct answer) then you have made a “calculus error”. If your approach was correct, but you did not find a correct answer, you might have made an “algebraic error”.

- Learn to distinguish between “Calculus error” and “algebraic error”. Calculus errors are eliminated by being confident in the strategies of finding limits, derivatives, sketching graphs of functions, setting up word problems, and so on. If you find yourself making many algebraic errors, you will need to teach yourself to slow down while working on the questions in your homework. This way, you will catch yourself making a mistake before moving on to the next step of your solution.

- Review your MyMathLab quizzes. You are able to see exactly which question you did not answer correctly and compare your answer with the correct one in each particular quiz after its due date has passed.

- Review your tutorial worksheets. As soon as the grade for the tutorial worksheet is released on the CourseSpaces, you can read comments left by the markers and see the detailed marking schema applied to each question on the worksheet.

- Talk to other students and the tutors in Math and Stats Assistance Centre about how to solve the questions correctly. Practicing how to reason through mathematics

problems is a vital step in preparing for upcoming assignments and exams.

- Know how to access Students Solutions Manual and the Study Plan in My-MathLab. Those tools are very useful when you are preparing for the upcoming examinations.

- Practice assessing your work objectively by yourself. After working on the question by yourself or with someone, ask yourself: 1. What was the most difficult part of this question for me? 2. What should I do next? (For example, find a similar problem in the textbook and work out the solution on my own.) 3. If I do this type of question again, would I do anything differently? If yes, what? 4. What did I learn from reviewing my work on this question?

Thinking about those four questions will help you master the material in your Calculus course. You can find more useful suggestions on how to succeed in Calculus at <http://www.berkeleycitycollege.edu/wp/lrc/how-to-succeed-in-calculus/>

If you have any questions or would like to talk to me about possible studying strategies, I would be happy to talk with you during the office hours.

Best regards,

Svetlana Oshkai

Math 100 Course Coordinator

**Letter sample of a feedback provided to the students after the midterm #1 for the student with the weak performance:**

Dear (Students name),

We have finished grading Math 100 Midterm #1 papers, posted the grades on CourseSpaces page and returned the papers this Thursday in lectures. The grade you have achieved on the midterm #1, 47%, is the reason why I am personally contacting you today.

The unclaimed midterm #1 papers can be found in the box in front of DTB A551 until the day of the final examination. Research shows that reviewing your work as soon as possible after the work is done is the most beneficial for your learning, so make sure that you work through your midterm paper now.

I believe that by applying some small changes in your studying approach you can positively affect the outcomes of your upcoming midterms and the overall course grade.

In particular, based on your answers to the midterm #1, I recommend to review the following sections using the textbook or MyMathLab Study Plan

(<https://coursespaces.uvic.ca/mod/page/view.php?id=1049903>):

Q6 from Sect.2.5 (#23-37); Q9 from Sect.2.6 (see in class examples of slant asymptote); Q11 from Sect.3.3 (#17-45); Q12 from Sect.2.5 (#41-50); Q13 from Sect.2.6 (#75-85, 93-97, 105-109), see limit definitions of slant and vertical asymptotes given in class that were needed to be calculated for your specific function  $f(x)$  ;

You will do better on the subsequent midterms and the final examination for Math 100 if you learn from the errors you made on midterm, quizzes and tutorial assignments.

Here are my recommendations: - If you have not already done so, pick up your midterm paper and work through it to find every error in it. Make sure not to alter

any pages of your midterm paper, in case you will need to apply for a grade review. If in a particular question your approach was incorrect (so it could not lead to the correct answer) then you have made a "calculus error". If your approach was correct, but you did not find a correct answer, you might have made an "algebraic error".

- Learn to distinguish between "Calculus error" and "algebraic error"

(<https://www.calvin.edu/~scofield/courses/materials/tae/tae2.html#lfb>). Calculus errors are eliminated by being confident in the strategies of finding limits, derivatives, sketching graphs of functions, setting up word problems, and so on. If you find yourself making many algebraic errors, you will need to teach yourself to slow down while working on the questions in your homework. This way, you will catch yourself making a mistake before moving on to the next step of your solution.

- Review your MyMathLab quizzes

(<https://coursespaces.uvic.ca/mod/page/view.php?id=1049901>). You are able to see exactly which question you did not answer correctly and compare your answer with the correct one in each particular quiz after its due date has passed.

- Start working on your next Calculus tutorial worksheet and MyMathLab homework assignment / quiz as soon as you have finished the current one. By practicing Calculus regularly (30 minutes every day), you prepare your long-term memory for the upcoming exam. If you wait to start your MyMathLab homework assignment until the day before it is due, you will only remember the information temporarily.

- Know how to access Students Solutions Manual

(<https://coursespaces.uvic.ca/mod/page/view.php?id=1049902>) and Study Plan (<https://coursespaces.uvic.ca/mod/page/view.php?id=1049903>) in MyMathLab. Those tools are very useful when you are preparing for the upcoming examinations.

- Review your tutorial worksheets. As soon as the grade for the tutorial worksheet is released on the CourseSpaces, you can read comments left by the markers and see

the detailed marking schema applied to each question on the worksheet.

- Talk to other students and the tutors in Math and Stats Assistance Centre (<https://www.uvic.ca/science/math-statistics/current-students/undergraduate/msac/>) about how to solve the questions correctly. Practicing how to reason through mathematics problems is a vital step in preparing for upcoming assignments and exams.

- Practice assessing your work objectively by yourself. After working on the question by yourself or with someone, ask yourself: 1. What was the most difficult part of this question for me? 2. What should I do next? (For example, find a similar problem in the textbook and work out the solution on my own.) 3. If I do this type of question again, would I do anything differently? If yes, what? 4. What did I learn from reviewing my work on this question? Thinking about those four questions will help you master the material in your Calculus course. You can find more useful suggestions on how to succeed in Calculus at <http://www.berkeleycitycollege.edu/wp/lrc/how-to-succeed-in-calculus/> If you have any questions or would like to talk to me about possible studying strategies, I would be happy to talk with you during the office hours.

Best regards,

Svetlana Oshkai

Math 100 Course Coordinator

**Letter sample of a feedback provided to the students after the midterm #2 for the student with the strong performance:**

Dear (Students name),

We have finished grading Math 100 Midterm #2 papers, posted the grades and the answers to all multiple-choice questions on CourseSpaces page, and returned the papers this Thursday in lectures.

The unclaimed midterm #1 and #2 papers can be found in the box in front of DTB A551 until the day of the final examination. Research shows that reviewing your work as soon as possible after the work is done is the most beneficial for your learning, so make sure that you work through your midterm paper now.

The important date to remember is October 31, i.e. today. This is the last day to drop any course at Uvic without consequence of failure.

The grade you achieved on the midterm #1, 12.5 or 65.8%, is above 65%. Your grade on the midterm #2, 18.5 or 74%, is in the same neighborhood as your midterm 1 grade, above 65%. Why did I mention 65%? Any grade below 65% on a midterm I consider to be in the "risk zone". Some programs, for example Engineering, requiring a course grade of 60% or higher in order for the course to count towards the program. Do you know what your program's requirements are? If not, please refer to the UVic calendar.

Midterm #2 is harder than the midterm #1, as the difficulty level of the material is increased. Congratulations on maintaining your grade! If you intend to improve your overall course grade, please take time to reflect on the changes you made in your study approach from midterm #1 to midterm #2, if any. Are you happy with your current grade, or do you aim to improve your overall course grade?

In order to succeed in Math 100, a student needs to demonstrate important foundational skills: calculating derivatives and calculating limits using derivatives and

limits rules. Those skills are essential in Math 100 course as well as in any of the future calculus-related courses. This is why I designed two practice tests using My-MathLab. The “Derivatives Gateway practice test” and the “Limits Gateway practice test” are not for grades, and can be taken as many times as each student wants. There are about 10 questions in each practice test, which will be different on every attempt. The time limit is 45 minutes. When the student acquired the skill necessary to correctly complete each practice test, it will take much less time than pre-set 45 minutes. Both skills will be used in the upcoming midterm #3 and the final examination.

Also, to succeed in Math 100, a student should master the material listed in the course outline. Please notice that “working on” the material is different from “mastering” it. This means that you should be able to solve the related questions on your own, in the reasonable amount of time. By all means, talk to your instructors, friends, classmates, Math and Stats Assistance Centre tutors and your private tutor in order to figure out how to approach the questions. But you only mastered a material if you are able to independently start and complete the work on each question by yourself.

Specifically, I recommend focussing on mastering the material using your: 1) homework assignments and the corresponding quizzes, 2) tutorial worksheets, 3) the recommended questions at the end of each textbook section, and 4) “Derivatives Gateway practice test” and “Limits Gateway practice test”.

I hope that you will find the “Derivatives Gateway practice test” and the “Limits Gateway practice test” useful in your preparation for the upcoming midterm #3 and the final examination. We, the entire Math 100 teaching team (markers, tutorial and lecture instructors), are rooting for you! We want to see you prevail and to achieve the grade that you set out to achieve.

If you have any questions or would like to talk to me about possible changes in

your studying approach, I would be happy to talk with you during the office hours.

Best regards,

Svetlana Oshkai

Math 100 Course Coordinator

**Letter sample of a feedback provided to the students after student missed two midterms #1 and #2:**

Dear (Students name),

We have finished grading Math 100 Midterm #2 papers, posted the grades on CourseSpaces page and returned the papers this Thursday in lectures. You did not write both midterms #1 and #2, therefore I cannot comment on your work based on the exams. I am concerned about your missing over 25% of the coursework in Math 100.

If you intend to drop the course, the last day to do so is October 31, i.e. today.

If you intend to stay in the course, then we need to meet and discuss your coursework weighting. If you have documentation that provides support for reweighting your course work in order to excuse your missed midterms, please bring the documents with you to the meeting.

I am available for a 15-minutes-long meeting on Tuesday, November 6 from 10:00am to 12:45pm. Please let me know the times that work for you, and I will set the time of the meeting.

In order to succeed in Math 100, a student needs to demonstrate important foundational skills: calculating derivatives and calculating limits using derivatives and limits rules. Those skills are essential in Math 100 course as well as in any of the future calculus-related courses. This is why I designed two practice tests using MyMathLab. The "Derivatives Gateway practice test" and the "Limits Gateway practice test" are not for grades, and can be taken as many times as each student wants. There are about 10 questions in each practice test, which will be different on every attempt. The time limit is 45 minutes. When the student acquired the skill necessary to correctly complete each practice test, it will take much less time than pre-set 45 minutes. Both skills will be used in the upcoming midterm #3 and the final examination.

Also, to succeed in Math 100, a student should master the material listed in the course outline. Please notice that “working on” the material is different from “mastering” it. This means that you should be able to solve the related questions on your own, in the reasonable amount of time. By all means, talk to your instructors, friends, classmates, Math and Stats Assistance Centre tutors and your private tutor in order to figure out how to approach the questions. But you only mastered a material if you are able to independently start and complete the work on each question by yourself.

Specifically, I recommend focussing on mastering the material using your: 1) homework assignments and the corresponding quizzes, 2) tutorial worksheets, 3) the recommended questions at the end of each textbook section, and 4) “Derivatives Gateway practice test” and “Limits Gateway practice test”.

I hope that you will find the “Derivatives Gateway practice test” and the “Limits Gateway practice test” useful in your preparation for the upcoming midterm #3 and the final examination. We, the entire Math 100 teaching team (markers, tutorial and lecture instructors), are rooting for you! We want to see you prevail and to achieve the grade that you set out to achieve.

If we have not already discussed your course re-weighting, I am looking forward to hearing from you before the end on the day on Friday, November 2 about the time of our meeting scheduled on Tuesday, November 6.

Best regards,

Svetlana Oshkai

Math 100 Course Coordinator

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