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Investigating the Impact of Active Learning in Large Coordinated Calculus Courses

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Abstract

Our study investigated the impact of active learning on student learning in a large, first-year, multi-section Calculus for Life sciences course(s). Two cohorts of students in control (traditional lectures) and experimental (active learning) conditions were compared based on achievement on identical test items, administered in a supervised in-person environment. We additionally held focus groups to ascertain student perspectives on active learning. Findings suggest that in both sets of cohorts, students in experimental conditions performed better, on average. Further, students felt that learning this way supported the development of transferable skills, such as work habits, self-directed learning and metacognition. We contend that with the combination of these results, in addition to our context and design, this study offers new evidence and insights into the impact of active learning in tertiary mathematics. We argue that, when implemented properly, active learning methods can improve student performance, even in large-enrollment and multi-section mathematics classes.

Keywords Active learning · Calculus · Large classes · Student engagement · Student-centered pedagogies · Flipped-classroom

Introduction

Calculus courses are routinely offered in post-secondary institutions around the world and are required by most STEM and other programs. Students in areas such as life and physical sciences, economics, computer science, and engineering typically complete one or more calculus courses in their first year of study. While these

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courses are prevalent, research has found that many courses have low student outcomes and retention rates (Freeman et al., 2014), prompting mathematics educators to examine ways to improve student outcomes. In particular, many researchers have been investigating ways of implementing evidence-based pedagogies such as active learning (Aji & Khan, 2019; Deslauriers et al., 2011; Kvam, 2000).

There have been recent calls to incorporate active learning methods in undergraduate mathematics courses in North America (e.g., Conference Board of Mathematical Sciences [CBMS], 2016). Following such calls, we implemented, since 2018, a new active-learning design that leveraged pre-class work and active engagement during classroom meetings (we provide details in the methods section). This study was motivated by our desire to revamp our Calculus for Life Sciences courses, which have been offered at our institution since 2005, and delivered using traditional lecture-based pedagogies. Over the years, we noticed low engagement, poor performance, and high drop-out rates in these courses. Moreover, as our classes are delivered in large lecture halls, with 130–150 students per lecture, we began investigating pedagogies and designs that could be successfully introduced in large courses, with 100 + students per lecture section.

In this paper we describe our new active learning design, and two quasi-experimental studies (Price et al., 2015) we designed in an attempt to answer the question: What is the impact of using active learning methods on students' learning outcomes in a large first-year calculus course? Under the umbrella of this research question, we more specifically asked:

- What is the effect of active learning on student achievement in large first-year calculus courses?; and
- What are student experiences with active learning in large first-year calculus courses?

Through the comparison of student achievement on identical test items, and student focus groups, we aim to better understand the value of and utility of active learning in large, coordinated, first-year calculus courses.

Moreover, the ongoing successful implementation of our active-learning design, and the positive effects on students' learning and engagement, prompted other mathematics instructors to implement a similar design in their large courses (e.g., in linear algebra, introduction to mathematical proofs, other calculus courses, etc.). Despite the challenges in implementing student-centered pedagogies in large classes in mathematics and other STEM disciplines (Apkarian et al., 2021; Gilbert et al., 2021), our studies indicate that careful and thoughtful implementation can result in better learning outcomes.

Literature Review and Theoretical Perspectives

Mathematics in post-secondary settings is typically taught through traditional, teacher-centered methods (most often lecture-style) that promote passive transmission of knowledge (e.g., Stains et al., 2018). Decades of research has suggested that this is not the most effective way to support mathematical learning (CBMS, 2016), and hence, researchers and instructors alike have been investigating ways of increasing student engagement and understanding through student-centered pedagogies. Along with numerous others (e.g., Faust & Paulson, 1998; Weiman, 2014, etc.), we propose the wider use of active learning as a student-centered pedagogy to teach post-secondary mathematics, specifically large, multi-section first-year calculus to students. In this section, we will explore how we are characterizing the term active learning, both generally and in the context of mathematics, and present literature that explores its use.

Active Learning

Student-centered pedagogies, and particularly the concept of active learning, have been widely discussed in higher education literature for decades (e.g., Faust & Paulson, 1998; Frederick, 1987; Prince, 2004; Weiman, 2014, etc.), often as a counter to so-called "traditional",[1] lecture-based teaching. The actual term 'active learning' evades exact definition, with scholars describing it in variable ways. After reviewing a variety of descriptions, Prince (2004) distilled "the core elements of active learning [to] student activity and engagement in the learning process" (p.223), thus providing a broad and discipline-transferable definition of the term. As it pertains to mathematics, the CBMS (2016) defines active learning as, "refer[ring] to classroom practices that engage students in activities, such as reading, writing, discussion, or problem solving, that promote higher-order thinking" (p.1). They further argue that post-secondary instructors must consider ways of engaging students more consistently and deeply in mathematics and contend that active learning holds promise for improving equity and access to the field itself. Indeed, Theobald et al. (2020)'s work suggests that the effective use of active learning can be particularly impactful for underrepresented groups in post-secondary STEM programs. For the purposes of the presented work, we consider active learning to be a pedagogy that engages students in the *doing* of mathematics during and outside of class time, through a combination of activities, video and reading materials, and assessment practices (see the section on context for further details).[2]

There is significant evidence across numerous fields that shows how incorporating active learning in higher education has positive effects on student learning and achievement (Aji & Khan, 2019; Cavanagh, 2011; Kramer et al., 2023; Kvam, 2000; Lugosi & Uribe, 2022). In their seminal study examining the effects of active learning on student performance in science, technology, engineering, and mathematics (STEM) programs, Freeman and colleagues (2014) performed a rigorous meta-analysis of over 200 active learning-focused research articles. They found that generally,

[1] The word "traditional" is used in this paper to reflect historically common pedagogy in higher education that relies on teacher-centered forms of teaching, most often lecturing (e.g., Kim et al., 2019).

[2] Note that we use the term "active learning" as shorthand for "active learning pedagogy." We note that it is the learners who engage in active learning, and we seek to investigate pedagogical practices that support student's active learning within classroom settings.

"the data indicate that active learning increases student performance across the STEM disciplines" (Freeman et al., 2014, p.8411). Further, this oft-cited study indicates that regardless of class size, the effects of active learning are positive, though this effect is most clearly evident with smaller classes.

In more recent studies, it becomes clear that the effectiveness of active learning is tightly linked to the quality of active learning students have access to (Theobald et al., 2020). Indeed, Prince (2004) warns that while evidence broadly indicates active learning has a positive impact on student learning, success is dependent on the means of implementation. Because active learning includes "a spectrum of… methods, techniques, and environments in which students can be effectively engaged in the process of learning" (CBMS, 2016, p.7), the way active learning is integrated into courses has a critical impact on its effectiveness. For example, Cavanagh (2011) found that while using active learning in a mathematics education course resulted in deepened and focused learning, as well as greater motivation to learn, students indicated that the type of activity and consistency of active learning strategies in the course were crucial components of student learning and engagement. Additionally, when researchers at a medical school adopted an active learning curriculum, they noticed that students were not participating in their courses, often skipping class (White et al., 2014). They sought to understand why and found that students took issue with the richness and quality (or lack thereof) of tasks, again suggesting that intentional and thoughtful design is paramount when adopting active learning pedagogies.

Active Learning & Mathematics

Over the past two decades, exploration of active learning has flourished in the STEM disciplines. However, while evidence from large undergraduate courses is prevalent in the life and physical sciences (e.g., Deslauriers et al., 2011; Moravec et al., 2010; Poirier & Feldman, 2007), it is noticeably limited in mathematics. There is, however, a burgeoning field of research focused on active learning in the form of flipped classrooms in tertiary mathematics (e.g., Jungic et al., 2015; Maciejewski, 2016). Briefly, "flipping" the classroom describes a pedagogical strategy wherein content is accessed by students before class time. Then, during class time, students engage with this material in a variety of ways. This is commonly done by assigning short videos related to specific topics for students to watch prior to class, and later working on problems with the guidance of a professor. In a quasi-experimental study that divided seven sections of a large calculus course into traditional or flipped groups, Maciejewski (2016) found that students achieved higher grades in the sections where they participated in the flipped classroom model. He found that the gains were particularly positive for students with a limited secondary calculus background, suggesting that flipped classrooms could be used as a means of achieving greater accessibility and equity in large calculus courses.

The majority of scholarly work done in the area of active learning in mathematics is either focused on the impact of varying levels of active learning in a course on student performance, or student perceptions of active learning in classrooms, explored further below.

Effect of Active Learning on Student Performance

Some scholars have conducted quasi-experimental studies that divided sections or portions of mathematics courses into traditional versus active learning-based teaching methods (e.g., Code et al., 2014; Maciejewski, 2016; Roop et al., 2018). In all of these studies, results have indicated that students who learned via active learning methods had improved comprehension or higher achievement compared to students taught through traditional methods. For example, researchers compared two sections of a large calculus for commerce course where they performed a one-week intervention using a switching replication model to assess the effect of using active learning strategies on student learning (Code et al., 2014). They found that the topics taught via active learning pedagogies promoted deeper conceptual understanding as compared to those taught with traditional methods. Additionally, Roop et al. (2018) saw that students in the active learning section of a calculus course performed marginally better than students in the traditional learning section of the course. They do note, however, that students self-selected into their respective course sections, and surmise that it is possible that students chose a section that accommodated their own learning styles, and thus caution interpretation of their results. Further, studies on the effectiveness of inquiry-based learning (IBL), a pedagogical framework that is sometimes employed in active learning classrooms, found evidence of improved mathematical competencies and confidence (Kogan & Laursen, 2014; Lenz, 2015). While these studies indicate promise in changing student attitudes and outcomes, it is key to note that the courses themselves were small, and it is unclear if using IBL in large courses will result in similar effects. Even still, there is indication that long-term effects of learning via active-learning based pedagogies are possible (Kvam, 2000).

In each of the studies above, the size of the courses where active learning pedagogies were variable but rarely large (i.e., 100+ students per section of a multi-section course). Though there are some recent studies that have begun to examine active learning in these large environments (Bennoun & Holm, 2020; Miller et al., 2020), these studies primarily describe the ways that they are implementing active learning. Given the common practice in many Canadian post-secondary institutions of having large first-year calculus courses, we are intrigued by the idea of investigating the effects of active learning pedagogies in these spaces.

Student Perceptions of Active Learning

While more post-secondary educators become convinced of the value of active learning, the student perception of active learning remains variable. In a medium-sized engineering calculus course that regularly incorporated active learning through peer instruction into lectures, researchers administered questionnaires twice throughout the course to gain an understanding of student perspectives on this pedagogy (Weurlander et al., 2017). They found that while many students enjoyed the methods of active learning, some did not and expressed concerns about learning in this way. However, in a study that incorporated active learning into a large calculus class by providing students with individual whiteboards for problem solving during class, students reported high levels of engagement and perceived active learning to be helpful in their understanding of course content (Reinholz, 2018). Bowers et al. (2019) corroborated this, finding that students reported greater engagement when learning via active learning in a large precalculus course.

While student perception of active learning can impact their engagement and consequent achievement in a course (e.g., Gasiewski et al., 2012; Lumpkin et al., 2015), researchers have found that even when students did not like active learning, their learning in a course still improved (Smith & Cardaciotto, 2011; Weurlander et al., 2017). Further, even when students had neutral (i.e., neither positive nor negative) perceptions of particular active learning tasks, they still perceived aspects of active learning to be helpful to their learning (Rosenthal, 1995).

Class Size as a Factor

Despite the evidence supporting the use of active learning in post-secondary mathematics (and other disciplines), there is continued resistance to adopt teaching strategies outside of the “traditional” lecture-style approaches, particularly for instructors teaching large classes. The issue of class size acts as a barrier or major area of concern for many instructors, including those who are interested in improving teaching and learning experiences in post-secondary education (e.g., Apkarian et al., 2021; Gilbert et al., 2021; Kim et al., 2019; Shadle et al., 2017). For example, Gilbert and colleagues (2021) found in a recent study that even amongst faculty who are interested in innovative practices the practical concerns of “scaling up” is “both time-consuming and unwieldy” (pp.133–134). The feasibility of using student-centred strategies, including those associated with active learning, is frequently cited as a challenge for instructors (Apkarian et al., 2021; Shadle et al., 2017). Given that many studies that do showcase the positive impact of active learning have class sizes below 100 (Aji & Khan, 2019; Kramer et al., 2023; Lugosi & Uribe, 2022), we are compelled to consider the potential of active learning in the context of large class sizes. We are particularly interested in exploring active learning in courses with class sizes of greater than 100 because the first-year calculus courses taken by students at our institution typically have 100 – 140 students per section. Further, we believe that while there is a variety of evidence in support of active learning, both in terms of effect on student performance, as well as student perception of active learning, there remains a gap in the literature of comparative data on the effectiveness of active learning, particularly from the perspective of large post-secondary calculus courses. Thus, we aim to address this gap by attempting to isolate active learning as a variable as much as possible and measure student outcomes in a large calculus course. In doing so, we hope to provide further insight into the utility and effectiveness of active learning as pedagogy in large undergraduate mathematics courses.

Context: Calculus for Life Sciences Design

Since 2018, we have implemented a new active-learning design in our Calculus for Life Sciences courses. In this design, students are required to prepare in advance, by reading the textbook, watching videos, and completing a pre-class quiz[3] before coming to class. During lectures and tutorials, whether conducted in-person or remotely, students participate in polls, short lectures and group work. Students also complete a more traditional homework assignment (the 'post-class quiz'), a week after the material is covered in class and tutorials. In September 2019, our full-year Calculus for Life Sciences course was split into two one-semester courses: 'Differential Calculus for Life Sciences' and 'Integral Calculus for Life Sciences'. However, we made no changes in terms of content and design, and continued to implement the active-learning design introduced in 2018–2019.

Prior to implementing the active learning design, the course was taught in a traditional lecture-based fashion. Instructors introduced new material, and students listened, took notes, and occasionally asked questions or answered questions posed by the instructor. In tutorials, the TAs summarized the material learned in class, and solved examples on the board. Though some TAs did promote active engagement of students during tutorials, this was inconsistent as it occurred at the discretion and interest of the individual TAs.

Our new course design is based on the following principles.

- **Presence.**
  Introducing new teaching methods in a course has little chance of impacting student performance and attitudes unless students *show up* to class. The new design must achieve at least 80-85% attendance and participation in lectures and tutorials.
- **Monitoring.**
  The new design should incorporate a mechanism for monitoring students' work and progress during class time.
- **Communication.**
  The new design should allow for two-way communication between the students and the instructor and/or teaching assistants on site. We must find ways to listen and watch students as they work, and provide meaningful guidance and feedback in real-time.

Meeting these goals in large classes, with more than 100 students, is challenging, due to the increased anonymity of students, and lack of more personal connection and one-on-one attention. Moreover, there are logistical difficulties which are specific to large classes (e.g., Shadle et al., 2017): Taking attendance, looking at students' work, and supporting students who need guidance becomes more difficult.

[3] This is not a supervised quiz, but merely a homework assignment labeled as 'a quiz' on our learning management system.

To achieve the above targets, we use evidence-based teaching strategies, combined with technological tools (such as iClickers) and presence of teaching assistants (TAs) during lectures. The iClickers and in-class TAs allowed us to quickly and efficiently monitor attendance, get immediate feedback from all students in class, and provide more support while students are working on a mathematical task.

To measure the effectiveness of the new design and isolate, as much as possible, active-learning as a variable, we made the following important decision: *There will be no change in the content covered, and we use the same level and question types on tests and exams.*

Covering the same content was achieved by spreading the learning over the various course components before, during and after class (see the Course Structure below). For instance, certain techniques and examples were covered in the pre- and post-class work and tutorials, making more time for discussions and activities during lectures. By doing so, we were able to maintain content coverage. The learning objectives, level of complexity and key concepts remained unchanged compared to prior years.

Keeping the level and style of tests and exams the same allowed us to reuse previous years' questions to measure the impact of the new design. We also continued to use the same textbook (Hass et al., 2017).

Course Structure

Each week's material was covered through a five-steps process:

1 **Preparation (Readings, Videos and Pre-Class Quizzes).**
Over the weekend, students are required to read the relevant sections from the textbook, watch videos, and prepare to complete a short assessment (pre-class quiz). This is the students' first exposure to the material.

2 **Pre-Class Quiz.**
The pre-class quiz, which is normally due on Sundays, consists of basic questions about the new content. It encourages students to go over the material and start processing new ideas, terminology and techniques.

3 **Active Class Meetings.**
Lecture sessions are designed to maximize students' engagement while still modeling an expert's thinking process and how to properly communicate mathematical ideas and processes. For each topic, we use a combination of polls (multiple-choice questions), group activities, short lectures and class discussions. More details are available in the online resource.

4 **Active Tutorials.**
In the week following lectures, each student attends a 50-minute tutorial session led by a teaching assistant. In tutorials, students review previously submitted assignments, and then participate in group work and discussions.

5 **Post-Class Quiz.**

At the end of the week, after attending a tutorial session, students complete a post-class quiz by Friday night. This quiz is more advanced than the pre-class quiz, and includes an automatically graded and a writing component.

Marking Scheme

Typically, 20% of the student's course mark come from unsupervised components such as pre/post-class quizzes, class and tutorial participation. The other 80% come from supervised components—midterms and a final exam.

Instructor and TA Training

Training and supporting instructors and teaching assistants is crucial, as some are assigned to teach this course with little experience in conducting active-learning sessions. We combine a full day of training before the start of the course together with ongoing checks, class visits, and staff meetings. Two or three class visits were conducted each term, followed by a meeting with the instructor to discuss the observed class and ways to improve the implementation of the new design. We worked closely with experienced instructors and experts in active learning from various departments and educational developers from our academic skills center to develop a training program and support instructors and TAs in the course.

Methodology

This study took place at a large post-secondary institution in Canada. We conducted a comparative study to measure the effectiveness of active learning in two cohorts of first-year calculus for life science students and investigate the impact of these pedagogies on student experiences in the courses.

Context

In the years 2005–2019, our Calculus for Life Sciences course was offered as a single full-year course over the fall and winter semesters (September-April, 24 weeks) and in a condensed form each summer (May–August, 12 weeks). In the first few years, the fall-winter enrollment was around 400, and the summer enrollment was about 100 students. In later years enrollment grew, and from 2012 to 2019 we had about 600–700 students in the fall-winter offering and another 200 in the summer. Students meet with an instructor for three 50-min lecture sessions per week and with a teaching assistant for one 50-min weekly tutorial session. The typical class size is about 100–140 students in a lecture section, and 25–35 students in a tutorial section. The course is tightly coordinated. Students in all sections complete the same homework assignments, tests and exams.

Table 1 Independent-samples t-test summary for senior high school mathematics grades (Cohorts 1A and 1B)

	Cohort 1A		Cohort 1B		*t*	*p*	Cohen's *d*
	N	*M(SD)*	*N*	*M(SD)*			
MHF4U	405	82.22(9.64)	352	82.40(9.02)	-0.269	0.788	0.019
MCV4U	376	78.75(13.71)	312	79.27(13.51)	-0.495	0.621	0.038

Research Design

Quantitative and qualitative data were both collected in this study through a sequential triangulation design (Creswell et al., 2011). In this design, the collection of qualitative data occurred after the collection of quantitative data, and after initial analysis, the aim was to interpret the data together to understand converging or diverging ideas. First, two experiments were conducted over the course of several years where student performance on identical test items were compared. Given the nature of educational research, we have attempted to create experimental conditions to the best of our abilities; however, we recognize that factors such as a lack of true randomness, human error, and non-equivalence of groups suggest that a quasi-experimental design best describes this work (Price et al., 2015). Nevertheless, we have attempted to reduce the effects of confounding variables as much as possible by ensuring comparison groups are as similar as possible given the available data. In doing so, we have followed the lead and learned from prior quasi-experimental studies on active learning (Code et al., 2014; Roop et al., 2018). We have ensured that comparisons were made only on identical test items, and we collected and analyzed senior secondary school mathematics achievement data to ascertain differences in background mathematical knowledge across comparison groups. Additionally, the course content and course coordinator remained the same across all comparison groups (i.e., experimental groups were not taught different or more calculus concepts than the control groups). Both experiments were conducted in scenarios where students were taught using traditional pedagogical methods (control groups) or active learning pedagogies (experimental groups). After the collection of the quantitative data, focus groups were conducted with students who learned under active-learning conditions. Both methods are described in further detail below.

First Experiment (February 2019) The 2018–2019 academic year was the last year in which we offered the full-year Calculus for Life Sciences course. It was also the first time we implemented an active learning design in the course across all sections. For the third term test in the course, in February 2019, we used an old script used for Term Test 3 in February 2014. Students did not know that an old script would be used, and had no access to old tests from that year. Moreover, the marking of the test was done using the same guidelines and marking scheme from 2014. This offered a unique opportunity to use the 2014–2015 cohort as the control group (cohort 1A), and the 2018–2019 cohort as the experimental group (cohort 1B). To establish

Table 2 Independent-samples t-test summary for senior high school mathematics grades (Cohorts 2A and 2B)

	Cohort 2A		Cohort 2B		*t*	*p*	Cohen's *d*
	N	*M(SD)*	*N*	*M(SD)*			
MHF4U	338	81.63(10.00)	489	81.61(11.44)	-0.02	0.984	0.002
MCV4U	315	76.15(17.25)	410	78.07(14.59)	-1.917	0.106	0.12

comparability between cohorts 1A and 1B, an independent-samples *t*-test was conducted to compare mean differences across two secondary mathematics courses that are commonly taken by students in Ontario (Advanced Functions [MHF4U] and Calculus & Vectors [MCV4U]). These tests revealed that there were no significant differences between cohorts 1A and 1B (see Table 1). Hence, we are reasonably confident that on the basis of senior secondary mathematics achievement, the two cohorts are similar.

Second Experiment (December 2019) In the 2019–2020 academic year, our full-year Calculus for Life Sciences was split into two one-semester courses, though the content did not change from prior years. We continued to use the active learning design in the two courses, while improving and adjusting our materials and training program. In December 2019, students wrote the final exam in 'Differential Calculus for Life Sciences' (the first course in the sequence). The exam had two parts: Part A—nine short questions, where only the final answer is graded, and Part B—four long answer questions, where the full solution is graded and part marks can be awarded. For Part A, we used the same questions as in Part A of Term Test 2 in November 2015 (when the course was still a full-year course). Again, the questions in Part A were used without making any changes. Students were not informed about the experiment and had no access to the 2015 test. As in the first experiment, secondary school data were analyzed to ascertain a baseline of comparison for both cohorts of students (cohorts 2A and 2B). After conducting independent-samples *t*-tests for both MHF4U and MCV4U, respectively, no significant differences were ascertained between the two cohorts of students (see Table 2). Again, this gives us confidence that in terms of prior mathematics achievement levels, these groups of students had no discernible differences.

While there are students in these cohorts who are not domestic and may have not taken these exact courses, the majority of the students (about 80%) in our experiments were domestic.

We note that instructors in the experimental groups were not the same as in the control groups. However, the course coordinator remained the same in all four cohorts, and the course was tightly coordinated. Course materials, homework assignments, tests and exams, as well as materials for conducting active-learning class sessions were used uniformly by all instructors. For both years of active learning, instructors remained the same. These were instructors who opted to teach the courses in question and were made aware that there would be an intentional active learning design embedded in the course. Instructors were given the opportunity to decide if they would be comfortable teaching in this way and had the option of switching courses if they were not. All instructors opted to remain teaching the course in its redesign. As a result, we were able to maintain consistency of instructors in both experiments.

In addition to the two experiments, we conducted two focus groups ($n=8$) with undergraduate students who took the Differential Calculus for Life Sciences course in the 2019–2020 academic year to better understand the impact of active learning pedagogies from a student perspective. Because of how large the calculus courses are, focus groups were chosen to offer a (voluntary) opportunity for as many students who were available and interested in offering their insights. Indeed, we aimed to use focus groups to "investigat[e] the extent of both consensus and diversity among the participants as they engage in sharing and comparing among themselves" (Flick, 2017, p. 251). The author of this study who was not a calculus instructor acted as the facilitator during the focus groups and used best practices as outlined by the ETR (2013). The framework of questions were developed through an iterative process with both authors creating questions, offering feedback, and refining ideas. Questions focused on student experiences with course pedagogies and how it impacted their learning.

Data Collection and Analysis

The main sources of data used in this study were senior secondary school grades (i.e., grade 12 mathematics grades), test scores from respective calculus courses, and verbatim transcripts from student focus groups. Secondary mathematics grades were collected directly from the university registrar and were anonymized and aggregated. The course coordinator, along with the head TA oversaw the marking of each test and exam in the course and consequently had direct access to student marks from every section through a central database.

Using convenience and purposive sampling procedures (Teddlie & Yu, 2007), we collected data from all students enrolled in Calculus for Life Sciences (or the split version, Differential Calculus for Life Sciences) for in the following years:

- Winter 2014 (Cohort 1A)
- Winter 2019 (Cohort 1B)
- Fall 2015 (Cohort 2A)
- Fall 2019 (Cohort 2B)

For clarity, we will refer to each group under study by cohort names (as above) for the remainder of this paper. Importantly, we were able to address the issue of self-selection into preferred learning-style courses (Roop et al., 2018) in that all sections of the course were taught via active learning in Cohorts 1B and 2B. Hence, any student that took the Calculus for Life Sciences courses during the experimental years will have learned the material through active learning pedagogies.

Participants for focus groups were recruited by the author who did not teach these calculus courses via email. Students were invited to participate in an in-person focus group on campus and offered both pizza and $20 gift cards for participating. These recruitment efforts took place in February 2020, after students had completed and received their grades for their first-term calculus course.

All quantitative data were analyzed using *SPSS* (v26). For each statistical analysis conducted, all assumptions (e.g., normality, homogeneity of variances, etc.) were checked and met. Qualitative data were transcribed by an outside source and iteratively coded and analyzed for emergent themes (Kolb, 2012) by the authors. Authors initially used a priori codes that were created based on themes in the focus group question protocol. Tables developed using Microsoft Word were used to organize data according to these codes. In the next cycle of coding, new codes were added based on emerging or new ideas that were present in the data. Following this, codes were consolidated into categories, and then themes, as a means of making sense of the data in the context of this study. During these cycles, authors remained in discussion as a way of member-checking and ensuring consistency in interpretation. In doing so, authors were better able to elucidate patterns and themes (Saldaña, 2013). Researchers received institutional ethics clearance for this study. All data were anonymized and/or de-identified, and securely stored by both researchers.

Results

In this section, we present findings on the impact of active learning on student performance and learning in first-year calculus. First, we share the quantitative results, comparing student performance on identical items from two experiments. Second, we explore students' perspectives on the impact of active learning on their experiences in calculus.

Comparing Student Achievement in Calculus

The nature of the data collected allowed us to conduct descriptive and inferential statistics to ascertain and compare mean and median values of each of the test items across the active learning and non-active learning cohorts, including senior secondary school mathematics grades (as reported in the previous section). Because there were no significant differences across cohorts for any of the senior secondary school mathematics courses analyzed, we proceeded with relative confidence in our further analyses and conducted independent-samples t-tests to evaluate the mean differences in percent scores across cohorts. Below are the results from scenario 1 and scenario 2, respectively.

Table 3 Results of independent-samples t-test comparing term test scores between Cohort 1A (2014) and Cohort 1B (2019)

	Cohort 1A		Cohort 1B				
	M	*SD*	*M*	*SD*	$t(1097)$	*p*	Cohen's *d*
Test 3 Score	45.608	23.39	52.628	24.63	-4.903	< .001	0.292

Scenario 1: Comparison of Term Ttests from February 2014 (Cohort 1A) and February 2019 (Cohort 1B)

An identical term test was given to Cohort 1A and Cohort 1B, respectively. An independent-samples *t*-test was conducted to evaluate the hypothesis that percent scores of Test 3 in Cohort 1B are different from total percent scores of Test 3 in Cohort 1A (Table 3):

These results indicate that the independent-samples *t*-test resulted in a p-value of < .001, suggesting a significant difference exists between Cohorts 1A and Cohort 1B's Term Test Scores. The 95% confidence interval for the difference of the means ranged from -9.83 to -4.21. The effect size (Cohen's *d*) of 0.292 indicates a small effect. In plain terms, these results suggest that there is a statistically significant difference in percent scores between Cohort 1A and Cohort 1B, and that, more specifically, students who learned calculus under the active learning model achieved better grades on average ($MD = 7.02$) than students who learned calculus under traditional models of teaching (see Fig. 1).

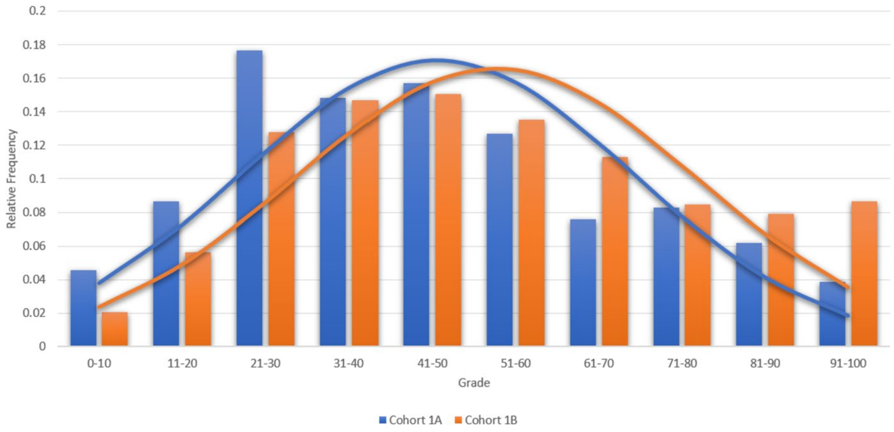

Fig. 1 Scenario 1: Comparison of Student Achievement on Test 3

Table 4 Results of independent samples t-test comparing term test, part A scores between Cohort 2A (2015) and Cohort 2B (2019)

	Cohort 2A		Cohort 2B				
	M	*SD*	*M*	*SD*	*t(1156)*	*p*	*Cohen's d*
Test 2, Part A Score	43.2	28.81	57.66	28.55	-8.575	< .001	0.504

Scenario 2: Comparison of Term Tests from November 2015 (Cohort 2A) and December 2019 (Cohort 2B)

Scenario 2 presented a situation where Cohorts 2A and 2B were each given different assessments that included an identical component. Specifically, Cohort 2A wrote a term test whereas Cohort 2B wrote a final exam but on each of these assessments, "Part A" was identical. However, unlike in scenario 1, Cohort 2A took their calculus course over the course of a full academic year, whereas Cohort 2B took their calculus course over one semester. Consequently, Cohort 2A took this test mid-way through the year whereas Cohort 2B took this test at the end of the course. We wish to acknowledge and account for possible influences this may have had on students' performance (e.g., in a full-year course, students may have dropped the course after the mid-way point while in a one semester course, students may have dropped the course before the end) and present two analyses: the first is one of that includes all of the marks in both cohorts (Table 4), and the second analysis adjusts for the average number of students who will have dropped the course prior to the test based on previous years' demographic data (Table 5). The number of students who were dropped from Cohort 2A were identified based on retention statistics from Cohort 2B, resulting in the lowest 70 marks from Cohort 2A being eliminated in the adjusted analyses. The lowest marks were the ones that were dropped to account for the "worst-case" scenario.

Both Table 4 and 5 showcase the results of independent-samples *t*-tests that were conducted to evaluate the hypothesis that the student scores in Part A of Test 3 for Cohort 2B are different from student scores on Part A of Test 2 in Cohort 2A. Both tests were significant (each resulting in a $p < .001$, respectively), indicating that on average, the percent scores for Cohort 2B were higher than the scores in Cohort 2A. For the unadjusted data, the 95% confidence interval for the difference of the means ranged from -17.77 to -11.15, and the effect

Table 5 Adjusted results of independent samples t-test comparing term test (part A) scores between Cohort 2A (2015) and Cohort 2B (2019)

	Cohort 2A		Cohort 2B				
	M	*SD*	*M*	*SD*	*t*(1083.55)	*p*	Cohen's *d*
Test 2, Part A Score	48.67	26.27	57.66	28.55	-5.403	< .001	0.328

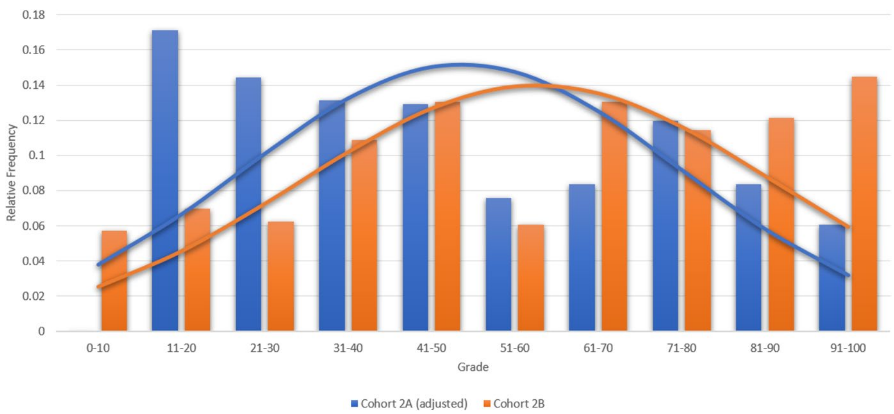

Fig. 2 Scenario 2: Comparison of Student Achievement on Part A (Adjusted Results)

size (Cohen's *d*) of 0.504 indicates a medium effect. Similar to scenario 1, these results suggest that the difference in percent scores of shared test items between Cohorts 2A and 2B is statistically significant and that, again, on average, students achieved higher grades under the active learning model compared to students who learned through the traditional model. Indeed, the mean difference in percent scores between cohorts 2A and 2B on the same test was approximately 14.46, indicating a substantial increase in scores for Cohort 2B.

Our adjusted analyses confirmed these results, further, where there was a 95% confidence interval for the difference of the means ranged from -12.25 to -5.72 and an effect size (Cohen's *d*) of 0.328, again indicating a medium effect. Though the mean difference in percent scores is smaller than with the non-adjusted analysis, students in Cohort 2B still achieved higher percent scores on average than those in Cohort 2A ($MD = 8.99$). See Fig. 2.

Notably, in both analyses for scenarios, similar conclusions were found. Specifically, in both instances, there were significant differences in the means between Cohorts 2A and 2B, with Cohort 2B scoring higher.

Exploring Student Perspectives

Two focus groups were conducted to ascertain student experiences with active learning in calculus. Focus group #1 (FG1) had six participants currently enrolled in 'Integral Calculus for Life Sciences' (winter term), all of whom took the 'Differential Calculus for Life Sciences' prerequisite in the previous semester (fall term). Focus group #2 (FG2) had two participants, both students enrolled in the 'Differential Calculus for Life Sciences' course (winter term). Participation in these focus groups was voluntary. Below are findings from these focus groups.

Active Learning for Skills Building

Participants in both focus groups discussed active learning in terms of the transferable skills that it offered to them. In FG1, the terms “independence”, “time management”, and “responsibility” were mentioned when asked about the benefits of active learning in calculus. Indeed, one participant noted that the structure of active learning “forces [students] to time manage and that’s kind of the whole point. Well, not the whole point, but a lot of the reason why we’re here is to learn real life skills and time management is number one.” While a skill such as time management is not indicated as an explicit learning goal for calculus courses using active learning, the participant is highlighting a perceived benefit of learning in this way and suggests that this is a skill that will be valuable to them beyond this particular course. In FG2, participants’ comments suggested that active learning helped with perseverance and focus due to greater engagement during class time. Again, participants indicated skill development outside of the practice and acquisition of mathematical content. Additionally, participants in FG2 felt that active learning offered an opportunity to build community and collaborate with other students in a lower risk environment. One participant explained:

> I feel like active learning maybe made it better for us…to meet new people and to kind of, like, figure out how to solve a question together rather than like, you getting stuck and trying to think about it at home or somewhere else. So, in that sense you’re able to interact with people, ask questions, not even just towards a professor but to, like, peers.

Given the typical size of the sections of this course hovers around 120 students, it is notable that participants felt that there was opportunity for peer-to-peer interaction, as this type of engagement (from their perspective) is not always the case in such large classes.

Participants’ comments suggest that active learning was helpful for developing their metacognition (although they did not explicitly use the term metacognition). One participant noted that active learning places “the emphasis on you learning from your mistakes and then getting a grasp of what you know”, suggesting that this method allowed them to understand their own competency levels better. Another participant explained:

> Active learning really helps me in the sense that I’m able to track my own progress, so after every like, after the week is done and I go for the post-quiz I know that there are some problematic areas. And I know that I need to work on it before the next mid-term. And then like pre-quizzes, same thing, time management, where am I lacking, like where is my understanding going wrong. And then if I do end up doing the homework before class then I can always ask the professor like could you help me out with this and that kind of thing.

This participant describes a consistent process by which they are able to check in with themselves using data that tracks their progress (i.e., course assessments and evaluations). Notably, this participant shares a reflective process that they engage in that informs their learning. This was a sentiment that was present in both focus groups, as being able to essentially stay engaged with material throughout the term was considered beneficial and supported their learning.

Active Learning for Conceptual Understanding

Participants offered mixed comments on the utility of active learning for conceptual understanding. In FG1, there appeared to be a divide situated around the use of active learning when content is new versus already learned (in their view). A participant who had taken calculus in secondary school said, "I felt that active learning was kind of redundant in the first half of [our differential calculus course] because you already know everything." Another participant explained, "[active learning] helps if you don't know it but if you already know it" it's largely "supplement[al]" for students. Notably, this same participant later noted that they felt a peer who learned calculus entirely through active learning likely had a deeper understanding than them. The juxtaposition of the comments around having background knowledge helping or not helping highlights the diversity of perceptions about when and why active learning is beneficial. While they did not provide specific explanations for why active learning influenced the development of their conceptual knowledge, participants indicated that the course structure, in a way, forced more engagement from students. Specifically, one participant from FG2 shared that, "you're actually like, doing other things that are involving yourself in the [differential calculus] class a little bit more, so you get to, like, understand and interpret the information better than just sitting there and looking at the board." Here, the participant provides a contrast between what is often viewed as the "traditional" method of teaching with a more active approach, and has reflected on how the *doing* of mathematics in class can impact understanding. A participant in FG1 noted that they had a similar experience, and the result was that for the "final exams for last semester, I feel like active learning really helped because the things stuck in my head."

Participants in FG2 brought up an important perspective, indicating that while doing problems in class and activities are helpful, they would like if instructors could "explain more of the way there's actual steps to do a question so [that] even though you don't always understanding something, like the concept of it, you still have a kind of basis of what to do so you're not always lost." In this case, it appears that participants are suggesting a need for explicit instruction, particularly around procedural components of different topics, as a way of ensuring there is a base level knowledge shared by students. In FG1, some shared this view, with one participant saying that "I would have really appreciated it if my professor had given a little bit more input on what is expected of me." When asked to expand on what this meant, the participant alluded to needing greater clarity on non-mathematical components of assessments (e.g., how much to write in an open answer), suggesting that a potential challenge they experience in these contexts is not necessarily related to mathematical understanding.

Structural Issues with Active Learning

Though participants in FG1 largely had favorable views towards active learning, they did note structural concerns such as the inclusion of "highlights"[4] and the desire (for one participant) of having a "proper lecture" in the course:

Participant: I find like, I don't know, my main issue with [parts of active learning] was why are you giving me questions if I could just do them at home. So, like I get it, it's practice, it's good, I'm not saying like take it out completely, but I do want to have a proper lecture too.
Facilitator: What do you mean by proper lecture?
Participant: Like the professor actually goes through the chapter itself. Sure, you can skim over parts that are like really simple. I know there are people in my class who would have really appreciated having a proper lecture instead of just coming in and attempting questions. Like he, my professors does go over some key things from the chapter before attempting the question, but I like, I feel like if he had, if there was a lecture component to it as well it would sink in more.

Though this participant is from FG1, their desire for "a lecture component" to deepen understandings aligns with those in FG2 whose perspectives were that there is a need for increased explicit instruction.

As noted earlier, participants held mixed views towards "highlights", a component of each class where key ideas of a particular chapter or topic were discussed and summarized through a short lecture. Participants in FG1 had largely negative views towards the inclusion of "highlights", while participants in FG2 had largely positive views towards the inclusion of "highlights" in course lectures. Though they did not go into depth in describing the reasoning behind their feelings, it appeared that the participants in FG1 did not feel they were necessary, whereas the participants in FG2 felt that they were a helpful reminder of key parts of a lesson. Further data is needed to better understand the discrepancies in these participants' experiences with this component of the course structure.

Finally, while they only briefly touched upon this topic, both focus groups also emphasized the importance of an effective instructor and/or teaching assistant (TA) for active learning to be successful. Participants indicated that tutorials could be helpful when a TA was well informed on active learning (from their perspective), and an instructor who is enthusiastic with regards to mathematics and active learning as a pedagogy aided in their understanding of the material. In both cases, it appears that the pedagogical knowledge as well as the demeanor of the educator using active learning is conveyed to students, and can influence how students engage with these calculus classes.

[4] "Highlights" are a component of each class structure where important ideas related to a concept/topic are discussed (this can be done orally, on a projected slide, a handout, etc.).

Discussion

This study sought to investigate the potential impact of active learning on student achievement and learning in a large, first-year calculus for life sciences course. Although many mathematics courses at post-secondary institutions are delivered using "traditional", teacher-centered methods (e.g., lecturing), decades of research suggests that these are not the most effective in supporting students' learning and achievement, nor in providing equitable access to higher education (CBMS, 2016). Through the comparative analysis of student grades on particular assessments over two separate experiments, and later, by speaking with students in focus groups, we attest that the overall impact of this pedagogy has been positive.

In both experiments, we saw a statistically significant difference between the control and experimental cohorts, where students in the active learning cohorts performed better on identical supervised assessments. These results are supported by existing evidence in other jurisdictions (e.g., Freeman et al., 2014; Kramer et al., 2023; Lugosi & Uribe, 2022; Maciejewski, 2016; Roop et al., 2018). Indeed, even when accounting for potential differences, we continued to see a significant and substantial difference between the control and experimental cohorts. These findings suggest that the implementation of active learning in this large first-year calculus course can lead to positive gains in student achievement. In speaking to students, we discovered that they felt that learning calculus with active learning pedagogies led to overall increased engagement during class (Bowers et al., 2019; Reinholz, 2018).

Further, while they recognized that learning via active learning was helpful for their conceptual understanding of the material, some still wanted more lecture-style classes. This finding is seen in previous studies (Rosenthal, 1995; Weurlander et al., 2017) where even when the positive benefits of active learning are evident, students sometimes still long for traditional ways of learning. Deslauriers et al. (2019) note that part of the rationale for the incongruence between student perceptions of effective pedagogies and the results of effective pedagogies may be influenced by a lack of familiarity with a style of teaching, as well as the discomfort with more active, cognitively-demanding tasks. We suggest that this may help explain these students' experiences. A surprising finding was that students indicated that engaging with calculus through active learning forced them to develop transferable skills such as organization, focus, and their metacognition about their own learning. Though we have not seen this result in mathematics-specific studies at the university-level, studies from other disciplines suggest that this is not an uncommon phenomenon (e.g., Sletten, 2017; Styers et al., 2018). We encourage others to investigate this further as they pursue active learning in their mathematics courses as this suggests that meaningful learning may be facilitated through active learning beyond discipline-specific concepts.

Importantly, though we attempted to isolate active learning as a variable as much as possible and account for other factors, we recognize potential limitations in our study. In particular, the second experiment was conducted after the splitting of the full-year Calculus for Life Sciences course into two one-semester courses. We acknowledge that this splitting could have potentially impacted our results in two ways:

- The assessment written by Cohort 2A (in 2015) was the second term test in the course. At that time, Calculus for Life Sciences was a full-year course, and this test took place half-way throughout the course. In contrast, the assessment written by Cohort 2B (in 2019) was the final exam in the first two-sequence Calculus courses, as the full-year course has been split by then. As a result, a significantly larger group of students dropped the course in 2019 compared to 2015, which impacted our data. However, even after adjusting the 2019 data to account for this change in our courses, we saw a statistically significant difference in students' achievements, favoring the active-learning design over the traditional one.
- Another difference between the two cohorts in the frequency of major assessments. Term Test 2 in 2015 was the second major assessment in the full-year course (Term Test 1 being the first). On the other hand, the Final Exam in 2019 was the third major assessment (the others were Term Test 1 and Term Test 2). One might argue that students perform better when tested more frequently. We did not make any adjustments to our data to account for this effect, but we are fairly confident that while the frequency of assessments may explain *some* of the improvement in Cohort 2B's results, the active learning served as a main contributor as well. However, there were no discrepancies in assessment frequency in the first experiment, and similar results to the second experiment were achieved. Thus, we are reasonably confident that active learning will still have had an effect.

Further, the focus groups conducted were limited in size for a variety of reasons, including that of the ongoing pandemic. Thus, we suggest that the critical observations brought forth from the students are further explored with more participants in the future. Indeed, we are interested in speaking with students to investigate the specific aspects of active learning and calculus topics that impacted their experiences in the course. While we did not seek to collect information that could speak to the impact of using active learning on improving equitable outcomes in calculus courses, we are encouraged by the findings of Theobald and colleagues (2020) and look to investigate this further in future studies.

Though prior studies have investigated the impact of active learning interventions on student achievement in mathematics (e.g., Code et al., 2014), we contend that our study offers an understudied perspective in the realm of post-secondary education. In particular, we believe that this work validates what has been seen in smaller mathematics classes and large non-mathematics classes, and is one of few studies that systematically investigates the impact of consistent active learning in large calculus courses. Similar experiments conducted in other institutions and courses (such as Linear Algebra) may provide further support and validation of our observations. Nevertheless, we suggest that mathematics departments may wish to consider encouraging their instructors and supporting faculty in replacing traditional methods with student-centered alternatives, and incorporate active learning strategies in their course design.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s40753-024-00234-6.

Data Availability Data collected in this study are available from the corresponding author upon reasonable request. Sharing of the data may be restricted to protect the confidentiality and privacy of participants, as per our ethics board approval protocol.

Declarations

Conflict of Interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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