The Examination of the Cross-Curricular Content Within the Ontario Grade 12 University-Level Mathematics Curriculum and Its Impact on Students Preparing for Future Studies in the STEM Field

by

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Abstract

This study explores the perspectives of Grade 12 students in Ontario regarding the cross-curricular STEM (Science, Technology, Engineering, and Mathematics) content within the Advanced Functions (MHF4U), Calculus and Vectors (MCV4U), and Data Management (MDM4U) courses. The research assesses university students' past experiences with Grade 12 cross-curricular elements of these courses and their perceptions of how the curriculum prepared them for STEM studies they are currently pursuing at the university level. A mixed-methods approach with quantitative and qualitative research methods was employed, utilizing an online survey distributed to Ontario STEM university students through their professors and STEM departments. The survey collected 364 responses, with 95 deemed suitable for analysis. Participants rated their experiences with STEM content in each Grade 12 course on a Likert scale from 1 to 5, as well as the perceived effectiveness of the courses in preparing them for STEM studies. For experience ratings, 1 indicated very limited cross-curricular content, and 5 indicated abundant cross-curricular content. For effectiveness ratings, 1 indicated preparation, and 5 indicated substantial preparation. The average experience ratings were 3.41 for Advanced Functions, 3.55 for Calculus and Vectors, and 3.49 for Data Management, while the effectiveness ratings were 3.36, 3.71, and 3.60, respectively. ANOVA test results revealed no statistically significant differences in experience ratings across the courses. However, significant differences were found in effectiveness ratings, with Advanced Functions being the reason and achieved the lowest average rating. Qualitative responses aligned closely with quantitative findings, offering additional insights into students' experiences with cross-curricular content, the impact on their STEM studies, and suggestions for improvement. The findings reveal both strengths and areas for development in Ontario's Grade 12 university-level mathematics curriculum. These results

suggest opportunities for curriculum revision, including enhanced cross-curricular learning components and improved alignment with students' needs when pursuing STEM-related university pathways. A key strength of the Grade 12 university-level mathematics curriculum lies in its emphasis on developing foundational mathematical skills crucial for university STEM studies. This finding is supported by detailed qualitative responses analyzing each Grade 12 university-level mathematics course. However, an area for enhancement lies in addressing the perceived gaps in the effectiveness of Advanced Functions, particularly the need to align the contents with the demands of university-level STEM programs.

Preface

This thesis is the original, unpublished, independent work by Qiye Huang.

This study was approved by the Research Ethics Board, Office of Research Services, Nipissing University. The ethical application number is 103519.

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CERTIFICATE OF EXAMINATION

Certificate of Examination

Supervisor(s):	**Examiner(s)**
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Chapter One: Introduction

UNESCO has indicated that Science, Technology, Engineering, and Mathematics (STEM) education needs to work together towards fulfilling “societal needs and aspirations” (Ng, 2019, p. 8). By considering UNESCO’s research on global education trends, which cover diverse societies, especially regarding the Fourth Industrial Revolution (Ng, 2019, p. 9), Ontario can better adapt its curriculum to meet the changing needs of society. The first industrial revolution introduced the steam engine; the second introduced electricity and mass production; the third introduced semiconductors and computing, along with the Internet; the fourth industrial revolution includes the applications of robotics, artificial intelligence, the Internet, quantum computing, and nanotechnologies (Ng, 2019), which are beginning to be applied and are expected to have a massive impact on human civilization.

Data from Statistics Canada has shown that our society is responding with an almost linear increase of enrolment in Ontario University STEM programs from 2009/2010 to 2021/2022 (Statistics Canada, 2023). Even with the growth in enrolment of STEM students, “Canada faces digital and STEM skills shortages” due to the COVID-19 pandemic (Mahboubi, 2022, p. 1).

There are advantages to studying mathematics starting from an early age: “The teaching of subjects such as mathematics can be given with greater hope of success, if aspects are incorporated that denote not only technical but also emotional aspects” (Solórzano et al., 2018, p. 6). Mathematical preparation in high school is important for students who plan on choosing STEM programs in universities and working in the STEM field (Wang, 2013). In high school, students who possess “better intellectual abilities, higher perceived competence for mathematics, higher intrinsic motivation” (Abín et al., 2020, para. 33), and greater perceived utility in mathematics tend to perform well in mathematics. Other researchers also suggest that mathematics supports high school students in building their thinking skills (Widyatiningtyas et al., 2015).

Mathematics studies can also strongly relate to STEM studies because that "STEM disciplines share the same conceptual process of sense making as learners, individually or in a group, actively engage with the natural or man-made world, explore it, and then develop, test, refine, and use ideas together with specific explanation. If mathematics was conceived as an 'empirical' discipline, connections with other STEM disciplines would be strengthened" (Li & Schoenfeld, 2019, p. 7). Besides, it is essential that high school students entering STEM degree programs in Ontario Universities have the abilities of problem solving and mathematical modeling (Deeken et al., 2020).

Mathematical modeling is the "solving of real-world problems [by] applying mathematical tools [and] evaluating different mathematical models for the same real-world situation" (Deeken et al., 2020, para. 30), which is a foundational skill for STEM. These skills are sought after by universities in their prospective students (Faculty of Applied Science and Engineering, 2023). "[M]athematics is typically organized as a linear sequence of topics in which certain concepts and skills must be mastered before a student is prepared to study more advanced material" (Schneider et al., 1997, p. 27). The students in STEM education are expected to "grow up to be problem solver[s], innovat[ors], self-confident [individuals], [and] logically thinker[s]" (Cinar et al., 2016, p. 1). Therefore, it is necessary for educators to work toward this goal, to help students develop these abilities, and to help them prepare for their STEM degree programs in universities.

In Canada, there is a “growing amount of evidence to support the notion that youth require a strong foundation in STEM education” to “enhance economic well-being and quality of life during later years in life” (Duodu et al., 2017, para. 4). The possibility of a STEM skills shortage may impact economic growth negatively (Mahboubi, 2022). Therefore, there is a need for more employees with STEM abilities and skills, as well as a need to ensure effective education around STEM abilities in high school mathematical studies as a necessary foundation for university STEM studies (Deeken et al., 2020). The choice of a high school mathematics curriculum critically shapes the character of mathematics instruction and therefore affects the depth of students’ mathematical learning (Agodini et al., 2013). The importance of the mathematical curriculum is underscored by the statistic that approximately 94% of all professions utilize some degree of mathematical understanding (Handel, 2016).

The Ontario Grade 12 university-oriented mathematics courses are often prerequisites for university admission in the STEM field (Deeken et al., 2020). The Grade 12 university-oriented mathematics curriculum courses in Ontario are: Advanced Functions (MHF4U), Calculus and Vectors (MCV4U), and Data Management (MDM4U) (Ontario Ministry of Education, 2007). As an example of the mathematics courses being prerequisites, applicants for undergraduate studies in engineering at the University of Toronto are required to complete Advanced Functions (MHF4U) and Calculus and Vectors (MCV4U); other prerequisite course requirements include Physics (SPH4U) and an optional prerequisite Data Management (MDM4U) course (Faculty of Applied Science and Engineering, 2023).

Students who are entering first year mathematics courses in STEM programs are required to exercise formal, rather than intuitive thinking, understand and utilize the formal mathematical terms introduced, follow formal proofs when learning new mathematical concepts, and cope with a “definition-theorem-proof-like” (Deeken et al., 2020, para. 12) style of presentation in mathematics (Deeken et al., 2020).

STEM university programs such as physics, environmental science, computer science, and health science (Edu Canada, 2024) are all interconnected with prerequisite mathematics courses. For example, mathematical modeling includes “designing, constructing, analyzing, mathematizing, verifying, revising, and communicating” (Kertil & Gurel, 2016, p. 46) and “mathematical modeling as a process is involved in all STEM-related applications” (Kertil & Gurel, 2016, p. 46). Additionally, the curriculum successfully integrates the use of technology to enhance mathematical understanding and application. For example, the phrase “with technology” appears in the Ontario Grade 12 university-level mathematics curriculum 16 times, in a wide variety of subjects, including Advanced Functions (MHF4U), Calculus and Vectors (MCV4U), and Data Management (MDM4U) (Ontario Ministry of Education, 2007).

The *Ontario Grade 12 University-Level Mathematics Curriculum* is a comprehensive and representative model of mathematical education in Canada, as evidenced by its alignment with the Common Core State Standards for Mathematics (CCSSM) (Common Core State Standards for Mathematics (CCSSM), n.d.; National Council of Teachers of Mathematics (NCTM), n.d.) and its performance in international assessments like PISA 2022 (Council of Ministers of Education, n.d.). “Canadian students achieved strong results in each of the four mathematics process subscales reported on by PISA” (Council of Ministers of Education, n.d., p. 1), where Canadian 15-year-olds scored well above the OECD average (Council of Ministers of Education, n.d.). Additionally, Ontario’s Grade 8 TIMSS results (513) closely match the Canadian average (512), demonstrating preparedness for high school mathematics and further supporting the curriculum’s effectiveness (O’Grady et al., 2019).

There is an absence of analyses comparing the Ontario Grade 12 university-level mathematics curriculum with other curricula. However, the Ontario curriculum showcases its comprehensiveness through the diverse array of topics covered across its various courses (Ontario Ministry of Education, 2007). The additional availability of courses like data management (Ontario Ministry of Education, 2007) further illustrates its comprehensive nature, acknowledging the significance of statistical analysis and data interpretation in today's data-driven world. The contents of financial literacy are also included in the Grade 9 Ontario mathematics curriculum, which continues in the college level courses (and other non-mathematics curricula). For example, the Grade 11 Ontario college-level mathematics curriculum includes topics such as "solv[ing] financial problems connected with vehicle ownership" (Ontario Ministry of Education, 2007, p. 67).

Students who follow the Grade 11 Ontario university-level mathematics curriculum also revisited financial literacy as a part of the contents in the Functions course (MCR3U) by studying the "financial applications involving compound interest and ordinary simple annuities" (Ontario Ministry of Education, 2007, p. 13). The students apply their mathematics knowledge to make financial decisions and to explain "how budgets can be modified based on changes in circumstances" (Ontario Ministry of Education, 2020b, para. 56). The purpose of this research is to explore whether the Ontario Grade 12 university-level mathematics curriculum effectively prepares students for STEM-related programs, like university economics.

The Ontario Grade 9 mathematics curriculum was revised in June 2021, while the Grade 10 Ontario mathematics curriculum was last updated in 2005 with minor revisions between 2021 and 2022. The mathematics curriculum for Grades 10 to 12 in Ontario has yet to experience a corresponding transition (Ontario Ministry of Education, 2021c). The revisions will be discussed in greater detail in Sections 1.1 (Background of the Problem) and 1.3 (The Rationale for Research).

1.1 Background of the Problem

As of September 2020, the mathematics curricula for Grades 1 through 8 in Ontario have been revised to align with the expectations set forth in the newly introduced curriculum policy (Ontario Ministry of Education, 2021c). The updated curriculum incorporates integrated learning among other subjects, for example, “all subjects, including health and physical education, can be related to the language curriculum” (Ontario Ministry of Education, 2019, p. 64), when words are used to communicate feelings; In social studies, history and geography, students “read about past events and current social and environmental issues and research new information” (Ontario Ministry of Education, 2023b, para. 11) and integrated learning into mathematics, thereby promoting the abilities to “make connections between mathematics and other subject areas” (Ontario Ministry of Education, 2020a, para. 5).

Subsequently, in September 2021, the Grade 9 mathematics curriculum was similarly revised to align with the new curriculum policy, emphasizing the development of higher-order mathematical thinking through multi-skill integration. (Ontario Ministry of Education, 2021c). However, secondary mathematics courses for Grades 10 through 12 continue to operate based on the mathematics curriculum from 2005 to Grade 10 (Ontario Ministry of Education, n.d.) with a minor addendum and the 2007 curriculum for Grades 11 and 12 (Ontario Ministry of Education, n.d.).

Research has underscored the advantages of cross-curricular instruction in mathematics. Mathematics is an evolving discipline that forms the backbone of contemporary life (Ward-Penny, 2010). Moreover, studies have investigated how cross-curricular education can lead to a deeper understanding of mathematical concepts. However, most of the studies on cross-curricular contents in mathematics focus on primary schools. A study found numeracy competency across the post-primary curriculum was successful in integrating numeracy and mathematics meaningfully and constructively in a range of ‘carrier subjects,’ the subjects that can be helpful for mathematics studies (Connolly et al., 2023). Another study conducted in the fifth grade at a primary school in Netherlands found that cross-curricular contexts can stimulate students’ learning motivation (Polman et al., 2021).

However, there has been an absence of research specifically investigating the cross-curricular content of the Grade 12 university-level mathematics curriculum in Ontario, based on Google search and library search results STEM is new or no curricular supports. The lack of research may be attributed to two key factors. First, STEM education has only gained significant attention in recent years, leaving limited time for in-depth studies on integrating cross-curricular content into existing mathematics curricula. Second, the Ontario mathematics curriculum currently lacks explicit frameworks or dedicated resources to support cross-curricular integration at the secondary level.

1.2 Problem Statement

The aim of this study is to examine STEM cross-curricular contents within the Ontario Grade 12 university-level mathematics curriculum, focusing on how this curriculum integrates concepts from other STEM fields such as technology, biology, and physics. Cross-curricular content involves integrating knowledge and skills from multiple subject areas, rather than focusing on a single discipline in isolation. The intention is to gather students’ perspectives about the cross-curricular contents in Ontario Grade 12 university-level curriculum, is to identify gaps in these cross-curricular connections that can potentially inform the curriculum revision process. While student perspectives rarely influence curriculum development, this research hopes to offer curriculum developers a chance to hear students' views on cross-curricular content in Ontario’s Grade 12 university-level math curriculum. This may also offer valuable insights into the extent to which cross-curricular learning is effectively integrated within these courses. The specific focus within the mathematics curriculum is the following three university preparation courses: Advanced Functions (MHF4U), Calculus and Vectors (MCV4U), and Data Management (MDM4U), which are the only three courses in Ontario Grade 12 university-level mathematics curriculum.

The intention of this research is to gather feedback on the cross-curricular contents in Ontario Grade 12 university-level mathematics curriculum from Ontario university STEM students. The focus is specifically on students, as opposed to teachers, because teachers are consulted by the Ministry of Education as part of the regular curriculum development and revision process, and they engage in professional activities to share curriculum implementation. By focusing on students, the aim of the investigation is to clarify the unique perspective from university STEM students about their high school experiences. If student perspectives are considered, this research could potentially contribute to future curriculum discussions in Ontario.

This investigation aims to provide insights that could assist curriculum developers in making informed decisions regarding student preparation for STEM programs. Additionally, the study may offer considerations for potential adjustments to the cross-curricular content in the Grade 12 university-level mathematics curriculum, though further research is needed to assess their impact.

1.3 The Rationale for Research

The importance of integrating STEM contents in mathematics curricula has been increasingly recognized across international borders (Li et al., 2020). In Ontario, the mathematics curricula for Grades 1 to 8 and Grade 9 were recently updated (i.e., 2020 and 2021, respectively); suggesting that revision of the Grades 10 to 12 curriculum, currently from 2005–2007, may follow in the next couple of years, to properly align later mathematics courses with the recent revisions. The revisions to the mathematics curriculum for Grades 1 to 8 were part of the broader Innovative Curriculum Policy (Ontario Ministry of Education, 2020e), which included specific changes to aspects of real-life applications, social-emotional learning skills (includes meta-cognitive skills), coding, and financial literacy (Ontario Ministry of Education, 2020e). The scope of these changes is enough to affect the trajectory of the curriculum for higher grades. "The math curriculum introduces coding concepts and skills to reinforce math learning, improve problem solving and develop fluency with technology." (Ontario Ministry of Education, 2020d, para. 8). Coding is now applied to mathematical modelling of real-life situations in conjunction with the algebra strand, spatial sense of graphic design, and planning of structures (Ontario Ministry of Education, 2020d).

The revision of the Grade 9 Ontario mathematics curriculum also includes similar changes, such the addition of financial literacy: "[i]dentify a past or current financial situation and explain how it can inform financial decision[s]" (Ontario Ministry of Education, 2021a, p. 16); coding: "[u]se code to understand variables, parameters, equations, and inequalities" (Ontario Ministry of Education, 2021a, p. 8); and relations: "[r]eal-life applications of Linear and Nonlinear relations" (Ontario Ministry of Education, 2021a, p. 8). These are indications that more STEM cross-curricular contents are likely to be added to the Grades 10 to 12 mathematics curriculum to align with the updated Grades 1 to 9 curriculum.

The Grade 9 Ontario mathematics curriculum was revised in June 2021 and the Grade 10 Ontario mathematics curriculum was last revised in 2005, followed by a few edits and additions during July 2021 to May 2022 (Ontario Ministry of Education, 2022), while the Grades 11 and 12 Ontario mathematics curriculum was last revised in 2007 (Ontario Ministry of Education, 2021c). One of the goals of the revised Grade 9 Ontario mathematics curriculum is to provide all students the key skills to "think critically and creatively to connect, apply, and leverage mathematics within other areas of study including science, technology, engineering, the arts, and beyond" (Ontario Ministry of Education, 2021b, p. 6).

While the mathematics curriculum for Grades 10 to 12 in Ontario emphasizes skills such as logical reasoning, critical thinking, and problem-solving—skills identified as essential for success in today's workplaces—its content has not been extensively updated to reflect evolving STEM needs (Ontario Ministry of Education, 2007, p. 4). "Mathematical knowledge becomes meaningful and powerful in application," (Ontario Ministry of Education, 2007, p. 4) with problem-solving contexts drawn from related disciplines such as computer science, business, biology, and physics, as well as from traditionally unrelated fields such as geography and art. Research conducted in this context has shown that advanced curriculum not only critically influences students' academic growth, but also significantly impacts their future career opportunities (Ontario Ministry of Education, 2021c). Research on the Ontario mathematics curriculum for Grades 10 to 12 can provide valuable insights for curriculum developers, particularly in aligning updates with evolving STEM demands.

Research conducted in the field of education highlights the merits and significance of incorporating cross-curricular content into the curriculum, asserting that this approach significantly enhances learners' understanding of the subject and enriches their knowledge application (Cotic et al., 2021). The Ontario mathematics curriculum, to some extent, informs teachers about pedagogical strategies. For example, around 40 example mathematics problems in the Ontario Grades 11 and 12 mathematics curriculum expectations require teachers to teach with technologies (Ontario Ministry of Education, 2007). A search of Google Scholar and the Nipissing University Library using the keyword *"cross-curricular content in the Ontario Grade 12 university-level mathematics curriculum"* yielded no relevant matches.

This search result indicates a gap in the existing literature, as no studies were found that specifically examine cross-curricular elements within the Ontario Grade 12 university-level mathematics courses (*Advanced Functions, Calculus and Vectors, and Data Management*). While research on cross-curricular pedagogies and cross-curricular content in other jurisdictions or grade levels does exist (see Section 2.2 for further discussion), there appears to be a lack of focused investigation on this topic within the specified Ontario curriculum context.

Overall, this study provides an opportunity to fill this research gap by collecting students' perceptions. Insights from this survey can serve as a consideration for curriculum developers for potential modification and enhancement of existing curricula, with the aim of providing students' perspectives on cross-curricular contents in Ontario Grade 12 university-level mathematics curriculum. There has been no announcement, that I am aware of, regarding a timeline for the Ontario Grade 12 mathematics curriculum to be revised, which is because Grade 12 students would need the prerequisite Grades 10 and 11 revised curricula, implies Ontario Grade 12 mathematics curricula may not be changed in the next two years.

1.4 Research Questions

Students currently enrolled in Ontario's Grade 12 university-level mathematics courses—as well as those who have taken these courses since 2007—have all engaged with the same curriculum established that year. They are the target population of the research, which will be further discussed in Chapter 3. The curriculum includes the focal courses Advanced Functions (MHF4U), Calculus and Vectors (MCV4U), and Data Management (MDM4U). With the recent revisions to Ontario Grades 1-8 and Grade 9 mathematics curriculum, attention may now turn to the Grade 12 mathematics curriculum. This context presents an opportunity to examine the following research questions, which aim to help students prepare for future STEM studies:

1. How do current undergraduate students in STEM fields from Ontario universities perceive the cross-curricular content in the Ontario Grade 12 university-level mathematics curriculum in terms of preparing them for future STEM studies? For those who found the cross-curricular content sufficient, how did they apply this knowledge? For those who found it insufficient, what specific cross-curricular topics do they wish had been included in the Ontario Grade 12 curriculum?
2. What insights can be derived from students' feedback to guide curriculum developers in potential modifications for a revised Ontario Grade 12 curriculum?

By addressing these questions this investigation seeks to better understand students' perspectives on the cross-curricular STEM content in the current Ontario Grade 12 university-level mathematics curriculum. The findings may offer insights that could potentially inform discussions about curriculum development, should such opportunities arise. This analysis focuses on understanding students' perceptions of how well the curriculum prepares them for pursuing the STEM field in their future university programs. The university-level courses in the Ontario mathematics curriculum are intended to “equip students with the knowledge and skills they need to meet the entrance requirements for university programs” (Ontario Ministry of Education, 2007, p. 8). The research is centered around informing the curriculum developers about possible enactment and modification of the Grade 12 Ontario university-level mathematics curriculum to better cater to students and to be more up to date—whether it needs reforming or not, according to the requirements of STEM-focused students. For this study, "sufficient" refers to cross-curricular content that students felt adequately prepared them for the demands of their university STEM programs. "Insufficient" describes content that students identified as lacking or inadequate in preparing them for STEM studies, creating noticeable gaps in their preparedness.

The Ontario Grade 12 university-level mathematics curriculum was chosen as the focus of this study, primarily due to time and resource constraints that necessitated narrowing the scope. This decision was driven by several key factors. First, mathematics is a foundational subject that underpins many academic fields and professions. For example, the course Calculus and Vectors (MCV4U) is intended for students “who choose to pursue careers in fields such as science, engineering, economics, and some areas of business” (Ontario Ministry of Education, 2023a, para. 9). Mathematical studies enhance “logical reasoning, analytical thought, and creative thinking” (Cresswell & Speelman, 2020, para. 3), which can be applied in other STEM subjects. Furthermore, Ontario boasts one of Canada's largest and most diverse student populations, offering a valuable and multifaceted dataset for my research. Third, Grade 12 marks the culmination of secondary education, and it is a pivotal point where students make important decisions about pursuing further studies and their chosen fields of study.

Most Ontario students start to consider their pathways beginning in Grade 8 because there are options of Academic or Applied level courses for Grades 9 and 10. Grade 12 university-level mathematics courses are designed for students who may pursue post-secondary education, particularly in fields that require advanced mathematical preparation. Finally, the rising enrollment in the STEM field (Statistics Canada, 2023) has increased the importance of Grade 12 university-level mathematics courses. The need for more employees with STEM-related abilities within society (Mahboubi, 2022) will lead to mathematics courses becoming an increasingly popular pathway for students who are pursuing higher education, with Grade 12 university-level courses serving as prerequisites for university admission.

Chapter Two: Literature Review

This chapter summarizes and evaluates existing research relevant to the topic. It begins with a brief history of cross-curricular learning, followed by an examination of studies related to cross-curricular approaches and their impact on student preparedness. The review includes previous research on instructional methods, pedagogical strategies, and the outcomes of cross-curricular curricula. Additionally, it explores the factors that impact students' preparedness, including motivations, behaviors, and academic performance. Finally, the chapter concludes with a review of the educational theories that support cross-curricular learning.

2.1 Background

A systematic analysis of 36 journals shows that globally, "research in STEM education is increasing in importance internationally and that the identity of STEM education journals is becoming clearer over time" (Li et al., 2020, para. 1). In 2016–2017, Canada had 48.6% of undergraduate students enrolled in STEM programs (Canadian Association of University Teachers [CAUT], 2019). In the US, the employment in STEM occupations has grown 79 percent in the past three decades and STEM jobs are projected to grow an additional 11 percent from 2020 to 2030 (O'Rourke, 2021). Studying STEM equips individuals with essential problem-solving, critical thinking, creativity, and collaboration skills, all of which are invaluable in both academic and professional settings.

Grade 12 mathematics plays a pivotal role in this process (Tibane et al., n.d.), as it consolidates high school math knowledge and introduces advanced concepts like calculus. This dual focus on review and expansion makes Grade 12 mathematics a crucial foundation (Tibane et al., n.d.) for students preparing for university studies in the STEM field. While physics and technology courses are also important, Grade 12 mathematics stands out as a foundational pillar due to its unique ability to demonstrate how math underpins and interconnects with various STEM disciplines. As interest in math-related fields and higher education continues to grow, Grade 12 university-level courses have become key pathways for students.

In Ontario, the following courses are particularly significant as precursors to university STEM studies: Advanced Functions (MHF4U), Calculus and Vectors (MCV4U), and Mathematics of Data Management (MDM4U). These courses are central to this research because they provide essential mathematical foundations (Ontario Ministry of Education, 2007) for STEM disciplines and are required for admission to STEM programs in Ontario universities (Faculty of Applied Science and Engineering, 2023).

The history of cross-curricular learning began more than two millennia ago (Barnes, 2015). Educators had always thought that it is essential to combine knowledge to understand the physical, social, or personal world. Plato first promoted a mix of story, physical education, and music in an early version of Personal, Social, and Health Education (PSHE) (Barnes, 2015). In the seventeenth century, Comenius believed that proper education should be about opening students' understanding to the outer world (Barnes, 2015). Similarly, Rousseau was also deeply inspired by nature, believing that the purpose of education was to learn how to live, and that it can be best accomplished by being very near to the natural world (Barnes, 2015). These were the early stages of cross-curricular learning, and both educators suggested that education should be life-long.

Cross-curricular learning can also be in non-STEM studies. For instance, a drama teacher can incorporate history into their curriculum by having students research and perform monologues or scenes based on historical figures or events like World War II (Price, 2013). On the other hand, Vygotsky's and Bruner's work focused on social intercourse in helping children make sense of the world (Barnes, 2015). In sum, these are the processes of cross-curricular education, helping educators and students realize that education is not just about the curriculum.

It is about how the different knowledges are connected, how they are connected to the real world, and the higher order thinking the connections generate. In the current context, the progressive method of teaching was one of the first fundaments of the cross-curricular content in the curriculum. Moreover, it is worth noting that these early educational approaches can implicitly embrace the idea of interconnectedness in education, rather than explicitly spelling it out. This implicit approach might have led to variations in curriculum enactment and the degree to which students perceived the interconnectedness, varying from place to place.

During the period from 1840 to 1870, Chief Superintendent of Education Egerton Ryerson implemented educational policies that laid the groundwork for an organized, systemic approach to education. This comprehensive framework, which contained the schooling system, standardized textbooks, and teachers' training, made it possible to develop interconnected, cross-curricular teaching methods. In 1938, John Dewey's philosophy of education emphasized the importance of learning through experience and practical social experience (Roberts, 2003). His emphasis of real-world connections was a hallmark of cross-curricular learning. Similarly, in the mid to late 20th century, holistic education was another approach that emphasized the interconnectedness of all aspects of human experience and aimed to promote a stronger balance for individual development (Mahmoudi et al., 2012). This was also fundamental to the cross-curricular content in the curriculum (Mahmoudi et al., 2012).

In 1998, Huntley presented the Mathematics and Science Continuum, a conceptual framework to understand and implement an integrated approach for education of mathematics and science (Huntley, 1998). Integrating disciplines can lead to meaningful, engaging, and effective learning experiences for students. By applying this approach and identifying barriers to cross-curricular integration, Huntley (1998) provided a clear structure for the cross-curricular content in the mathematics and science curricula.

Nowadays, cross-curricular learning continues to be intentionally incorporated into the Ontario curriculum (Ontario Ministry of Education, 2020a). Specifically for mathematics, the Government of Ontario highlighted the development of students' mathematical thinking, such as in proportional reasoning, algebraic reasoning, and spatial reasoning (Ontario Ministry of Education, 2020a). The expectations for a mathematics course in Ontario reflect the interconnectedness of learning, encompassing categories of achievement commonly integrated into curriculum documents, including knowledge and understanding, thinking, communication, and application (Ontario Ministry of Education, 2007). These categories have been integral to Ontario's curriculum framework since 1998 and are also found in documents such as *Growing Success* (Ontario Ministry of Education, 2010, p. 1).

The categories of achievement along with detailed mathematics skills are "the expectations for any given mathematics course" (Ontario Ministry of Education, 2007, p. 25). For example, in the applications category, for the Data Management course (MDM4U; Ontario Ministry of Education, 2007) includes the following curriculum expectation for students: "[g]ather, interpret, and describe information about applications of data management in occupations (e.g., actuary, statistician, business analyst, sociologist, medical doctor, psychologist, teacher, community planner)" (Ontario Ministry of Education, 2007, p. 121). Students are also learning literacy during mathematical activities, such as understanding mathematical terminology, reading, and writing.

Educators wish to develop transferable skills in mathematical learners by facilitating cross-curricular learning across the curriculum. These skills include critical thinking, problem solving, innovation, creativity, self-directed learning, communication and collaboration, global citizenship and sustainability, and digital literacy (Ontario Ministry of Education, 2020a). In terms of the curriculum, cross-curricular learning is currently a lot more developed than it has been historically. This approach had been applied in many different fields, ranging from environmental education, Indigenous education, and financial literacy to social-emotional learning, critical literacy, mathematical literacy, and STEM education (Ontario Ministry of Education, 2021c).

The purpose is to incorporate a variety of perspectives, themes and skills into the teaching of all subjects and disciplines of the curriculum (Ontario Ministry of Education, n.d.). Over the years, cross-curricular learning has been receiving the approval of educators, who are actively attempting to implement cross-curricular learning in their classes. Due to the varied interpretations and implementations of STEM cross-curricular learning, educators have different approaches to it. Some emphasize the cross-curricular contents in different subjects, some highlight the real-world connections of knowledge, some think that discussions and cooperation between teachers of different subjects is a key strategy to ensure implementation, and some consider real projects rather than problems on paper. These studies are further discussed in Section 2.2.

In 2020, the Government of Ontario introduced a policy aimed at reinforcing the existing curriculum expectations by fostering connections between mathematics and other subjects (Ontario Ministry of Education, 2020b). While this policy emphasizes the importance of cross-curricular connections, it is important to note that the concept of connecting mathematics with other subjects, including the application category of achievement, has been integral to Ontario's curriculum framework since 1998 and is explicitly mentioned in documents such as 'Growing Success,' which was introduced in 2010 (Ontario Ministry of Education, 2010).

The study focuses on three specific courses within the Ontario curriculum: Advanced Functions (MHF4U), Calculus and Vectors (MCV4U), and Data Management (MDM4U), which are the only three university-level courses in Ontario Grade 12 mathematics curriculum. The paths to, or prerequisites for these Grade 12 university-level mathematics courses are detailed in Appendix D. In September 2021, the Grade 9 mathematics curriculum underwent a transition to align with the standards set by the new Grades 1–8 curriculum (2020).

For Grade 9, this transition placed a stronger emphasis on establishing connections between related mathematics concepts and various disciplines (Ontario Ministry of Education, 2021a). Currently, Grade 10 mathematics continues to follow the 2005 mathematics curriculum (Ontario Ministry of Education, n.d.), and Grades 11 and 12 still adhere to the 2007 curriculum (Ontario Ministry of Education, n.d.). It is conceivable the Grade 12 curriculum will be altered, but it seems likely that Grades 10 and 11 mathematics will have to be implemented first. The following chart lists the detailed intentions and expectations of Grade 12 university-level mathematics curriculum in 2007.

Table 1

Three Grade 12 mathematics courses (Advanced Functions, Calculus and Vectors and Data Management) intentions and expectations

Course Name	Couse code	Course Intentions	Course Expectations
Advanced Functions	MHF4U	This course extends students’ experience with functions. (Ontario Ministry of	This course is intended both for students taking the Calculus and Vectors course as a prerequisite for a university program and for those wishing to consolidate their understanding of mathematics before

		Education, 2007, p. 85)	proceeding to any one of a variety of university programs. (Ontario Ministry of Education, 2007, p. 85)
Calculus and Vectors	MCV4U	This course builds on students' previous experience with functions and their developing understanding of rates of change. (Ontario Ministry of Education, 2007, p. 99)	This course is intended for students who choose to pursue careers in fields such as science, engineering, economics, and some areas of business, including those students who will be required to take a university-level calculus, linear algebra, or physics course. (Ontario Ministry of Education, 2007, p. 99)
Mathematics of Data Management	MDM4U	This course broadens students' understanding of mathematics as it relates to managing data. (Ontario Ministry of Education, 2007, p. 111)	Students planning to enter university programs in business, the social sciences, and the humanities will find this course of particular interest. (Ontario Ministry of Education, 2007, p. 111)

2.2 Related studies on cross-curricular learning and students' preparedness

2.2.1 Cross-curricular curriculum

Cross-curricular learning has been substantiated through decades of educational research, with three key strands of evidence supporting its value: the integration of emotional, practical, and intellectual skills in meaningful learning (Barnes, 2015); the demonstrated benefits of holistic learning approaches in progressive education frameworks (Drake & Reid, 2020); and the natural interdisciplinary connections emphasized in constructivist pedagogy. The holistic learning principle is an approach that emphasizes the learning of an individual, integrating cognitive, emotional, and social aspects. This principle is connected to cross-curricular learning by encouraging the interconnection of knowledge and skills across different subject areas to create more meaningful and comprehensive learning experiences.

Constructivism is a learning theory that posits that knowledge is constructed by learners through active engagement and experiences, connected with a cross-curricular approach when applying experiences from real-life and other subjects (Barnes, 2015, p.228). The cross-curricular competencies have been well-defined by the Ministry of Education in British Columbia (British Columbia Ministry of Education, 2013) and applied by the Ministry of Education in Ontario (Ontario Ministry of Education, 2020a). According to the Ministry of Education in British Columbia, the cross-curricular competencies are "the set of intellectual, personal, and social skills that all students need to develop in order to engage in deeper learning—learning that encourages students to look at things from different perspectives, to see the relationships between their learning in different subjects, and to make connections to their previous learning and to their own experiences" (Ministry of Education, 2013, p. 3).

Cross-curricular curriculum provides necessary skills and allows students to take a holistic approach to the materials they learn with real-world applications. In the book titled *The Creative Primary Curriculum*, Barnes introduced cross-curricular learning as "links between subjects [which] combine skills, disciplines, knowledge and competences from several subjects to problem-solve real-life situations" (Barnes, 2015, p. 261). Cross-curricular learning has commonly been described as an overview of the bigger picture of knowledge, the links between subjects, and the connections to real-world applications.

There are different types of cross-curricular learning. Hierarchical cross-curricular learning is when ideas in one subject enhance learning in another. For example, studying Copernican heliocentrism involves history and science (Barnes, 2015). Multidisciplinary, cross-curricular learning strives to equalize the importance of two or more subjects. For instance, in this approach, science and history can complement each other in a way where the study of historical events enhances the understanding of scientific developments, and vice versa. One key aspect of multidisciplinary cross-curricular learning is that it is based on the same experiential context or theme, but the study of each subject is separated. For example, students could explore the impact of historical events on scientific discoveries by delving into the history of the space race and its influence on space exploration technology (this topic could align with topics in Grade 9 science, such as the study of space, or with history courses that examine 20th-century global events).

Opportunistic cross-curricular learning on the other hand, is when teachers make educational plans regarding students' reactions (Barnes, 2015). Only a vague academic expectation would be provided, and it is up to the teachers and/or the students to determine how to accomplish it. The double-focus, cross-curricular learning attempts to establish a balance between the deep exploration of concepts within a single subject with opportunities to connect and integrate knowledge across multiple curricular subjects. In a double-focus cross-curricular learning approach, a course could integrate biology and literature (Barnes, 2015). For instance, students might study the novel 'Frankenstein' by Mary Shelley, which explores themes of science, ethics, and societal consequences (Barnes, 2015).

The course would involve a deep dive into both the literary analysis of the novel and the biological concepts related to the creation of life (for example Grade 12 English University course, ENG4U), offering students a comprehensive understanding of how literature and science intersect in this classic work of fiction. The two study methods would be utilized by a student for a long period (Barnes, 2015).

Furthermore, studies indicated that cross-curricular learning is beneficial to students. A literature review from Costley (2015) emphasizes definitions of integrated curriculum, which is the process of bringing subjects together. Costley (2015) also summarized the purposes of the integrated curriculum, which include creating an engaging and student-centered learning environment, providing higher order thinking skills, fostering cooperative learning, and addressing social issues, as suggested by the literature. They found that a benefit of cross-curricular learning is making connections between subjects and real life while fostering critical thinking skills. Based on the literature review, the main foci of the studies relevant to this research are:

1. The concepts and benefits of cross-curricular learning.
2. The pedagogical strategies.
3. The results of cross-curricular learning.
4. Other important features (i.e. teacher collaborations, activities) of cross-curricular learning.

Researchers have articulated diverse perspectives on the value of cross-curricular learning, including its relevance to the STEM field. Beckmann considered the most important benefit to be linking ideas from various disciplines, where students can develop a holistic understanding of complex topics (Beckmann, 2009). Wijngaards-de Meij and Merx (2018) argued that one of the benefits of cross-curricular learning is its capacity to infuse dynamism into the curriculum. In this context, the term 'dynamic' refers to a curriculum that is adaptable, responsive to students' needs, and open to incorporating real-world developments and interdisciplinary connections, as opposed to a rigid and static program.

Volk et al. (2017), on the other hand, highlighted the importance of how their tablet-based, cross-curricular curriculum can enhance students’ engagement and sustain their interest in learning. For cross-curricular learning in mathematics, some researchers focused on content knowledge, like Saeki et al. (2001), who thought that cross-curricular activities should be designed to enable primary students to apply their mathematical knowledge to solve physics problems. While some other researchers, like Ward-Penny (2010), emphasized the practical applications of cross-curricular learning. According to them, “[t]eaching mathematics in a cross-curricular way can help to familiarize pupils with the idea of applying mathematics in context, encouraging them to develop the skills of selecting appropriate mathematics, applying it, and critically evaluating its use against real concerns and limitations” (Ward-Penny, 2010, p. 5). Ward-Penny's perspective underscores the tangible real-world relevance that cross-curricular approaches bring to mathematics education.

Höfer & Beckmann (2009) also thought that the focus of mathmatical cross-curricular learning is to apply mathematics in real-life experiments. In United States, there was a case study of a new type of high school, which include a focus on engineering, known as Inclusive STEM High Schools (ISHSs) (Peters-Burton & Johnson, 2018). ISHSs include the intentional and explicit integration of engineering learning opportunities into coursework, and the coursework is centered by engineering. It is not a traditional curriculum, but some students reported that “their tendency to see engineering design as a way of thinking about the world and ways to problem solve” (Peters-Burton & Johnson, 2018, p. 338).

Overall, cross-curricular learning is generally understood as the expansion into additional subjects or the integration of diverse subjects, sometimes the integration of real-world applications, and diverse problems. Cross-curricular approaches have been used to facilitate the development of materials to support literacy instruction across the curriculum, for example, the document “Think Literacy: Cross-Curricular Approaches, Grades 7–12 – Mathematics: Subject

Specific Examples, Grades 10–12, 2005" has been used to help with integrating literacy instruction in mathematics courses (Ontario Ministry of Education, 2007, p. 36).

While various researchers have explored diverse pedagogical strategies in the context of cross-curricular learning, particularly within classroom settings and practitioner implementations, the objective of the present research is to investigate the integration of a cross-curricular approach at the curriculum level. This study aims to go beyond the confines of traditional research by examining how curricular support can enhance cross-curricular learning experiences.

Traditionally, it is a flexible approach by integrating mathematics into practical work across the curriculum. Costley (2015) considered that bringing subjects together instead of teaching them separately, as is typically done, can enhance the general. An illustrative example of cross-curricular learning in the curriculum and the educational method is a study from Wijngaards-de Meij and Merx (2018). They used a digital curriculum mapping tool for the high school curriculum that allowed students to visualize the learning trajectories across the curriculum. While completing a biological research task, the students used links to related courses to study or review the related knowledge, allowing them to see the connections between different subjects within STEM.

On the other hand, Volk et al. (2017) showed that for the elementary school mathematics curriculum, integrating the use of tablet devices (such as iPads or Android tablets) with cross-curricular activities is a great educational pedagogy that enhances students' problem-solving skills, collaboration and communication, creativity and innovation, and self-regulated learning. Saeki et al. (2001) used Graphing Calculators (Texas Instruments TI-83) with an accessory called a Computer Based Laboratory (CBL) in Japanese mathematics and physics classrooms for physics investigations. In this case, students use CBL to connect mathematics and physics topics. For example, students studied the motion of a walking person to connect functions and straight-line motion with CBL (Saeki et al., 2001). They believed that this method could connect the abstract mathematical ideas with concrete physics examples, allowing the students to better grasp the concepts and see their practical implications (Saeki et al., 2001).

Höfer and Beckmann (2009) used practical experiments to prompt students to discover mathematical terms and ideas. For instance, they engaged in hands-on physics experiments, participated in verbal argumentative discussions, and participated in model-building activities related to functions. These experiences preceded formal instruction by the teacher and facilitated the acquisition of cognitive terminology and knowledge (Höfer & Beckmann, 2009). Another interesting example from an elementary mathematical learning experiment is applying number skills in physical education and English, where elementary students ordered numbers in a game and arranged storybooks by page count in an activity in the school library (Haylock, 2007).

While this study focuses on cross-curricular learning within curricula, direct research examining Ontario's Grade 12 university-level mathematics curriculum from this perspective remains limited. Therefore, this review incorporates studies of cross-curricular pedagogies for two key reasons: Curriculum documents inherently influence instructional approaches, making pedagogy a meaningful proxy for understanding curricular implementation; and examining teaching practices reveals how cross-curricular learning manifests in actual classroom contexts. This parallel mirrors how technology integration in Ontario's curriculum (e.g., the "with technologies" components) (Ontario Ministry of Education, 2007) ultimately translated into teachers' instructional practices, demonstrating the interplay between curricular intentions and classroom reality.

Due to the limitations of the learning environment, especially in terms of scientific equipment, not all mathematical concepts and phenomena can be explored through hands-on experiments or discovered in instructional settings. However, there are valuable alternatives, such as using resources like a spirograph®, which can provide a hands-on experience in classroom settings. Additionally, many websites offer simulations and learning objects to supplement students' understanding. For instance, Desmos (https://www.desmos.com), Spirograph (https://seedcode.com/SpirographN) and GeoGebra (https://www.geogebra.org/calculator) allow students to create graphs with mathematical functions. A website called "PhET" has many other simulations and activities, for example Fourier: Making Waves (University of Colorado Boulder, 2023). Students can control the type of waves and wavelengths to create their own waves. Activities and simulations like these can enhance the mathematics curriculum. While the intent is to analyze cross-curricular approaches in the curriculum, other studies also explored cross-curricular learning with a variety of teaching methods, learning methods, and self-study methods.

The results of cross-curricular teaching and learning depend on the assessment and evaluation of the students. Many researchers have used Standardized tests, such as Trends in International Mathematics and Science Standards (TIMSS) (Cotič et al., 2021; Volk et al., 2017), Program for International Students Assessment (PISA) (Volk et al., 2017), or other methods like oral communications and examinations (Höfer and Beckmann, 2009). Most of the results found that the cross-curricular approach enhances students' learning as seen in their grades along with improving their confidence in studying. Although these results could be affected by other factors, cross-curricular learning generally tends to improve students' understanding of the subject.

Some other researchers emphasized the importance of aligning assessment methods with the integrated nature of the curriculum and evaluating students' ability to apply knowledge in multiple subjects without necessarily implying bias in student achievement (Beckmann, 2009). Cotič et al. (2021) studied other effects of cross-curricular learning, such as increase of students' enjoyment, achievement, motivation, and collaborative abilities. In sum, assessments and evaluations play important roles in determining cross-curricular learning outcomes and some researchers have successfully used standardized testing results to demonstrate the effectiveness of cross-curricular learning to improve students' ability to apply knowledge, critical thinking, problem solving, and applications among different subjects.

There are other significant features of cross-curricular learning that have been studied, for example, teacher collaboration in an interdisciplinary learning environment (Beckmann, 2009; Saeki et al., 2001; Ward-Penny, 2010), implementation of cross-curricular activities (Volk et al., 2017), the role of experiential learning in enhancing cross-curricular learning (Cotič et al., 2021). These insights highlight the multifaceted nature of learning across the curriculum and provide valuable guidance for educators seeking to implement effective integrated instructional strategies in the classroom. By considering these additional dimensions, educators can create holistic and impactful learning experiences for their students more consistently.

While much of the existing research focuses on elementary education, where teachers often provide instruction across multiple subjects, there is less research specifically addressing cross-curricular STEM case studies in high school settings. However, the studies that do focus on high school highlight an emphasis on science and its integration with other disciplines, such as technology and engineering, offering valuable insights into how interdisciplinary approaches can foster deeper engagement and understanding in the STEM field.

The four dimensions for research in cross-curricular learning include understanding the concepts and strengths of interdisciplinary learning, implementation of effective instructional strategies, consideration of the outcomes of a cross-curricular approach and other important elements within this pedagogical framework. The related studies of these four aspects foster a deeper understanding and engagement in the STEM field, contributing to a holistic educational experience that fosters connections between diverse disciplines and real-world applications.

2.2.2 Impact on students' preparedness in STEM

In the Ontario Curriculum, the Grades 11 and 12 sections highlighted that "[s]tudents choose course types on the basis of their interests, achievement, and postsecondary goals" and that university type courses are designed to "equip students with the knowledge and skills they need to meet the entrance requirements for university programs" (Ontario Ministry of Education, 2007, p. 8). The purpose of this thesis is to analyze cross-curricular content in the curriculum to clarify opportunities to improve students' understanding of the STEM field and set them up for their future university programs.

The National Center for Education Statistics found that, in 2011–2012, 30% of post-secondary students changed majors, and 10% of these students changed majors more than once (Leu, 2017). Research conducted by Council of Graduate Schools (CGS) in the United States in 2012 showed that 16% of the respondents indicated that they are "[uncertain] on what to do in life" (Wendler et al., 2012, p. 18). Changing programs can impact negatively on students' credits for graduation and is both time-consuming and costly. "Mathematics majors changed majors at a rate higher than that of students in all other fields" (Leu, 2017, p. 2). Possible reasons for this phenomenon are that mathematics majors have many program options and are often uncertain about what to pick.

Furthermore, mentorship, financial support, and professional development opportunities could also be reasons that STEM students change their pathways. Methods of enhancing students' preparedness for their next steps in university are based on the factors that affect students' preparedness most are as follows:

1. The design of the curriculum.
2. The methods of teaching and learning in the classroom.
3. Students' motivations, behaviors, and performance.

This research examines how the design of Ontario's Grade 12 university-level mathematics curriculum influences students' preparedness for STEM studies at the postsecondary level. An Ontario Association for Mathematics Education (OAME) conference record in 1975 showed that, at the time, students thought that statistics, algebra, and probability were useful for their later studies; while analytic geometry, Euclidean geometry, trigonometry, and actuarial mathematics were not as valuable (OAME Committee, 1975). At the time, social scientists predicted increasing importance for topics like computer science, probability, statistics, and matrix algebra, while topics like Euclidean geometry and actuarial mathematics were seen as low-growth areas (OAME Committee, 1975).

The importance of cross-curricular learning was already emphasized in 1975, and it is clear they understood the importance of in-depth understanding and practical application skills in studying mathematics (OAME Committee, 1975). Norman et al. (2011) investigated the relationship between high school mathematics curricula and students' post-secondary mathematics placement recommendation. They found that different high school curricula (traditional commercially developed (CD), National Science Foundation-funded (NSFF), or University of Chicago School Mathematics Project (UCSMP) curricula) in five levels, gender, and ethnic groups, did not have significant effect on their university mathematics course placement recommendation. “In general, placement recommendations are made based on the position of resulting score relative to certain cut-off scores” (Norman et al., 2011, p. 438). The level of difficulty of their high school classes was the most relevant factor affecting students’ performances in their first year of university (Norman et al., 2011). On the other hand, Kowski (2013) discovered that lower high school performance (as measured by GPA), lack of advanced mathematics coursework, and attending a high school with lower socioeconomic status are important factors that increase the likelihood of community college freshmen requiring remedial math courses.

“High school curriculum plays a significant role on shaping the outcome of students’ success during their studies at the postsecondary institutions” (Assayed & Alsayed, 2025, p. 462). Margot and Kettler (2019) considered that STEM understanding in previous courses plays a crucial role in students' preparedness for future STEM education. They think that STEM pedagogy in the curriculum uses several principles, such as using a conceptual approach, pursuing advanced understanding, engaging in real-world problem-solving, and allowing for self-directed learning fueled by student interest. The curriculum should allow students to apply their knowledge for STEM, while solving real-world problems (Margot & Kettler, 2019). Furthermore, other researchers argued that mathematics education based on the curriculum should prepare students by going beyond teaching procedural skills and focusing on developing students' mathematical thinking and problem-solving abilities (Gravemeijer et al., 2017).

The importance of integrating technology and real-world applications into the mathematics curriculum as preparations for students has been highlighted by many researchers (Gravemeijer et al., 2017; Margot & Kettler, 2019). Gravemeijer et al. (2017) also thought that mathematics education needs to not only prepare students for later studies but also adapt to the demands of a future society and equip students with the necessary skills to thrive in an increasingly complex and interconnected world. English and Gainsburg (2015) think that, in general terms (i.e., without specifying a curriculum or giving examples), current mathematics curricula are linking mathematics education and workplace preparedness more, while the link with life is lessened. They also suggest that the curriculum should focus on all future options for students including advanced studies, work, and life (English & Gainsburg, 2015).

A student-centered approach—combined with cross-curricular learning, project-based lessons, and critical thinking assignments—helps students develop the understanding and skills necessary for STEM fields. While these strategies may appear purely pedagogical, they can also be influenced and encouraged by the curriculum itself. The curriculum plays a key role in shaping STEM preparedness by providing students with the opportunities, experiences, and learning methods needed to build essential knowledge, skills, and mindsets. However, research on how curricula directly affect students' preparedness for STEM remains limited. As a result, this study also explores teachers' pedagogical approaches, recognizing that their instructional methods can be shaped by curricular frameworks. While the primary focus is on how the mathematics curriculum enhances students' preparation for future STEM studies, the pedagogical implications of curriculum implementation are also examined. Although these pedagogical insights may not directly translate into current curriculum policy in Ontario, they offer valuable evidence of the feasibility and benefits of such an approach, informing future educational practices.

For example, the Ontario mathematics curriculum for Grades 11 and 12 suggests that "[t]eachers bring enthusiasm and varied teaching and assessment approaches to the classroom, addressing different student needs and ensuring sound learning opportunities for every student" (Ontario Ministry of Education, 2007, p. 6). While there is a variety of pedagogical options suitable for senior high school math, the scope of the curriculum leads many teachers to frequently use lecture-style approaches. The curriculum can suggest some effective teaching and learning methods, such as activities, experiments and so on, to help improve classroom engagement. Sun and Xie (2020) tested three types of education: low time-spent lecture-focused studying; average time-spent lecture-quiz-balanced studying; and high time-spent quiz-focused studying. Students' performance trajectories differed significantly among the three profiles. As a result, it was suggested that teachers can use students' learning analytics to provide targeted lectures. In the context of the Chinese education system, it is important for education to be student-centered, and teachers should strive to create an autonomy-supportive learning environment that promotes performance-approach goals (Sun & Xie, 2020).

Alberta Education suggested that Grades 10-12 mathematics can involve activities, and that the "[a]ctivities that take place in the mathematics classroom should be based on a problem-solving approach that incorporates the mathematical processes and leads students to an understanding of the nature of mathematics" (Alberta Education, 2008, p. 11). On the other hand, the Ministry of Education (Ontario) provides some activities and resources for high school students to study mathematics online and at home, or outside of the classrooms with their teachers (Ontario Ministry of Education, 2020c).

Overall, the Ontario Curriculum does not prescribe specific teaching methods but offers suggestions that can guide the design of lessons, including options for incorporating STEM cross-curricular activities, experiments, and lectures to enhance student learning. Teachers have the flexibility to choose their own teaching strategies and create a classroom environment that aligns with curriculum objectives. By leveraging these suggestions, mathematics teachers can boost student engagement and understanding through a cross-curricular, interactive, and hands-on STEM approach. This approach not only promotes active learning but also encourages students to apply mathematical concepts to real-world situations. Ultimately, the mathematics curriculum serves as a valuable resource for fostering an engaging, project- or activity-based learning environment—supporting effective teaching practices and reinforcing STEM cross-curricular connections in mathematics education.

Other than the pedagogies of teaching, students' own interests can be affected by the materials in the curriculum. Researchers collaborated to develop the Interest-Driven Creator (IDC) Theory to design activities oriented to student interests. In this experiment, the activities were included in the curriculum as suggestions to teachers and the teachers followed the curriculum in their lessons during the experiment (Looi et al., 2023). The results showed that, when students are driven by the interests that the curriculum was designed to foster, they engage in innovation and excel in learning performance. With the implementation of the IDC Theory in the curriculum, an IDC experimental school intends to establish lifelong learning, academic growth, physical wellness, and character building for the students (Looi et al., 2023).

Daugherty et al. (2014) considered that STEM education can influence the interests and abilities of the next generation of students, fostering a willingness to engage in STEM subjects. It enhances students' problem solving and reasoning, which can be useful in their later academic studies (Daugherty et al., 2014). Bicer et al. (2020) considered that the interest of the students towards STEM can be affected by hands-on, inquiry-based learning, role models and mentors, and collaborative and inclusive learning environments. In sum, a well-designed and engaging curriculum can inspire teachers to adopt pedagogies that blend practical activities, real-world applications, and opportunities for creativity and problem-solving—fostering student curiosity and deepening their interest in learning.

The results of enhancing students' preparedness in STEM can be examined in students' performances based on standardized tests or students' own feelings. Standardized tests have been used in many studies, like quizzes (Sun & Xie, 2020) and tests (Norman et al., 2011). Rudnick (2014) also suggested that mathematics competitions, like the Canadian Open Mathematics Challenge Competition (COMC), Math Team Canada (MTC), the International Mathematical Olympiad (IMO), and other competitions are helping students to have "strong analytical and problem-solving" abilities (Rudnick, 2014, p. 1) to face challenges in the future.

On the other hand, there are many studies that investigate whether high school students feel more prepared mentally often using self-reported data that may be from pre-class activities (Sun & Xie, 2020). Standardized tests serve as valuable indicators of a student's academic abilities, but mental preparation is equally important. When students are confident and mentally prepared, they are more likely to approach STEM subjects with enthusiasm, persistence, and a growth mindset. These positive attitudes foster a love of learning, a willingness to take risks, and the ability to overcome challenges—qualities essential for long-term success in the STEM field.

In sum, a cross-curricular mathematics curriculum can enhance preparedness for university STEM programs by strengthening conceptual understanding across disciplines while simultaneously building student confidence. By integrating interconnected subject applications and fostering problem-solving resilience, such an approach develops both the skills and self-assurance needed to thrive in university STEM studies. Beyond academic performance on standardized tests, students' psychological preparedness for STEM is equally crucial. This study explores students' perceptions of how the cross-curricular content in Ontario's Grade 12 curriculum prepared them for university STEM studies—focusing on their self-reported confidence in STEM courses rather than their academic performance.

2.2.3 STEM instructional supports for Mathematics teacher in Ontario

To determine whether supports for teacher exist to facilitate strengthening STEM cross-curricular content and enhance the connection between the Ontario Grade 12 university curriculum and students' later STEM studies, further research is needed. A search for terms like "lack of STEM cross-curricular content" or "need for more STEM cross-curricular content" reveals that most existing literature focuses on the importance of cross-curricular education rather than practical strategies for implementation. These articles often discuss activities, pedagogies, and strategies for implementing cross-curricular studies but rarely address whether the current content is sufficient or how effective it is for students. This gap in research underscores the importance of further investigation into adequacy and the impact of existing cross-curricular content in preparing students for their academic and professional futures. It is worth noting that much of the existing literature may be influenced by the pursuit of funding, with researchers often aligning their focus with the priorities of funding bodies rather than critically evaluating the sufficiency or effectiveness of current practices.

I examined reading materials for mathematics teachers and curriculum developers, including all issues of four journals published in the past ten years. These journals are *Ontario*

Mathematics Gazette, the *Journal for Research in Mathematics Education* (JRME) and *Mathematics Teacher* (MT), *Mathematics Teacher Educator*, published by the National Council of Teachers of Mathematics (NCTM). These journals are influential journals for mathematics education researchers and teachers respectively that, in the case of NCTM, are available to roughly sixty thousand members. They play a key role in shaping the direction of mathematics education in Ontario by providing insights into effective teaching strategies, curriculum design, and the latest research findings. These resources are especially important because they help educators stay up to date with best practices and innovative approaches to teaching mathematics. By fostering a deeper understanding of how students learn and how mathematics can be applied in real-world contexts, these journals contribute significantly to improving mathematics education at all levels.

In the *Ontario Mathematics Gazette*, Volume 52 (2014) to Volume 63 (2024). Out of 737 articles reviewed, the 53 articles focus on applying technology in mathematics teaching. 25 of these articles are from *Technology Corner*, a series in the *Ontario Mathematics Gazette*, which shares resources like websites and online activities (e.g., Desmos) to enhance mathematics instruction. Additionally, 14 articles address STEM-related topics without focusing on the use of technology. These articles are listed below in order of year of publication:

1. **“Vectors and the Track-and-Field Jumping Events”** explores the application of Newton’s laws of physics to analyze human motion during athletic events (Russel, 2015).
2. **“Calculation of Shooting Angle for a Maximum Range”** solves a kinematics problem using quadratic and trigonometric functions (Lemaire, 2017).

3. **“Balancing Chemical Equations, Using Linear Equations”** discusses chemical reactions, specifically the production of carbon monoxide in charcoal grills (Vander Klok, 2018)
4. **“In the Middle: STEM as an Aspirational Medium”** highlights the growing availability of math resources that emphasize diversity within and across STEM disciplines (Ziniuk, 2019c).
5. **“In the Middle: Problems in Science”** examines challenges arising from the transition between scientific concepts and the use of mathematics to rearrange formulas (Ziniuk, 2019b).
6. **“In the Middle: Lean into Learning About Inclined Towers”** shares insights into learning the mathematics behind inclined structures (Ziniuk, 2019a).
7. **“Science, Technology, Engineering, and Mathematics (STEM) OAME/AOEM Position Statement (June 2020)”** outlines OAME’s support for the development and integration of STEM program goals and expectations (Anonymous, 2020).
8. **“Linking Mathematics Concepts to Economics”** discusses teaching macroeconomics, time series, and microeconomics through mathematics instruction (Irvine, 2021).
9. **“Business Applications of Calculus”** explores the use of calculus to solve business problems, such as maximizing revenue (Irvine, 2022).
10. **“Elementary Math Matters: The State of STEM Education”** highlights the role of Let’s Talk Science (https://letstalkscience.ca/) in supporting STEM education (Colgan, 2023).

11. **“Coding in the Classroom: A Holistic Approach and Video Game Design Coding”** shares the author’s experience integrating coding and other STEM programs, including video game design, into K-12 education (Brodie & Sezer, 2023).
12. **“An Interdisciplinary Opportunity: Mathematics and Accounting”** provides examples of applying mathematics to financial statements and other accounting topics (Irvine, 2023).
13. **“In the Middle: The Geometric Perfection of a Solar Eclipse”** features a teacher, Ziniuk, discussing the geometry of a solar eclipse observed in Canada (Ziniuk, 2024b).
14. **“In the Middle: Math Needs Some Space”** shares experiences integrating space-related topics, such as NASA activities and projects, into K-12 mathematics classes using engaging materials (Ziniuk, 2024a).

These papers offered valuable insights into the integration of STEM cross-curricular content into the curriculum, presenting examples such as projects tailored for mathematics education, sharing practical teaching experiences in STEM-related mathematics, or supporting the development and integration of STEM program goals and expectations. These journals serve as excellent instructional resources for teachers and curriculum developers seeking to enhance their practices.

In the *Journal for Research in Mathematics Education*, published by the National Council of Teachers of Mathematics, Volumes 45 (2014) to 55 (2024) were examined. Out of 280 articles reviewed, 7 were found to be related, to some extent, to other subjects in STEM within the context of mathematics education. Among these, four articles discussed the integration of other subjects in mathematics education across various grade levels, such as kindergarten, elementary school, and Grade 9 (Luz & Yerushalmy, 2023; McCulloch et al., 2021; Nickels & Cullen, 2017). Only three articles focused on the integration of other STEM subjects in Grade 12 mathematics learning, two published in 2018 and one in 2014.

The article *"A Framework for Computational Thinking Dispositions in Mathematics Education"* proposed a framework for incorporating computational thinking into mathematics education across all grade levels (Pérez, 2018). *"Students' Conceptions of Sine and Cosine Functions When Representing Periodic Motion in a Visual Programming Environment"* explored secondary students' ability to model the periodic motion of a Ferris wheel using a visual programming environment (DeJarnette, 2018). *"Can Technology Help in Mathematical Assessments? A Review of Computer-Aided Assessment of Mathematics"* examined the role of technology in mathematics assessments (Kloosterman & Warren, 2014). These articles primarily focused on how technology can enhance the understanding of mathematics, rather than exploring the interconnectedness of mathematics with other STEM subjects.

Pérez's research stood out as it introduced computational thinking, a concept in computer science into mathematics education across all grade levels. This approach allows computer science students to better connect their studies with Grade 12 mathematics, fostering cross-curricular learning. Notably, the 2020 and 2021 updates to the Ontario mathematics curriculum for Grades 1–9 incorporated elements of computational thinking, suggesting a growing recognition of its value in mathematics education. This implementation in earlier grades may hint at further integration of computational thinking when the Grades 10–12 curriculum is updated, potentially strengthening cross-curricular connections for senior students. On the other hand, Kloosterman and Warren's research emphasized the application of technology in mathematics assessments, while DeJarnette's study focused on using technology to deepen students' understanding of advanced functions.

In the *Mathematics Teacher*, published by the National Council of Teachers of Mathematics, volumes 3 (2014) to 12 (2024) were examined. Out of 129 articles reviewed, 7 explicitly focused on the integration of other STEM subjects into mathematics education. Similar to the *Journal for Research in Mathematics Education*, *Mathematics Teacher* also includes articles that explore the use of technology and computer science to enhance mathematics learning (Lovett et al., 2020; Mangram & Sun, 2021; Sherman et al., 2017; W. McCulloch et al., 2020). In 2019, eight preservice mathematics teachers participated in a model-eliciting activity to describe the strength of the magnetic field generated by a solenoid. This activity was detailed in the paper *"Engaging Preservice Secondary Mathematics Teachers in Authentic Mathematical Modeling: Deriving Ampere's Law"* (Corum & Garofalo, 2019). This article is unique, as it is the only one in *Mathematics Teacher* over the past decade to integrate other STEM subjects into a mathematical project designed for senior high school students. The study was also published in *Mathematics Teacher Educator* in September 2019.

In *Mathematics Teacher Educator*, volumes 3 (2014) to 13 (2024) were examined. 7 out of 130 articles addressed STEM-related topics. Six of the STEM-focused articles were also published in *Mathematics Teacher*. The remaining article, *"An Online Professional Development Model to Support Teachers' Abilities to Examine Student Work and Thinking"* (Fukawa-Connelly et al., 2018), focused on using technology to assist mathematics teaching.

In 2019 and 2022, there was a noticeable increase in attention to food and water security as topics of "social justice" in mathematics education. This shift may have been influenced by the water crisis in Flint, Michigan, which began in 2017 (Aguirre et al., 2019). Studies such as *“Engaging Teachers in the Powerful Combination of Mathematical Modeling and Social Justice: The Flint Water Task”* and *“Adaptations to Support the Flint Water Task”* focused on investigating water quality using mathematical modeling. Participants in Grosser-Clarkson and Hung’s (2023) study explored high school mathematics topics, such as functions and sequences, within the context of the Flint water crisis (Aguirre et al., 2019; Grosser-Clarkson & Hung, 2023). Both studies were published in *Mathematics Teacher Educator*. Although the target audience for these studies may have been high school graduates, the projects are applicable to teachers of high school students. In these cases, students connect the "mathematical modeling cycle" with social justice issues, particularly environmental concerns. Similarly, *“Dilemmas and Design Principles in Planning for Justice-Oriented Community-Based Mathematical Modeling Lessons”* examines justice-oriented Community-Based Mathematical Modeling (CBMM) units implemented in elementary classrooms. These units encourage students to engage with and contribute to food security initiatives (Suh et al., 2023).

2.3 Theoretical context

Cross-curricular learning can effectively prepare STEM students by drawing upon foundational educational theories, including progressivism, constructivism, and experiential learning. These theories serve as the backbone of cross-curricular approaches. The following section will provide a detailed explanation of how these theories support cross-curricular learning and contribute to preparing students for future academic and professional pursuits.

2.3.1 Progressivism

Progressive education theory is an important foundation of cross-curricular learning. One of the main tenets of progressive education was that knowledge was not bound by disciplines (Drake & Reid, 2020). Progressivism promotes interdisciplinary approaches, project-based learning, and the integration of various subjects, which align with the principles of cross-curricular learning. John Dewey suggested that curriculum should begin with students' questions and inquiry, rather than disciplines (Queen's University, 2020).

The progressive education theory also supports preparing students for the real world. The Open University in the United Kingdom presents a set of innovative pedagogical approaches that have the potential to guide teaching and transform learning. These approaches are "either attached to specific technological developments or have emerged due to an advanced understanding of the science of learning" (Herodotou et al., 2019, p. 1). Herodotou et al. (2019) also stated that the goal of progressive education is preparing students for a dynamically changing economy and job market, where the need exists to possess the skills and flexibility to continue learning while on the job. Progressivism believes that education should go beyond the traditional focus on academic content and examinations.

2.3.2 Constructivism

Constructivism is related to cross-curricular learning because it emphasizes the active construction of knowledge by learners and the importance of engaging in meaningful experiences. The key is that learners do not passively receive knowledge but instead internalize and make sense of it in their own individual ways. The two branches of constructivism, radical and social, affect cross-curricular learning in their own ways (Haylock, 2007). Radical constructivism states that learners should build knowledge based on their experiences, including learning experiences derived from the curriculum (Haylock, 2007). Social constructivism emphasizes the social nature of learning and the importance of social and intersocial collaboration in cognitive development. Social constructivism can be introduced to the curriculum as suggested activities, such as “[p]upils extend[ing] their learning from interpreting the relationship between their movements and the graph to apply the relationship to generate a particular shape of graph” (Haylock, 2007, p. 38).

Carpenter and Lehrer (1999) considered that teachers should create classrooms where they support students to solve problems. They should only guide students’ discussion, but they also “convey to the students that they themselves can figure out strategies and do not need to appeal to the authority [of] the teacher to find out whether a procedure is correct or acceptable” (Carpenter & Lehrer, 1999, p. 46).

Mathematical tasks like field trips, science projects, or reading math books can also be helpful for intermediate students (Carpenter & Lehrer, 1999) and can be suggested in the curriculum. Constructivism emphasizes that learners actively construct knowledge through meaningful experiences. Although their research was on Grades 6-8 students, the idea of having support from teachers to use problem solving and activities to keep the classroom engaging is similar for Grade 12 students. In the examples given, students extend their learning by applying their understanding of the relationship between their actions and the creation of a specific shape on a diagram. It proposes a cross-curricular approach by integrating mathematics with other subject areas. By combining concepts from different STEM courses, students can explore connections and deepen their understanding of mathematics and related subject areas.

The key idea of constructivism is that meaningful knowledge and critical thinking are actively constructed, in a cognitive, cultural, emotional, and social sense, and that individual learning is an active process, involving engagement and participation in the classroom. Constructivist learning theory and constructivist pedagogy are useful in supporting effective educational approaches to improve learning, performance, standards, and teaching (Scotland Education, 2020). Another study found that the constructivist approach is helpful in developing collaborative skills and teamwork, which are essential for STEM students in their future studies (Sasson et al., 2021).

2.3.3 Experiential Learning Theory

Cross-curricular learning recognizes the importance of providing students with authentic, real-life experiences that go beyond memorizing facts and procedures, and it is based on experiential learning. According to the Council of the European Union, the focus in education should be on developing problem-solving skills, critical thinking, collaboration, computational thinking, and self-regulation, which are essential for students to apply their knowledge effectively in real-time situations (Cotič et al., 2021). "A child experiences the world as a whole, and it is thus important to provide contents arising from real-life situations and based on experiential learning" (Cotič et al., 2021, p. 3134). Therefore, cross-curricular learning based on experiential learning acknowledges the importance of connecting education with real-life contexts, fostering a comprehensive understanding of the world, and preparing students with the skills and knowledge needed for their future.

Experiential learning is also supportive in preparing students for later studies. It is contributing in "improving the value of education which centers on developing abilities, and experiences” (Kong, 2021, para. 1). It motivates and engages students in learning, making education more effective, building confidence for students in the future. Anderson et al. (2022) suggested that experiential learning, such as a co-learning university-school-community partnership model, summer residency, and coursework, using critical and culturally relevant outdoor experiential learning can also be necessary for students to know more about the surrounding environment. To a certain extent, this approach can influence students' choice of program in higher education, making them willing to learn more skills to improve their surrounding environment. Commonly, universities offer courses with experiments that require students to have hands-on experience. Experiential learning in high school offers indispensable experiences to students in preparation for their university STEM studies.

2.4 Gaps in Existing Literature

Currently, there is a lack of research specifically examining how cross-curricular content in mathematics courses influences students' preparedness for university STEM studies. Many studies have focused on using standardized test scores to assess whether curricula adequately prepare students academically. While it is important for students to achieve higher levels of content knowledge and academic success, it is equally critical to ensure they are mentally prepared for the transition to higher education. This study examines students' perceptions of how cross-curricular content in Ontario's Grade 12 curriculum prepared them for university STEM studies, specifically quantifying their self-reported confidence in STEM courses rather than their academic performance. A well-designed curriculum should not only provide students with the knowledge they need but also offer opportunities to explore program options, helping them make informed decisions about their future studies.

Although research has explored the effects of cross-curricular learning on academic performance and student engagement, little attention has been given to how this approach can support students' psychological preparedness for the challenges of university. Additionally, there is a gap in research focusing on the effectiveness of cross-curricular content within the Ontario curriculum, as well as STEM students' perceptions of their high school curriculum. Understanding these perspectives is crucial, as students' attitudes and confidence play a significant role in their ability to navigate the transition to higher education successfully.

Chapter Three: Methodology

This chapter outlines the methodology of a cross-sectional online survey, including the background research, design, target participants, data collection process, and methodological limitations. It begins by reviewing existing methodologies from the literature and evaluating their applicability to cross-curricular research, providing a rationale for the chosen approach. The study utilizes a survey designed for Ontario STEM university students, combining quantitative and qualitative questions to evaluate how cross-curricular content in the Grade 12 university-level mathematics curriculum impacted their preparation. The online recruitment process, which involves distributing the survey through STEM professors, university STEM departments, and STEM communities, such as First Year Math and Stats in Canada (FYMSiC) is also detailed. Finally, the methodological limitations, particularly those inherent to online surveys, are discussed.

3.1 Research Approach

To address the problem of the examination of the cross-curricular content within the Ontario Grade 12 university-level mathematics curriculum and its impact on students preparing for future studies in the STEM field, an investigation of students' perceptions regarding the Ontario Grade 12 university-level mathematics curriculum was needed. The research questions focus on the following two points. This study first examines how effectively the existing cross-curricular content in Ontario's Grade 12 university-level mathematics curriculum prepares students for STEM studies. It investigates whether students are successfully applying these cross-curricular mathematical concepts in their university STEM programs. Second, the limitations can be identified within the cross-curricular content in the curriculum; and the elements appear to be absent or under-represented. In students' perceptions, what should stay in the curriculum and what can be improved, in Ontario's Grade 12 university-level mathematics curriculum. Sample questions in the survey are further discussed in the survey section.

Regarding these foci of the research questions, this research focuses on understanding university STEM students' perspectives regarding their learning experiences with cross-curricular content in Ontario's Grade 12 university-level mathematics curriculum, and how effectively they believe it prepared them for their STEM studies. Researchers believe that educators can enrich the learning environment by treating students as having opinions that matter (Cook-Sather, 2007). Providing "forums within which practicing teachers can hear student perspectives outside of the regular structures and power dynamics of classrooms" (Cook-Sather, 2007, p. 357) is a way to support improvements in education.

Feedback from students can enhance reflective capacities in educators and inform educators about the individual needs of students (Seldin, 1997, p. 767). "Curriculum flexibility is conceptualized as adaptability and accessibility of the curriculum" and they are to "respond to students' needs and capabilities" (OECD, 2021, p. 3). Besides, the curriculum should be designed "around students to motivate them and recognize their prior knowledge, skills, attitudes and values" (OECD, 2019, p. 6). Overall, students' perceptions can be considered to the development or revision of the curriculum because they provide valuable insights into how the curriculum affects their engagement, comprehension, and preparation for the STEM field, thereby informing potential improvements in the educational system.

This methodology captures perspectives from university STEM students around 1-4 years after completing Ontario's Grade 12 university-level mathematics curriculum, allowing them to reflect on their preparation with sufficient temporal distance while maintaining clear recollection of their secondary mathematics experience.

This mixed-methods study, with quantitative and qualitative research methods, combines an online cross-sectional survey of university STEM students with analysis of practitioner literature on cross-curricular mathematics education. The survey methodology was selected for its ability to efficiently gather retrospective perceptions from students who completed the Ontario mathematics Grade 12 curriculum (2007-present) while actively engaged in STEM studies.

3.2 Participants

The survey questionnaire, which will be administered online through the Qualtrics platform (https://www.qualtrics.com/), will be carefully structured to gather essential information related to participants' educational backgrounds, program choices, mathematics study interests and experiences, as well as their course evaluation scores. The research population is selected to be all STEM university students in Ontario who have completed Ontario Grade 12 university-level mathematics courses aligned with the Ontario curriculum. There are various versions of the Ontario curriculum, including those implemented after 2007, between 2003 and 2007, and the OAC curriculum before 2003. Considering most of the participants might not be aware of the version of their Grade 12 curriculum, the question that asks about their year of graduation from high school will help the researcher to decide the version of their curriculum.

Regarding the sample selection, Nipissing University and other universities across the province have been chosen to provide geographical representation and diversity. This includes STEM professors from Brock University, Carleton University, McMaster University, Nipissing

University, Ontario Tech University, and 13 universities in total (listed in alphabetical order). The full list of the universities that received recruitment letters can be found in Appendix E. The French program at the University of Ottawa was excluded since the curriculum for this research is in English. Similarly, Lakehead University was not included to ensure the sample predominantly consists of participants who studied the Ontario Grade 12 university-level mathematics curriculum, as students at Lakehead may disproportionately represent out-of-province or international academic backgrounds, because of its geographic location (Lakehead University, 2023).

The professors recruited are from programs such as Chemistry, Earth Sciences, Biological Sciences, and other STEM disciplines. Recruitment letters were sent to 354 professors, covering a wide range of STEM programs at these universities. However, only a limited number of professors in each program were contacted due to the large number of professors available. The decision to include multiple universities in the sample is based on the need for a comprehensive understanding of the cross-curricular impact within Ontario's STEM education landscape.

Furthermore, it is important to note that the Research Ethics Board (REB) has been consulted, and the research design aligns with their guidelines and considerations. Circulation of a request to engage with the survey through math-focused organizations such as FYMSiC (First Year Math and Stats in Canada), general social media such as online university groups and university’s students’ unions and contacting universities' Math departments and professors. To ensure the representativeness of our sample within the STEM field, there are specific questions in the survey questionnaires that prompt participants to identify their academic focus. Additionally, outreach methods are pivotal in achieving this goal. For instance, the survey questionnaires is prominently featured on math-centric platforms such as FYMSiC (First Year Math and Stats in Canada), enabling the investigator to connect with students deeply immersed in mathematical and related disciplines. Furthermore, the investigator collaborates with university mathematics departments and professors, enlisting their support in disseminating the survey questionnaires to eligible students.

Participants are asked to complete an online survey questionnaires that asks questions about cross-curricular aspects of high school math courses that they have taken. The survey questionnaires have a descriptive section, followed by three sections specific to three separate courses. Participants are asked to complete a section regarding a course and then asked if they are willing to complete additional sections about their other courses.

To ensure their willingness to complete the survey questionnaires, they are given the opportunity to participate in a draw for a small reward. This requires them to provide an email address, which removes anonymity, and so it is provided as an option as opposed to being required. To ensure a high response rate, the consideration of providing a gift card as an incentive is explored, while simultaneously maintaining participant anonymity to minimize bias and enhance the reliability of responses.

3.3 Research methods and methodological strengths

Research methodologies for this study will be detailed in the following sections, which include the survey research method, quantitative and qualitative research methods, aimed at collecting perceptions from Ontario STEM university students, assessing the influence of cross-curricular content in the Grade 12 university-level mathematics curriculum.

3.3.1 Survey research method

In the process of designing the data collection method for this study, the aim is to ensure a representative sample of Ontario STEM students. The intention is to use a survey that effectively captures a diverse range of participants from across the province. While the Grade 12 mathematics curriculum is standardized across Ontario, many students tend to attend universities close to their home region, influenced by convenience, familiarity, and access to resources. The Ontario Universities' Application Centre (OUAC) system further simplifies this process (Ontario Universities Application Centre, 2024), allowing Ontario high school students to apply to multiple Ontario universities with guidance provided by high school counselors. This makes it particularly important to survey a wide geographic range of participants to ensure representation of varied local contexts, teaching approaches, and school resources, which may influence students' experiences and preparedness.

A survey is a systematic method for "gathering information from (a sample of) entities for the purposes of constructing quantitative descriptors of the attributes of the larger population of which the entities are a [sic] member" (Groves et al., 2009, p. 2). Therefore, the survey research is a suitable design for this study because it enables the systematic collection of data from a broad sample of Ontario STEM students, allowing for a comprehensive assessment of their experiences with the cross-curricular content. Survey questions, such as Likert scale responses which can provide quantitative insights into how prepared students feel for STEM studies, are efficient for gathering structured data. Additionally, open-ended questions in the survey can capture qualitative insights and examples, providing a well-rounded view of students' experiences. Survey research also allows for the efficient collection of data from a large and diverse group of participants, making it practical for assessing the impact of curriculum content on a wide range of students, which is especially relevant in the context of Ontario's diverse educational landscape.

In the survey methodology, a series of systematic steps are undertaken. First, the research questions, focusing on the impact of cross-curricular content in the Grade 12 university-level mathematics curriculum on the preparedness of Ontario STEM students for university studies, are defined. Next, the target population, Ontario STEM university students, is identified. The survey design, a cross-sectional survey, has been chosen to align with the research objectives. The online survey was accompanied by clear instructions, informed consent, and an option that participants could opt out. Finally, systematic data collection and organization occurred, resulting in a Spreadsheet of response. The results were then analyzed using statistical techniques, including descriptive statistics and tests for specific purposes that will be described along with the results in the next chapter (Fisher & Marshall, 2009). The survey consent form is in Appendix A, and the survey questionnaire is in Appendix B, which will be further discussed in Section 3.4.

3.3.2 Qualitative and quantitative research methods

The survey questionnaires combine both qualitative and quantitative research methods. Qualitative methods are used to gather insights from Ontario university STEM students through open-ended questions, such as specific examples and suggestions. These qualitative responses can provide a clear understanding of the cross-curricular impact of the existing curriculum (Ontario Ministry of Education, 2021c). In contrast, quantitative methods are utilized to collect structured data. The survey questionnaires include Likert scale questions that assess students' perceptions regarding the preparedness and potential gaps resulting from the cross-curricular content within the curriculum.

Additionally, it is crucial to note that this quantitative approach will also help identify topics or concepts that students may not mention in their responses. For instance, if a significant number of respondents do not mention a particular topic, such as radians, it may indicate its perceived insignificance or that it is not a gap in their preparation. This observation can potentially highlight areas for further research beyond the scope of this thesis.

This approach allows for a comprehensive exploration of the research questions, combining the strengths of both qualitative and quantitative data to provide a holistic view of the topic. The primary focus of the quantitative method is to describe and analyze the relationships and trends between the factors and STEM preparedness scores, with an emphasis on data analysis that prioritizes examining trends, comparing groups, and exploring relationships between variables to assess the impact of cross-curricular content on STEM preparedness.

Qualitative research in this context involves an open-ended exploration of the subject matter, aiming to obtain detailed information from respondents to gain a comprehensive understanding of their experiences and perspectives. Open-ended questions enable participants to share their insights and examples in their own words about the Ontario Grade 12 university-level mathematics curriculum.

Mixed-method research with qualitative and quantitative methods is a suitable design for this study because it allows a comprehensive exploration of the cross-curricular content in the Grade 12 Ontario university-level mathematics curriculum. It allows data collection to be interpreted in quantitative and qualitative ways, allowing comparison in the findings (Doyle et al., 2009). Different kinds of methods are needed in this case because “social phenomena are so complex” (Byrne & Humble, 2007, p. 1), and that the mixed-method research method “enable[s] the researcher to answer confirmatory and exploratory questions at the same time and as a result the research is able to construct and confirm theory in the same study” (Byrne & Humble, 2007, p. 1).

To conduct mixed-method research effectively, a systematic approach is undertaken. Initially, the survey's targets and objectives are defined, encompassing the identification of the target population, Ontario STEM university students, and the specific study objectives pertaining to the cross-curricular content in the Grade 12 Ontario university-level mathematics curriculum. Subsequently, a comprehensive survey instrument featuring both qualitative and quantitative components is developed. Structured questions with Likert scale responses quantify students' perceptions, while open-ended inquiries facilitate qualitative insights and examples. Finally, the survey is distributed via online platforms, targeting Ontario STEM students through educational organizations and relevant online communities, which was explained in the previous section. As responses are collected, they are systematically recorded, ensuring accuracy, and preserving anonymity and confidentiality. Invalid responses are appropriately discarded.

After the data collection, the survey data is structured and quantitatively and qualitatively analyzed. Quantitative analysis uses statistical techniques in Excel to analyze responses to various questions, while qualitative analysis identifies themes and patterns from open-ended responses. The themes are identified by the researcher to group similar ideas, and key insights are highlighted to address the research questions. The findings, including trends and examples from participants, will be detailed in Chapters 4 and 5.

3.4 Survey and Data Collections

The survey design involves three sections. The first section, the introduction, addresses consent required to adhere with the Tri-Council for consent in research (Government of Canada, 2020) and approved by the Nipissing University Research Ethics Committee. The application number is 103519. The consent form obeys the general principles that consent is given voluntarily, can be withdrawn at any time, and participants can request the withdrawal of their data if consent is withdrawn (Government of Canada, 2020). The consent form is outlined in Appendix A. To encourage participation, a $25 Indigo gift card draw is included as an incentive for students who complete the survey questionnaires. While the reward aims to motivate engagement, it is designed to attract genuine participation rather than encourage responses solely for the purpose of receiving the reward.

The second part of the survey questionnaires, outlined in Appendix B, is designed to collect essential participant information. This section aims to confirm that participants align with the survey's target sample and categorize them accordingly. Detailed questions inquire about their high school and university experiences. High school-related queries encompass whether they completed Grade 12 in Ontario, the specific university-level mathematics curriculum they followed, and the courses they took. The survey questionnaires focus on three specific courses within the Ontario curriculum: Advanced Functions (MHF4U), Calculus and Vectors (MCV4U), and Data Management (MDM4U).

The paths to or prerequisites for these Grade 12 university-level mathematics courses are detailed in Appendix D. Notably, Advanced Functions and Calculus and Vectors are fundamental prerequisites commonly required for enrollment in STEM programs at Ontario universities (McMaster University, 2023; University of Guelph, 2023). Regarding university experiences, participants are asked if they are currently enrolled in or have attended Ontario universities, their enrolled programs, and their current year of study. (Dr. Sibbald's current and former students will be excluded for ethical reasons.) Additionally, a non-bot verification process, reCAPTCHA, is incorporated to validate their responses (Sivakorn et al., 2016). The non-bot verification is a built-in program on Qualtrics, which allows the system to detect whether a human is filling out the survey and thereby stops bots. The system tells the difference between humans and machine responses by virtue of speed and precision.

The third section of the survey questionnaires, detailed in Appendix B, is dedicated to capturing students' perspectives on the curriculum. This section is structured around three core courses: Advanced Functions (MHF4U), Calculus and Vectors (MCV4U), and Data Management (MDM4U). Participants are asked which of the three courses they have taken in the participant information section. Based on their selection, the survey will randomly direct them to one of the corresponding sections. For example, if a participant selects both Advanced Functions and Calculus and Vectors, they will be directed to either the Advanced Functions section or the Calculus and Vectors section to begin the survey. After completing one section, participants will be asked if they would like to proceed to another section based on the courses they selected. In the example above, a participant who finishes the Advanced Functions section will have the option to complete the Calculus and Vectors section next.

Once participants complete two sections, they will be directed to the optional questions section, which includes an opportunity to provide their email to participate in a prize draw. Participants can also exit the survey after completing just one section. The order of the sections is randomized to ensure that no specific section consistently appears last, which helps prevent participants from becoming fatigued and potentially rushing through or skipping certain sections, such as the Data Management section, if it were always placed at the end.

Each course is further broken down into three to five topics in alignment with the current Ontario Grade 12 university-level mathematics curriculum (Ontario Ministry of Education, 2007). To help participants recall the topic content, a sample math question is provided for each topic. Within each topic, participants encounter four questions. First, they rate their experiences with the cross-curricular content within that specific topic in the curriculum, using a scale from 1 (very limited cross-curricular content) to 5 (abundant cross-curricular content). Second, they assess the effectiveness of this cross-curricular content in preparing them for their academic pursuits, scoring it from 1 (did not provide preparation) to 5 (provided substantial preparation). For convenience, these ratings will be called the experience and effectiveness ratings from now on. Third, they are prompted to share examples of how the cross-curricular content in that topic either assisted or hindered their preparation for their academic field. Finally, participants are encouraged to suggest potential improvements that could enhance the cross-curricular content within the topic.

In summary, the third section of the survey, as outlined in Appendix B, provides a framework for gathering valuable insights into the students' perspectives on the curriculum. By breaking down key courses and topics, offering sample questions, and soliciting detailed feedback, this section aims to gain a nuanced understanding of the cross-curricular content's impact and effectiveness.

Data collection for this study is conducted primarily through online recruitment channels, including social media platforms, math-focused organizations like FYMSiC (First Year Math and Stats in Canada), and direct outreach to STEM professors and student unions. Recruitment requests were sent to 354 professors across various STEM programs and universities, selected to ensure a diverse and representative sample. These professors were chosen from disciplines such as Chemistry, Earth Sciences, Biological Sciences, and other STEM-related fields, spanning 13 universities across Ontario (listed in Appendix E). Additionally, recruitment requests were distributed to first-year offices at institutions such as the University of Toronto, the University of Waterloo, and Ontario Tech University, among others. The purpose of these requests was to circulate access to the survey, which participants could complete privately and asynchronously at their convenience. The recruitment letters, which outline the study's objectives and participation details, are provided in Appendix C.

Once the survey questionnaires period concludes, the data will be downloaded from the online survey platform, Qualtrics, in Excel format for analysis. This format allows for efficient organization and examination of both quantitative and qualitative responses. The survey questionnaires include specific questions designed to capture participants' academic focus, ensuring the representativeness of the sample within the STEM field.

3.5 Methodological Limitations

The methodology has some limitations because it is using an online survey. Validity is a concern where "it is impossible to verify, with any reliability, that participants met those qualifications" (Rice et al., 2017, p. 64). It becomes exceedingly challenging to establish with certainty whether participants meet the specified qualifications, casting doubt on the representativeness of the respondents. In this instance, the target population comprises all Ontario university STEM students who have undergone the Ontario university-level mathematics curriculum during their Grade 12 studies. The participants in this survey are essentially individuals who happened to be online when the survey questionnaires were made available on specific websites or who had a professor who shared the link with it. Despite proactive outreach efforts to engage university STEM departments and professors, the randomness of participant selection remains an unavoidable challenge.

Furthermore, addressing the potential issue of low response rates is crucial. To incentivize participation, a gift card reward system has been implemented, randomly rewarding one of the respondents. However, this approach introduces a potential complication, as it may motivate participants primarily for financial gain and, in extreme cases, lead to fraudulent responses. In response, the value of the reward was minimal ($25) and robust non-bot verification measures have been integrated into the survey process, complemented by careful examination of survey responses by the researcher to safeguard data integrity.

Moreover, some of the potential participants may not be comfortable with computer technologies (Boyer et al., 2001, p. 5), which could affect the validity of their responses. This introduces an additional layer of complexity in ensuring the quality of the collected data. Finally, the decision to forgo post-survey interviews in this study is not solely due to the anticipated number of participants.

The survey itself is designed to be comprehensive and gathers extensive data that would be required to inform the development of effective interview questions. Incorporating interviews would necessitate an additional research phase, extending beyond the project's intended scope. As such, the research focuses primarily on the survey data analysis to attain a thorough understanding of the research problem at hand. While collecting further information through additional interviews or instruments could provide more detailed insights, an effort was made to balance the various options and limitations of the study design.

Chapter Four: Results

This chapter presents the findings of the survey, describing the comparisons between topics, comparisons between programs, and examining the qualitative data. The quantitative and qualitative results focus on the participants' perceptions on how the curriculum could have better aligned with the needs they perceived as university students in the STEM field reflecting on what they learned as high school students. The survey consists of five sections: the Participant Information section, Advanced Functions section, Calculus and Vectors section, Data Management section, and an optional section. The Participant Information section includes questions to help validate participants' responses.

4.1 Profile of Participants

With the survey posted online and the recruitment process initiated on Feb.20, 2024, 134 responses were successfully collected over two weeks. However, some challenges associated with online surveys became evident. Upon reviewing the results, many responses were found to be unusable. This situation will be further discussed later in this section. Despite clear recruitment criteria specifying that participants should be Ontario STEM university students that went to high school in Ontario; a significant number did not meet this requirement. One issue was that communication for participants was done through third parties, who may not have considered or been aware of the specific requirements.

As a result, some participants entered the survey and did not complete it (though no one formally withdrew). Additionally, some individuals attempted to use bots to complete the survey in pursuit of the prize, evident by a few bots detected in the responses. Therefore, before proceeding with data analysis, it is necessary to review the responses and remove any that do not meet the required criteria.

After completing the Participant Information section (first section), some participants did not proceed to fill out any of the second section options: the Advanced Functions, Calculus and Vectors, Data Management, or optional sections. This means they provided their descriptive information but did not complete the survey or contribute detailed responses to the investigation. To be considered a valid contributor, participants were required to complete the Participant Information section and at least one additional section. This requirement was clearly stated in the consent letter, which participants were asked to read and agree to before starting the survey.

The initial review of the survey responses took place on March 21, 2024, approximately four weeks after recruitment began. At this time, there were 134 responses. This review aimed to give the researcher an initial understanding of how many responses could be used for analysis. After examining the 134 responses, 94 were excluded from further analysis. Table 2 below outlines the reasons for excluding these responses and the corresponding number of responses removed for each reason.

Table 2

Reasons for removal of participant responses after first two weeks of surveying

Reasons for Removal of Data from Data Analysis	Number of responses removed
Did not agree to participate in survey	2
Did not pass the non-robot Verification or quit right after the non-bot verification	31
The year of graduation from high school is invalid or before 2006	10

Did not provide responses to any sections of the survey (Advanced Functions, Calculus and Vectors, Data Management, or the optional section), other than participant information	51

Invalid responses to the high school graduation year included irrelevant answers such as “no” or a year later than the participant’s university enrollment year. “In most cases, you need a high school diploma to go to college or university in Ontario” (Ontario Ministry of Education, 2012). Therefore, the answer was considered inconsistent or illogical if the participants claimed their high school graduation was in 2023 with university enrolment in 2022.

Additionally, participants who reported a graduation year before 2006 were excluded because they would not have followed the current Ontario Grade 12 university-level mathematics curriculum, which was implemented in 2005. While there was a minor update in 2007, it had little to no impact on the courses of interest in this study (Mueller, 2019). Therefore, restricting the sample to students who graduated in 2006 or later ensures that all participants experienced a consistent curriculum framework.

Ten responses were removed because they claimed to have graduated high school prior to 2006. The participants that were willing to contribute to the survey were expected to have responded to the participation information section and at least one other section. This is to ensure the meaningfulness of the responses. However, 51 responses were excluded because they only completed the Participant Information section without proceeding with any other part of the survey, leaving their contributions incomplete and lacking the required details. The possible reasons for these participants to only complete the Participant Information section are discussed in the research limitation section in Chapter 5.

After the initial review of the survey results, it became evident that nearly half of the participants chose to exit the survey after completing the Participant Information section, without providing any details for the Advanced Functions, Calculus and Vectors, Data Management, or optional sections. The investigator speculated that the non-robot verification process might have caused difficulties for participants, potentially discouraging them from proceeding further. To address this, the non-robot verification was removed, and a duplicate version of the survey without this verification was created. For clarity, the survey with the non-robot verification (which was a CAPTCHA) is called the *original survey* while the duplicate without the verification is called the *updated survey*.

Researchers have found that CAPTCHA as a non-bot verification and has caused users to have difficulty in using them (Bursztein et al., 2010). Researchers also found that "[w]hen looking at misspellings and casing errors, an average 29.45% of the 1,027 test subjects failed to complete each CAPTCHA" (Scott, 2018, para. 12). Although the reason for CAPTCHA to be applied is to avoid robot filling out the survey for the reward, however, "in practice [they] also cause users to give up" (Scott, 2018, para. 7) and they do not continue to complete the survey in this case.

Studies also showed that "AI-automated attacks on various CAPTCHA schemes have been successful" (Ngila, 2023, para. 4). To avoid robots filling out the survey, CAPTCHA or reCAPTCHA are not the only ways. Responses to this survey can also be examined by researchers to determine whether they meet internal validity checks (such as whether the year of high school graduation and entering university are consistent and reasonable).

There were three occasions when examinations and removal of results occurred, each explained in the corresponding tables (Tables 2, 3, and 4). The first examination, conducted on March 21, 2024, is detailed in Table 2. During this preliminary examination, I suspected that the non-bot verification process was causing difficulties for participants to complete the survey. As a result, the non-bot verification was removed from the original survey to create an updated version. Both the original and updated surveys remained available for further data collection. Subsequent examinations involved analyzing the full dataset for the original survey and separately for the updated survey.

The updated survey was redistributed to the same professors and participants groups for recruitment. The recruitment letter for this updated survey can be found in Appendix F. This recruitment letter indicates that there may be a problem with the non-bot verification, and an updated survey was made available for participants. The updated survey started to collect responses on March 21, 2024.

The surveys were officially closed on April 26, 2024, roughly eight weeks from the initial survey, and roughly four weeks since the non-bot verification was removed. The response rates for both surveys were low for approximately a week. Therefore, I decided to close the survey and start data analysis. By this date, the original version of the survey (both before and after the removal of the non-robot verification) had collected a total of 184 responses.

A thorough examination of these responses was conducted on April 26, 2024, to identify and exclude invalid or incomplete responses from the original survey. Responses were collected from February 20 to April 26, 2024, for the original survey. Table 3 outlines the reasons for removing specific responses and the corresponding number of exclusions from the original version of the survey for all 184 responses. Out of the 184 responses, 51 responses remained after the removal of invalid responses.

Table 3

Reasons for removal of data for data analysis of the original survey (March 21 to Apr 26, 2024)

Reasons for Removal of Data from Data Analysis	Number of responses removed
Did not agree to participate in survey	2
The year of graduation from high school is invalid or before 2006	3
Did not provide responses to any sections of the survey (Advanced Functions, Calculus and Vectors, Data Management, or the optional section), other than participant information	128

The examination in Table 3 analyzes the remaining data after the removals detailed in Table 2, along with any new data collected since March 21, 2024. The investigator did not remove responses solely due to the failure of the non-bot verification. Instead, each response was carefully reviewed individually to assess its validity. Additionally, some responses were removed for special reasons. For example, four participants provided meaningless or irrelevant answers, such as “no,” “a very good education,” or responses in other languages, to one of the optional section problems. These participants did not provide any other responses in the remaining sections. As a result, these responses were excluded under the reasoning that they “Did not provide responses to any sections of the survey.” Overall, out of the 184 responses, 51 responses remained after the removal of invalid responses.

An updated version of the survey was posted after March 21, 2024. This version retained the exact same questioning and structure as the original survey but removed the non-bot verification step. On April 26, 2024, a thorough examination of the responses from the updated survey was conducted to identify and exclude invalid or incomplete responses. Table 4 summarizes the results of this review, including the reasons for responses removal and the corresponding number of responses excluded. 44 valid responses remained out of the 180 responses from this updated survey. 136 responses were removed.

Table 4

Reasons for removal of data for data analysis of the updated survey (Feb 20 to Apr 26, 2024)

Reasons for Removal of Data from Data Analysis	Number of responses removed
Did not agree to participate in survey	1
The year of graduation from high school is invalid or before 2006	20
Did not provide responses to any sections of the survey (Advanced Functions, Calculus and Vectors, Data Management, or the optional section), other than participant information	115

The same validity criteria that were used for the original survey were applied to remove invalid responses from the updated survey. In addition, there were some unique cases where responses were excluded. For example, three participants provided meaningless answers, such as “Excellent” or “no,” to the optional section problems without completing any other course specific sections. These responses were also removed under the reason “Did not provide responses to any sections of the survey.”

After applying these removal criteria, 44 valid responses remained out of the original 180. It is possible that some of the students completed both the original survey and the updated survey, with different responses. If that is the case, their programs and years of graduation would be the same. By comparison of programs and years of gradations in both surveys, it was noticed that two students in both surveys shared the same year of graduation and year of entering university with the same program. The possibility of repetition of responses in two surveys is unlikely but cannot be ruled out, as will be further discussed in section 5.2 limitations.

For the original survey, 27.7% (51/184) of responses remain for further data analysis. The removal number adds up from before and after the removal of the non-bot verification, before and after March 21, 2024. For the updated survey, 24.4% (44/180) of responses remains for further data analysis. The number of removed responses was very similar between the original and updated surveys, indicating that the non-bot verification had minimal impact on participant behavior. This suggests that the presence or absence of the non-bot verification did not significantly influence the quality or quantity of responses. The slight difference in the number of eligible responses between the original and updated versions of the survey may be attributed to the recruitment process.

Participation requests were sent out gradually over time, and there was often a delay between requests made by professors and when responses from their students were received. Additionally, the recruitment letter informing professors about the updated survey (with the non-bot verification removed) may have been overlooked or ignored by some professors. This could have limited the reach of the updated survey.

The removal of non-bot verification did not create a systematic bias in the responses, since there is no evidence to suggest that it disproportionately affected the responses. Therefore, the differences in eligible responses are more likely due to the timing and distribution of recruitment efforts rather than the presence or absence of the non-bot verification. In the absence of any evidence of unintended effects arising from the non-bot verification, the responses from the original and updated versions of the survey are pooled for further data analysis with 95 valid responses.

4.2 Quantitative Data Analysis and Results Display

The interpretation of the responses is conducted in two parts. First, a quantitative analysis is conducted using statistical techniques to identify patterns and correlations in the structured data—this was done using Microsoft Excel. This provides an overview of participants' preparations for university STEM programs based on their ratings in each topic of the Ontario Grade 12 university-level mathematics courses. Second, Analysis of Variance (ANOVA) tests are performed to compare scores between the three courses and within each course across different topics. Finally, the responses will be categorized by participants' STEM programs to examine the relationship between their program choice and their ratings of cross-curricular content learning in Grade 12 university-level mathematics courses, as well as their perceived preparedness for STEM studies.

4.2.1 General comparison of the Experience and Effectiveness rating

This section provides an overview of the rating scores associated with participants' perceived experiences and the effectiveness of cross-curricular contents in the three Grade 12 university-level mathematics courses, as evaluated by STEM university students. Table 5 shows the average ratings of participants' experience and effectiveness of the cross-curricular contents in Grade 12 Ontario university-level mathematics curriculum.

Table 5

Average ratings of participants cross-curricular content experience and effectiveness by topic and course

Courses	Advanced Functions	Advanced Functions
Topics	Average Rating of Experience	Average Rating of Effectiveness
Exponential and Logarithmic Functions	3.31	3.36
Trigonometric Functions	3.38	3.41
Polynomial and Rational Functions	3.56	3.28
Characteristics of Functions	3.38	3.38
Courses	Calculus and Vectors	Calculus and Vectors
Topics	Average Rating of experience	Average rating of effectiveness
Rate of Change	3.62	3.71
Derivatives and their Applications	3.52	3.72
Geometry and Algebra of Vectors	3.52	3.71

Courses	Data Management	Data Management
Topics	Average Rating of experience	Average Rating of effectiveness
Counting and Probability	3.51	3.61
Probability Distribution	3.22	3.63
Organization of Data for Analysis	3.66	3.44
Statistical Analysis	3.37	3.61
Culminating Data Management Investigation	3.68	3.73
Courses	Average Rating of experience	Average Rating of effectiveness
Advanced Functions	3.41	3.36
Calculus and Vectors	3.55	3.71
Data Management	3.49	3.60

Table 6

Mode ratings of participants cross-curricular content experience and effectiveness by topic and course

Courses	Advanced Functions	Advanced Functions
Topics	Mode of Rating of experience	Mode of Rating of effectiveness
Exponential and Logarithmic Functions	4	4

Trigonometric Functions	4	5
Polynomial and Rational Functions	4	4
Characteristics of Functions	4	5
Courses	Calculus and Vectors	Calculus and Vectors
Topics	Mode of Rating of experience	Mode of rating of effectiveness
Rate of Change	4	4
Derivatives and their Applications	4	5
Geometry and Algebra of Vectors	3	5
Courses	Data Management	Data Management
Topics	Mode of Rating of experience	Mode of Rating of effectiveness
Counting and Probability	4	4
Probability Distribution	3	4
Organization of Data for Analysis	4	3
Statistical Analysis	4	5

Culminating Data Management Investigation	5	5
Courses	Mode of Rating of experience	Mode of Rating of effectiveness
Advanced Functions	4	4
Calculus and Vectors	4	4
Data Management	4	4

Table 5 and 6 show the average and the mode, respectively, of participants' cross-curricular content experience and effectiveness by topic and course. The ratings of cross-curricular content experience and effectiveness for each topic in Advanced Functions, Calculus and Vectors, and Data Management are shown in the tables, in order.

Participants' learning experiences with the cross-curricular content across the three mathematics courses are very similar, with ratings ranging from 3.41 to 3.56. Similarly, participants' perceptions of how well this cross-curricular content prepared them for STEM university studies are less aligned, ranging from 3.36 to 3.71. Among the courses, Advanced Functions received a slightly lower effectiveness rating, while Calculus and Vectors received the highest ratings. Based on the mode, most participants selected "4" to rate both their cross-curricular learning experience and how well the content prepared them for STEM university studies.

Within these courses, on average, participants have found that they are the most satisfied when learning the cross-curricular contents in the topic of Rate of Change (3.62). In terms of the effectiveness of how much the cross-curricular contents in these topics prepared for university

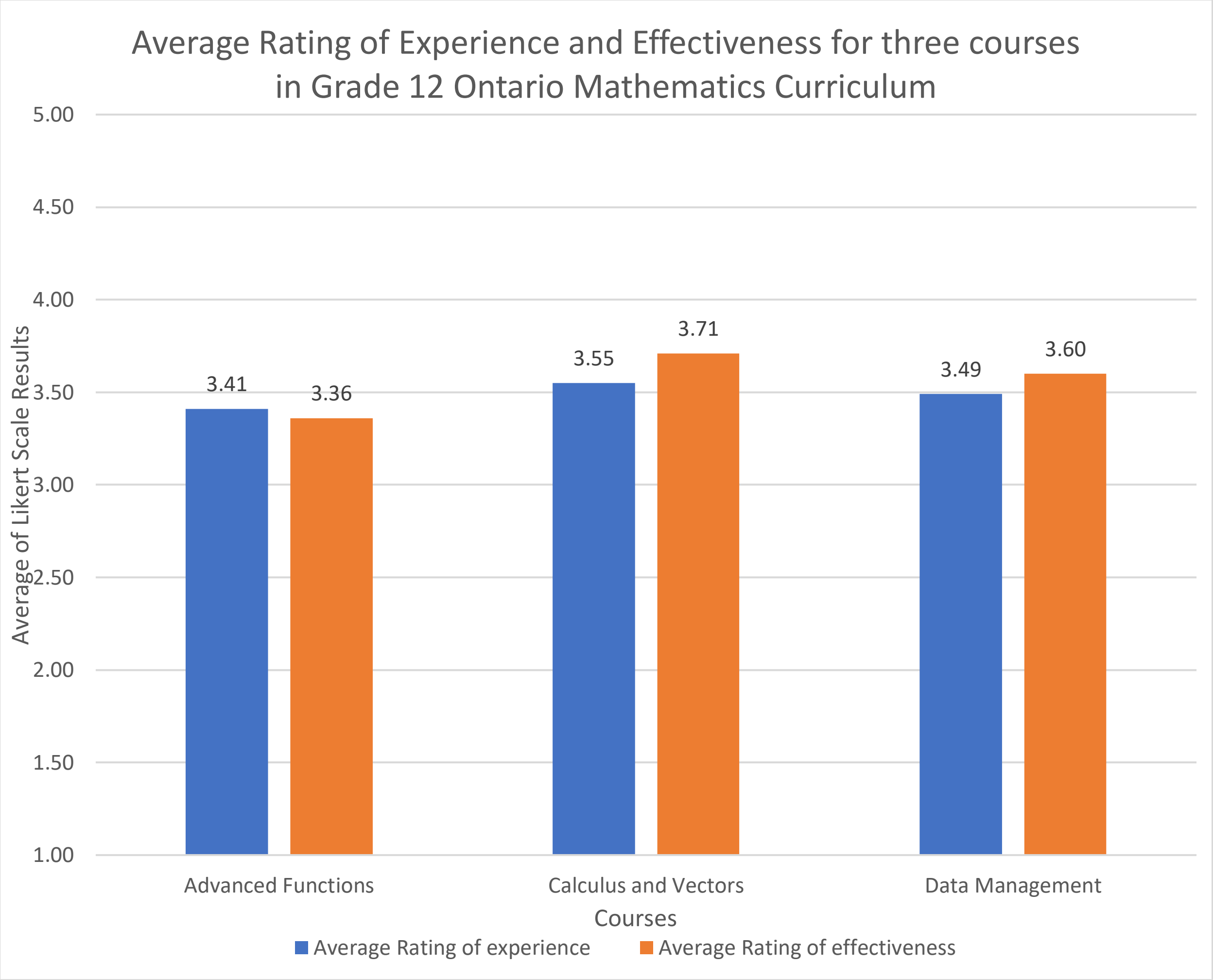
STEM studies, Derivatives and their Applications and Geometry and Algebra of Vectors both show strong effectiveness ratings (3.72 and 3.71).

In Advanced Functions, Polynomial and Rational Functions stands out with the highest experience rating (3.56) but has a notably lower effectiveness rating (3.28). For Data Management, Organization of Data for Analysis and the Culminating Data Management Investigation have the highest experience ratings (3.66 and 3.68, respectively), with the latter also achieving the highest effectiveness rating (3.70) across all topics. These results will be further discussed in the data analysis section, together with the qualitative responses from the participants.

To better visualize the findings of the combined results, a graph is presented to show the average ratings of experience and effectiveness for the three Grade 12 Ontario university-level mathematics courses. The graph illustrates participants' perceptions of their experiences with cross-curricular content and how they felt it supported their preparation for university STEM programs.

Graph 1

Average rating of experience and effectiveness for three courses in Grade 12 university-level Ontario mathematics curriculum



Examining the average and mode ratings of experience and effectiveness for three Grade 12 Ontario university-level mathematics courses, it is noticed that participants are most satisfied with their experience on the cross-curricular contents of Calculus and Vectors and thought that these contents aided them in university STEM studies. The numbers reach the highest average rating of 3.55 for experience and 3.71 for effectiveness, both modes being 4. Data Management follows closely, with an average experience rating of 3.49 and effectiveness rating of 3.60, also with modes of 4. Advanced Functions has slightly lower ratings, with an average experience rating of 3.41 and effectiveness rating of 3.36, though it still maintains a mode of 4. The consistency in modes suggests a general alignment in participants' perceptions across the courses. The three graphs of the experience and effectiveness ratings of the cross-curricular contents of the topics in the three courses can be found in part 3 in Appendix G.

4.2.2 ANOVA test of ratings for comparison between courses and topics

Analysis of Variance (ANOVA) was used for a detailed comparison of the experience rating scores between each topic within these three Grade 12 university-level mathematics courses (Advanced Functions, Calculus and Vectors, Data Management). An ANOVA test determines whether there is a significant difference between the means of groups of data, by “analyzing the levels of variance within more than two groups through samples taken from each of them” (Carpenter, n.d., para. 7). In this study, the assumptions of ANOVA are met due to the sufficiently large sample sizes, with the smallest group containing 156 rating scores. Given that the ratings are based on a Likert scale of 1–5, the central limit theorem ensures that the sum of these values approximates a normal distribution.

Additionally, the data points are assumed to be independent and identically distributed (iid), further justifying the use of ANOVA. While there were two instances of duplicates (participants with the same program and year of graduation), they provided different ratings. These duplicates are statistically insignificant given the overall sample size and do not impact the validity of the ANOVA assumptions (Carpenter, n.d.).

A one-way ANOVA test was employed, as the objective was to compare differences among the three groups based on a single independent variable, which is the participants' rating scores. This test evaluates whether the participants provided significantly different ratings for the three courses. The null hypothesis states that "the means of the experience ratings for these three courses are not significantly different," implying that participants perceived the learning experiences across the courses (Advanced Functions, Calculus and Vectors, and Data Management) as similar.

Table 7 displays the results of the ANOVA test for the experience rating.

Table 7

ANOVA test results for experience ratings on cross-curricular contents across Grade 12 university-level mathematics courses

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Advanced Function Experience	156	532	3.41	1.86
Calculus and Vectors Experience	174	618	3.55	1.44
Data Management Experience	205	715	3.49	1.51

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.65	2	0.82	0.52	0.60	3.01
Within Groups	844.00	532	1.59			
Total	845.64	534				

The variance in this table represents the average of the squared differences from the mean, indicating how the data points deviate from the mean. In the ANOVA table, Sum of Squares (SS) measures the total variation within and between groups, degrees of freedom (df) reflects the number of independent values used to calculate a statistic, and Mean Square (MS) is the average of the squared deviations, calculated by dividing the sum of squares by the corresponding degrees of freedom (Eberly College of Science, n.d).

Using these values, the resulting p-value is approximately 0.60. When compared to the standard significance level (α = 0.05) used in one-way ANOVA tests, the p-value in this case is significantly higher. This indicates that there is no statistically significant difference between the means of the experience ratings for the three courses. As a result, the null hypothesis that the means of the experience ratings for these three courses are not significantly different, is accepted. In other words, participants perceived the learning experiences across the three courses (Advanced Functions, Calculus and Vectors, and Data Management) as similar.

For the effectiveness ratings, an additional ANOVA test was conducted. The null hypothesis states that "the means of the effectiveness ratings for these three courses are not significantly different," implying that participants perceived the cross-curricular content across the courses (Advanced Functions, Calculus and Vectors, and Data Management) as similarly effective in preparing them for university STEM studies. On the other hand, the alternative hypothesis posits that "the means of the effectiveness ratings for these three courses are significantly different," suggesting that participants perceived notable differences in how the cross-curricular content of the three courses prepared them for STEM studies at the university level. Table 8 presents the results of the ANOVA test for the effectiveness ratings.

Table 8

ANOVA test results for effectiveness ratings on cross-curricular content across Grade 12 university-level mathematics courses

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Advanced Function Effectiveness	156	524	3.36	1.92
Calculus and Vectors Effectiveness	174	646	3.71	1.39

Data Management Effectiveness	204	734	3.60	1.43

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	10.64	2	5.32	3.41	0.03	3.01
Within Groups	828.57	531	1.56			
Total	839.21	533				

On the other hand, the resulting p-value for the effectiveness ratings is approximately 0.03. When compared to the standard significance level (α = 0.05) used in one-way ANOVA tests, this indicates that there is a statistically significant difference between the means of the effectiveness ratings for the three courses. As a result, the null hypothesis is rejected. This means that the effectiveness ratings for these three courses are not equal. In other words, participants perceived notable differences in the effectiveness, among the three courses (Advanced Functions, Calculus and Vectors, and Data Management), of preparation for their university STEM studies. Note, however, the ANOVA test does not indicate which measures of effectiveness are significantly different, only that there is at least one that is different (with statistical significance).

To locate the specific difference that ANOVA indicates is present, t-tests (also referred to as t-statistic or t-distribution tests) were conducted to compare the means (averages) of two groups at a time (Qualtrics, n.d.). In this analysis, a two-tailed test was used because the direction of the difference was not of primary interest. The t-tests were not paired, as the survey design did not oblige participants to respond to all three courses; participants were typically asked to consider only one course, and the option to evaluate all three was rare. Consequently, paired data was not available. Three independent two-sample t-tests with two tails were performed to compare the average effectiveness ratings of the three courses. However, using multiple statistical tests requires Bonferroni correction to avoid type I errors. This is explained further before presenting the results.

To determine whether the statistically significant differences in the mean effectiveness ratings across the three courses are primarily driven by the ratings for Advanced Functions, the Bonferroni correction was applied. The original significance level ($\alpha = 0.05$) was adjusted to account for the three pairwise comparisons, resulting in an adjusted alpha of approximately 0.0167 (0.05/3) (Ranstam, 2016). The right column of Table 9 compares the t-test results to this new significance level. After applying the Bonferroni correction, the results show that Advanced Functions has a significantly lower mean effectiveness rating compared to Calculus and Vectors ($p = 0.01$). However, there is no significant difference between Calculus and Vectors and Data Management ($p = 0.38$) or between Advanced Functions and Data Management ($p = 0.08$).

The results of these t-tests are presented in Table 9. The analysis was conducted using Excel's data analysis tool, specifically the function t-Test: Two-Sample Assuming Unequal Variances. This function calculates t-statistics, which measures the difference between the means of the two groups relative to the variation in the data. Smaller absolute t-statistics indicate less evidence of a difference between the groups, while a larger absolute t-statistics suggests a more significant difference. In Excel, the t-statistics are computed such that its magnitude (absolute value) reflects the strength of the difference, not its direction. This calculation aligns with standard statistical interpretation, where a larger absolute t-statistic corresponds to greater evidence against the null hypothesis of no difference.

Table 9

The results of the three t-tests for comparison between the average effectiveness ratings for three courses

Courses to compare	T-statistics	Significant with α = 0.0167?
Advanced Functions and Calculus and Vectors	0.01	Yes (0.01 < 0.0167)
Calculus and Vectors and Data Management	0.38	No (0.38 > 0.0167)
Advanced Functions and Data Management	0.08	No (0.08 > 0.0167)

The data gives an answer to "what the probability is the differences" and "[i]f that probability is very small, then […the] difference is meaningful (or statistically significant)" (Qualtrics, n.d., para. 3). Based on the results of the three t-tests, the p-value of 0.01 is less than the Bonferroni-adjusted significance level (α = 0.0167), indicating that Advanced Functions and Calculus and Vectors exhibit the most statistically significant difference in their average effectiveness ratings for cross-curricular content.

In contrast, the p-value of 0.38 is greater than the adjusted significance level (α = 0.0167), meaning the average effectiveness ratings for cross-curricular content are relatively similar between Calculus and Vectors and Data Management. The Bonferroni correction was applied to account for multiple comparisons, adjusting the significance level to α = 0.0167 (0.05 / 3) to control Type I errors. Since the t-tests in Excel are two-tailed, the p-values are interpreted directly without further division by 2 (Frost, 2019).

Given the small differences between Calculus and Vectors and Data Management, the effectiveness ratings for cross-curricular content in these two courses were combined and compared to Advanced Functions. The results of this t-test yielded a p-value of approximately 0.02, which is less than the standard significance level ($\alpha = 0.05$). This indicates a statistically significant difference in the average effectiveness ratings between Advanced Functions and Calculus and Vectors, but the difference between Advanced Functions and Data Management does not reach statistical significance. These findings suggest that the statistically significant differences in the mean effectiveness ratings across the three courses are primarily driven by the ratings for Advanced Functions, which differ significantly from Calculus and Vectors but not from Data Management.

Calculations were also performed to determine whether participants provided significantly different ratings for each topic within the courses. The results (provided in Appendix H) indicate that all p-values for the learning experience ratings of cross-curricular content are greater than the standard significance level ($\alpha = 0.05$). This suggests that participants perceived no significant differences in their learning experiences across the topics. Similarly, the p-values for the learning effectiveness ratings of cross-curricular content also exceed the significance level ($\alpha = 0.05$), indicating that participants did not find substantial differences in how well the cross-curricular content across topics prepared them for their university STEM studies. Detailed calculation tables are provided in Appendix H.

Within the data management course, the organization of data for analysis is closely related to the culminating data management investigation, because both topics focus on the organization and interpretation of data. In contrast, probability distributions and statistical analysis deal with the analysis and interpretation of one or two variables, often involving normal or probability distributions (Ontario Ministry of Education, 2007). Additionally, probability distributions and statistical analysis have similar experience (3.22 and 3.37) and effectiveness (3.63 and 3.61) ratings to the cross-curricular content. Similarly, the organization of data for analysis and the culminating data management investigation have comparable experience ratings (3.66 and 3.68) based on the average ratings of the cross-curricular content in Data Management.

Given these similarities, the topics of organization of data and culminating data management investigation can be combined and compared to the topics of probability distributions and statistical analysis. Two t-tests were conducted on the combined data: one to compare the experience ratings of the cross-curricular content and the other to compare the effectiveness ratings of the cross-curricular content. Table 10 presents the results of these t-tests.

Table 10

T-tests results of the experience and effectiveness ratings for comparison between the combined topics in Data Management

Topics	Experience ratings t-test statistic	Effectiveness ratings t-test statistic
Organization of data and culminating data management investigation vs. probability distributions and statistical analysis	0.049	0.84

Although the ANOVA tests indicate no significant difference in the experience and effectiveness ratings between the topics in Data Management, the result of the experience t-test is approximately 0.049, which is statistically significant (α = 0.05). This suggests that the experience ratings of the cross-curricular content differ between the groupings of topics. This finding aligns with the data, as the average experience ratings for probability distributions and statistical analysis are 3.22 and 3.37, respectively, while the average experience ratings for the organization of data and culminating data management investigation are higher, at 3.66 and 3.68.

In contrast, the effectiveness t-test statistic is approximately 0.84, indicating no significant difference in the effectiveness ratings between the two combined topics. Based on the average ratings, the experience ratings for the organization of data and culminating data management investigation are significantly higher than those for probability distributions and statistical analysis. These quantitative findings are supported by most of the qualitative responses, which will be further discussed in Section 4.3.3: Data Analysis on Data Management.

The topics of exponential and logarithmic functions, as well as polynomial and rational functions, show differences in their experience (3.56 and 3.31) and effectiveness (3.28 and 3.36) ratings for cross-curricular content. A t-test can be conducted to determine whether these differences are statistically significant. The t-test results yield p-values of approximately 0.43 for the experience rating and 0.80 for the effectiveness rating, both of which are higher than the standard significance level ($\alpha = 0.05$). This suggests that there are no statistically significant differences in the cross-curricular content ratings between these two topics. In other words, participants perceive their learning experiences with these topics, as well as the extent to which these topics aided them in university, to be relatively similar.

4.2.3 Comparisons of ratings based on participants' programs

Participants' ratings were categorized based on their chosen university programs to determine whether participants in the same programs provided similar ratings for their Grade 12 mathematics experience. However, some participants listed the courses they were taking instead of their specific programs when responding to the question: “Please indicate the primary university program you are currently enrolled in or have completed.” For instance, some participants selected options such as “Mathematics and Statistics, Chemistry (excluding health sciences), Biology (excluding health sciences but including botany, zoology, microbiology), Physics.” Others chose “Other program that is a STEM program (Please specify):” without providing further details. Additionally, most participants selected more than one program in their response.

It is important to note that all the options selected by participants were STEM programs, and none of the participants indicated that they were enrolled in non-STEM programs. This suggests that the participants were likely considering or enrolled in the STEM field. However, the issue arises when participants listed specific courses (e.g., chemistry, physics) or combinations of programs without specifying their primary program. It is possible that some students were uncertain about their final program of study and were indicating the range of options they were considering at the time of the survey.

To ensure clarity and consistency in future research, this question should be redesigned to better capture participants' primary focus. One approach could be to frame the question around general career trajectories, such as: “Do your current studies head toward a health focus, math/stats/computer focus, engineering/material science focus, etc.” This would provide clearer and more consistent responses compared to asking for specific programs. For the purposes of this analysis, responses that did not specify a single primary program or selected multiple programs were excluded. Only 54 of the 95 responses that clearly indicated one primary program were used in this section of the data analysis. Computer Science was also counted as part of mathematics programs. Medical Science was counted as part of health science.

The data results are presented in Appendix I, which includes tables summarizing the experience and effectiveness ratings for each program. The sample sizes indicate the number of participants categorized under each program. For example, the table for health sciences provides the average experience and effectiveness ratings for cross-curricular content in each course, along with the percentage of health sciences participants who selected ratings of "1", "2", "3", "4", and "5", respectively.

Out of an abundance of caution and ethical considerations, programs with only one or two participants, such as environmental science, earth science, general science, physics, and nursing, are excluded from this thesis, as their sample sizes are too small to be meaningful. As a result, the focus of the analysis is primarily on programs with larger sample sizes. The empty space in these tables means that there were no ratings for the corresponding course. It is noteworthy that physics has only received one response, and engineering has only three responses. This limited number of responses is because most physics and engineering participants also selected other programs as their primary programs. The data analysis based on these programs with small sample sizes has been conducted; however, they are excluded from Appendix I and retained in a separate document for review upon request.

The following statistics stand out in the tables for programs with sample sizes greater than 3. Health science participants gave the highest ratings for both the experience and effectiveness of cross-curricular content in Data Management (3.6 and 3.9, respectively) and the lowest for Advanced Functions (2.9 and 2.5). Interestingly, 50% of health science participants selected "4" as their score for the learning experience of cross-curricular content in Advanced Functions. However, the average was significantly lowered by the 25% of health science participants who selected "1". Health science students who selected a rating of "1" for their learning experience of cross-curricular content did not provide explanations for their choices. In contrast, comments from health science students who rated their experience as “4” or higher are presented in the next Section 4.3 Quantitative and Qualitative Data Analysis. The effectiveness scores for Advanced Functions were evenly distributed, with 25% of participants selecting “1,” “2,” “3,” and “4,” respectively. This statistic suggests that health science participants held widely varying perceptions on how well the cross-curricular content in Advanced Functions prepared them for university studies.

In contrast, biology participants placed higher value on the experience and effectiveness of cross-curricular content in Advanced Functions (3.75 and 3.7, respectively). Calculus and Vectors also received high ratings for both experience and effectiveness (3.7 and 4.0), particularly for effectiveness. This indicates that biology participants felt the cross-curricular content in Calculus and Vectors effectively prepared them for their university studies in biology.

Chemistry, with a small sample size of 6, showed that participants rated the cross-curricular content in Calculus and Vectors as providing a better learning experience and better preparation for university chemistry studies (3.7 and 4.1, respectively). However, they gave relatively lower ratings to the experience and effectiveness of Advanced Functions compared to participants in other programs. Notably, 42% of chemistry participants selected “2” as their score for the learning experience of cross-curricular content in Advanced Functions.

In Mathematics and Statistics programs, participants provided very similar scores for both the learning experience and effectiveness of cross-curricular content across the three courses, with ratings ranging from 3.0 to 3.5. Notably, the highest percentage of participants in this program selected “4” for the learning experience of cross-curricular content in all three courses. Similarly, they also rated the effectiveness of cross-curricular content in preparing them for university mathematics studies with a “4,” which was the most frequently chosen score.

There was a consideration that computer science participants might have significantly different ratings for these topics compared to participants from Mathematics and Statistics-related programs. However, only three computer science participants clearly identified themselves as such in the survey, and their Likert-scale responses did not show high consistency. As a result, computer science did not significantly impact on the overall ratings for Mathematics and Statistics-related topics. The limited responses from computer science participants may also be due to the unclear primary program question.

4.2.4 Comparisons of ratings based on participants’ graduation years

To investigate whether participants’ high school graduation years influenced their experiences and effectiveness ratings of the cross-curricular content in the Ontario Grade 12 university-level mathematics curriculum, ratings were grouped based on graduation year for analysis. Specifically, participants who graduated in 2023, 2022, 2021, 2020, and 2019 were selected, and their average experience and effectiveness ratings were calculated. Additionally, the percentage of participants who selected ratings of 1, 2, 3, 4, or 5 were determined for each group. These years were chosen under the assumption that participants entered university in the same year they graduated from high school. Thus, 2023, 2022, 2021, 2020, and 2019 correspond to university students in their first, second, third, fourth, and fifth years, respectively.

Using high school graduation years rather than university entry years also provides an estimate of the time gap between when participants completed the Ontario Grade 12 university-level mathematics curriculum and when they completed the survey. This allows for testing the hypothesis that participants with a larger time gap may provide higher or lower ratings due to the potential difficulty of recalling cross-curricular content from the curriculum. The results of this analysis are provided in Appendix J.

Out of the participants who graduated from high school between 2019 and 2023, most of them graduated in 2022, and in 2019. The average ratings based on high school graduation year, as well as the percentage of participants selecting ratings of 1, 2, 3, 4, or 5, showed strong alignment between experience and effectiveness ratings. Participants who graduated from high school in 2023—likely in their first year of university or yet to begin—provided relatively lower experience and effectiveness ratings for the cross-curricular content (3.23 and 3.04). Nearly 20% of this group assigned a rating of "1" for both experience and effectiveness. Participants who graduated in 2022 (3.56 and 3.44) and 2021 (3.54 and 3.41), likely in the first few years of their university studies, gave average ratings for the cross-curricular content. Interestingly, those who graduated in 2020 assigned the lowest experience and effectiveness ratings (3.19 and 3.09). In contrast, participants who graduated in 2019, likely in their final year of university, completed research, or having recently entered graduate school or the workforce—provided the highest experience and effectiveness ratings (3.92 and 3.94).

These ratings raise the question of whether the lower ratings from participants in their third and fourth years of university emerge from the reduced relevance of the Ontario Grade 12 curriculum to their advanced STEM studies. Conversely, the higher ratings from those in their final year or beyond may reflect a renewed appreciation for the cross-curricular content as they engage in research, graduate studies, or professional work, prompting them to recall and value their high school mathematics curriculum These responses may also stem from the fact that the

COVID-19 pandemic began in early 2020 in Canada (Detsky & Bogoch, 2020), which did not impact the high school studies of participants who graduated before that time.

4.3 Quantitative and Qualitative Data Analysis

The reason that quantitative and qualitative data analysis are placed in one section is because qualitative responses help with explaining the statistics shown in the quantitative responses. Although online surveys provide faster and more accessible ways of distribution, their disadvantages become obvious when it comes to qualitative data analysis. Responses such as "N/A" and "no" to an open-ended question that is not simply yes-or-no are very common. Most of the quoted qualitative responses are from the original survey, which might be because of the non-bot verification, or the time difference in recruitment.

4.3.1 Data Analysis pertaining to Advanced Functions

Advanced Functions is a prerequisite course for Calculus and Functions (Ontario Ministry of Education, 2007, p. 9). High school students must complete Advanced Functions before taking Calculus and Vectors. As a result, students' performance in Advanced Functions might be influenced by the time gap since they last took the course. The study results showed that participants rated the learning experience with cross-curricular content in Advanced Functions as about average (3.41) compared to the other two courses. This rating could be because the concepts in Advanced Functions are more straightforward than those in Calculus and Vectors.

However, the effectiveness rating for Advanced Functions (3.36) was the lowest among the three courses. This rating suggests that, on average, participants felt the cross-curricular content in Advanced Functions prepared them the least for their studies. Interestingly, the mode of the effectiveness rating for Advanced Functions was "5." The difference between the mean and mode indicates that participants had very mixed opinions about how well the cross-curricular content in Advanced Functions prepared them.

When categorized by program, engineering participants gave Advanced Functions an average effectiveness rating of "5." For example, one engineering student noted that "[t]hese [concepts] were very important for STEM topics and are needed in almost all mathematics and engineering courses." On the other hand, participants from health science and chemistry programs gave lower average ratings of around 2.5 and 2.9, respectively, for the effectiveness of Advanced Functions.

A Chemistry student commented that "[t]here was not a lot of cross-curricular content in Advanced Functions. Most of the content was purely math-related and did not connect to other academic fields." They also expressed that "[i]t would have been helpful if more of the Advanced Functions curriculum focused on applying math to solve real-world problems. For example, after graphing a data set, it would have been useful to learn how to represent the data as a possible function in high school."

Based on the expectations outlined in the Ontario Grade 12 Advanced Functions curriculum, there is limited emphasis on applying functions to other fields in the topics of Exponential and Logarithmic Functions, Trigonometric Functions, and Polynomial and Rational Functions. Only the Exponential and Logarithmic Functions section mentions solving equations algebraically, "including those in problems arising from real-world applications" (Ontario Ministry of Education, 2007, p. 87). Most of the applications of functions are concentrated in the topic of Characteristics of Functions. The focus of the three function topics is primarily on identifying key features and solving equations graphically and algebraically. Even in the Characteristics of Functions topic, the emphasis is on finding rates of change, combining two functions, and, as the final point, “comparing the characteristics of functions and solving problems by modeling and reasoning with functions” (Ontario Ministry of Education, 2007, p. 95). Notably, the curriculum does not explicitly mention that these skills can be applied to solve problems in other STEM fields.

A Computer Science student commented, “I don’t think the content in Advanced Functions contributed much to my studies in computer science, which involves a lot of logical thinking but focuses much less on pure mathematics. Most of the knowledge here is good to know but isn’t a prerequisite for computer science.” A Biomedical student felt that the cross-curricular content in Advanced Functions “helped me learn to think outside the box.” A Nursing participant noted, “[i]t is not a requirement for admission, but it’s a bonus in this case.” Similarly, a biology student shared, “It did help because my first math course in university was easier to pass due to having a strong foundation.” Overall, it seems that some participants viewed Advanced Functions as a mathematical foundation that helped them develop problem-solving skills and logical thinking abilities for their later studies.

However, they did not see a direct connection between the course content and what they studied in their STEM programs at university. This phenomenon may be because a significant portion of the course focuses on understanding families of functions—such as distinguishing polynomials from exponentials, trigonometric, and rational functions—which might not align directly with the specific applications or advanced topics encountered in their university programs.

The topics in Advanced Functions are, in fact, strongly connected to other STEM-related fields, as recognized by some participants. The cross-curricular content in Exponential and Logarithmic Functions received an average experience rating of 3.31 and an average effectiveness rating of 3.36. For example, one participant from Earth Science mentioned that their science courses involving lab work still incorporate the use of exponential and logarithmic functions. They also noted that an Earth Science course requiring data analysis used polynomial functions to create graphs. Similarly, a Health Science student noted, "[F]or my specific program requirements, I feel exponential and logarithmic functions helped me the most in terms of practicing the use of [exponents] and working with the calculator."

Exponential and Logarithmic Functions have wide applications in finance, biology, health science, and physics. For example, compound interest is a common application of exponential functions (Perencevich et al., 2007). In biology, the University of Ottawa's Biology program requires students to study topics such as cell cycles and reproduction in Introduction to Cell and Molecular Biology and organismal interactions at the population and community levels in Introduction to Organismal Biology. These topics often require students to apply their knowledge of Exponential and Logarithmic Functions to model population growth (University of Ottawa, n.d.). A Mechanical Engineering student also highlighted the importance of Exponential and Logarithmic Functions in understanding radioactive decay. For instance, Ontario Tech University's Nuclear Engineering program includes a course on Radiation Protection, where students examine radiation decay and distance in detail (Ontario Tech University, n.d.-b). Additionally, a Nursing student mentioned that functions helped them "read graphs to identify abnormalities in patients." In this case, nursing students apply their knowledge of periodic functions in their work.

On average, trigonometric functions received low ratings in terms of experience (3.38) but relatively high ratings in effectiveness (3.41), compared to other topics. A Mathematics and Statistics student commented that “[t]he logarithmic functions section of the curriculum was very limited and did not set me up for success in my future math courses” and “[I] think the trigonometry section could be further enhanced as trigonometric functions are more commonly used across many courses.” This was the only qualitative response that mentioned trigonometric functions. It seemed that this Mathematics and Statistics student was not in finance but instead applied trigonometric functions more frequently in their studies. Since trigonometric functions provide fundamental knowledge to wave functions, they are widely used in fields like engineering and physics, which may explain the average effectiveness rating.

For example, in the Physics program at Queen’s University, oscillatory motions and waves are covered in ten courses. The course Vibrations and Waves focuses on standing and traveling waves, requiring students to derive the classical wave equation and understand classical wave behavior (Queen's University, n.d.). Similarly, the Electrical and Computer Engineering program at the University of Windsor includes two courses on electrical and magnetic waves and radiation (University of Windsor, n.d.), which applies the knowledge of Trigonometric Functions.

The topic of Polynomial Functions and Rational Functions received the lowest score in effectiveness (3.28) for its cross-curricular content among all topics in all three courses. This topic was also mentioned by only one student. It appears that participants found this topic less helpful for their later STEM studies or struggled to see its relevance to their coursework. A General Science student commented: “[M]y science courses that involve lab content still incorporate the use of exponential and logarithmic functions. Additionally, an Earth Science course that involves manipulating data has used polynomial functions for the creation of graphs."

Polynomial functions are widely used to record changes and model the motion and properties of objects over time, and they can also be applied to complex systems. For example, polynomial functions have been used to describe the expansion of the universe (Moraes et al., 2016). Rational functions, which were not mentioned in any qualitative responses, also have broad applications across the STEM field. Since rational functions are ratios of polynomials, they are useful for modeling various phenomena. For instance, they are used in finance to calculate cost-benefit ratios. Additionally, Inverse square law which uses rational functions, is applied in study of gravitation (Newman et al., 2009) and dark matter (Sereno & Jetzer, 2006). One reason for their effectiveness is that Padé approximants, which are rational function approximations, provide a powerful tool for approximating more complex functions (Aptekarev & Van Assche, 2004). Padé approximants make rational functions particularly valuable in fields like physics, engineering, and numerical analysis, where accurate approximations of functions are often required.

The topic Characteristics of Functions involves identifying key features of functions, such as their rate of change, and performing operations like addition, subtraction, multiplication, and division with functions. It also includes comparing these characteristics. As a result, the Characteristics of Functions can be applied wherever functions are used. This topic received a high effectiveness rating (3.38) among advanced function topics, likely because the Ontario Grade 12 Advanced Functions curriculum focuses on applying functions in this section, while the previous three topics are more theoretical. This approach may have made it harder for students to connect earlier topics to STEM studies. However, the topic's broad nature might also be perceived as too general by some students. For instance, those who go on to work with specific families of functions, such as exponentials, may not find the distinctions between general function characteristics as relevant to their specialized needs. This reason could explain why there were no qualitative responses to discuss Characteristics of Functions in detail.

To summarize, Advanced Functions has strong connections to other STEM subjects, though only a few participants in the qualitative results acknowledged this. Some participants viewed Advanced Functions as a foundational mathematics course that provides problem-solving and mathematical thinking skills for other math subjects. However, the Ontario Grade 12 Advanced Functions curriculum places most of its cross-curricular applications in the final topic, Characteristics of Functions. This structure of curriculum may have led to students struggling to see how their studies connect to earlier topics like Exponential and Logarithmic Functions, Trigonometric Functions, and Polynomial and Rational Functions. One participant recommended learning Advanced Functions while "[h]aving … practical projects along with theory."

4.3.2 Data Analysis pertaining to Calculus and Vectors

The cross-curricular content in Calculus and Vectors has received the highest ratings from participants for its learning experience and effectiveness in preparing students for university STEM studies (3.55 and 3.71). Chemistry students, in particular, found this content more beneficial for their preparation compared to students in other STEM programs. For example, in the University of Toronto Chemistry program, courses like Physical Chemistry for Life Sciences (CHM220H1) cover topics such as thermodynamics, kinetics, phase equilibrium, and quantum mechanics (University of Toronto, n.d.), where students apply calculus concepts like rates of change, integration, and differential equations. This suggests that high school Calculus and

Vectors knowledge is directly applicable to university-level chemistry studies. One Chemistry student in the survey noted, “Cross-curricular content in Calculus and Vectors helped a lot with physics, especially kinematics.” This is relevant as chemistry students often need to take physics courses, such as at University of Toronto, where first-year biology and/or physics are required for specialist programs (University of Toronto, n.d.). The student also suggested that “more calculus questions could be directed to real-world problems, such as finding maximum areas.”

Some participants experienced the Covid-19 pandemic while taking Calculus and Vectors, which impacted their learning. An Earth Science student shared: “So far in my program, I've never had to use calculus or vectors besides knowing what dx/dt means.” They added, “[W]e never actually finished the course,” and “the teacher posted only one set of optional calculus questions on Google Classroom for the rest of the year … I'd assume word problems would be helpful.” This student speculated that cross-curricular content in Calculus and Vectors with real-world applications could be beneficial but lacked the opportunity to experience it fully due to the Covid-19 pandemic.

Although statistically, topics in Calculus and Vectors received very similar scores in experience (ranging from 3.52 to 3.62) and effectiveness (ranging from 3.71 to 3.72), this was not reflected in the qualitative responses. This is likely because many participants were from Mathematics, Statistics, and Engineering programs. As a result, on average, participants felt that the cross-curricular content in Calculus and Vectors provided a good learning experience and prepared them well. A Mathematics and Statistics student suggested improvements to the cross-curricular content in Calculus and Vectors:

> Rate of change and derivatives need more than just practicing finding the derivatives. It’s incredibly important to understand the concept[s] and be able to put that into your own words and put it into practice. This should be emphasized and not so much the actual calculation [and] memorizing the derivative rules.

A Chemistry student shared a similar perception: “As well as some more derivative applications and real-world uses in different academic fields, not just plots and their max [and] mins.”

In the Ontario high school curriculum for Calculus and Vectors, students are required to “demonstrate an understanding of rate of change by making connections between average rate of change over an interval and instantaneous rate of change at a point, using the slopes of secants and tangents and the concept of the limit” (Ontario Ministry of Education, 2007, p. 101). The curriculum also emphasizes determining derivatives graphically and algebraically but does not explicitly mention their applications in the overall expectations (Ontario Ministry of Education, 2007).

While the expectations for derivatives and their applications include solving real-world optimization problems (Ontario Ministry of Education, 2007, p. 105), participants may have felt that focusing only on optimization is insufficient for a deep understanding of rate of change and derivatives. There can be more cross-curricular applications to these two topics. For example, the program Mathematics for Science and Industry, at Ontario Tech University provides a course Industrial Mathematics. Rate of change is applied to chemical kinetics and heat transfer in this course. Additionally, Calculus III, applications of Calculus and Vectors includes volumes, arc length, polar coordinates, and the use of differential and integral calculus (Ontario Tech University, n.d.-a). These examples show the possibility of connecting calculus concepts to real-world scenarios across the STEM field.

Engineering students consider Calculus and Vectors to be “central” to their field. They highlight that concepts like velocity and acceleration are directly tied to derivatives, and “vectors play a crucial role in engineering, especially in the analysis of forces and motion.” On the other hand, Nursing students and one Biochemistry student felt that Calculus and Vectors did not contribute to their university studies. However, Biology students rated the cross-curricular content in Calculus and Vectors relatively high in terms of effectiveness. In fact, Calculus and Vectors can be applied in Biology. For example, in York University's Biology program, rate of change and optimization are applied in courses like Population Ecology and Community Ecology, where students study "the dynamic and changing field of population ecology" (York University, n.d.). Additionally, enzyme kinetics, which involves derivatives when rearranging the Michaelis-Menten equation (Blaber, n.d.) is a key topic in the Biochemistry course, particularly in the study of "protein structure and function." These examples demonstrate how calculus and vectors are integrated into biological studies, despite differing perspectives across disciplines.

Many qualitative responses revealed that participants struggled to understand concepts in Calculus and Vectors, particularly those who took the course during the Covid-19 pandemic. They expressed a desire for cross-curricular content to help them grasp these concepts more effectively. Six participants suggested incorporating project-based learning and technology into Calculus and Vectors teaching, such as math software, online tools, video tutorials, and online classroom discussions.

Most positive feedback about cross-curricular content in Calculus and Vectors connected it to Physics and Engineering studies, with little mention of other fields. A Chemistry participant suggested exploring "how calculus applies in different areas of science." Additionally, a statistics student noted, "I did not approach integrals until university, but I would've liked to be introduced to the concept before that." This highlights a gap in preparation for integrals, which are essential in their field.

Outside of Engineering and Physics, Geometry and Vectors were rarely mentioned. Only one participant, from Computer Science, mentioned that geometry was useful for representing the position and direction of computer graphics. This phenomenon suggests that the application of geometry and vectors in other disciplines may be underemphasized or overlooked by participants, possibly due to a lack of emphasis in the curriculum. A Mathematics student commented: “The geometry and algebra of vectors section had very little material and very few practice [opportunities] in high school. As I am not very far into my post-secondary studies, I am unsure if I am disappointed in my lack of education within this section or if it was unnecessary and I didn’t need to learn it.”

Geometry and algebra of vectors can also be applied to arrangement of atoms in Chemistry, molecular forces in Biology, Geographic Information Systems (GIS) in environmental science (Al-Hanbali et al., 2003), and positioning in astronomy. It is likely that students overlook these connections because the curriculum for Geometry and Algebra of Vectors lacks explicit links to other STEM subjects. The curriculum expectations focus on performing operations on vectors and representing lines and planes (Ontario Ministry of Education, 2007), without emphasizing real-world applications. As a result, students may struggle to see how these concepts are relevant outside of pure mathematics. This result highlights the need for a more interdisciplinary approach to demonstrate their practical uses across different fields.

To summarize, the topics of Rate of Change, Derivatives, Geometry and their applications, and Algebra of Vectors could benefit from including more real-world applications to help students develop a deeper understanding. Currently, participants primarily recall applications in Physics and Engineering as cross-curricular content in Calculus and Vectors. By expanding these connections to other STEM-related fields, such as Chemistry and Biology, students may gain a stronger grasp of Calculus and Vectors concepts. These connections would also help them better connect their high school knowledge to their university studies, fostering a more meaningful and practical understanding of these mathematical principles in their respective fields.

4.3.3 Data Analysis pertaining to Data Management

The cross-curricular content in Data Management received moderate scores in experience and effectiveness (3.49 and 3.60). Among all programs, participants from Health Science and Mathematics and Statistics rated their learning experiences of cross-curricular content the highest, as well as how well it prepared them for their later studies. Based on qualitative responses, some participants praised the cross-curricular content in this course. These compliments were less common in the Advanced Functions and Calculus and Vectors courses.

A nursing student mentioned that they had to take a statistics course in their program, and "[a] lot of the Data Management material was repeated in that class." They also noted that they applied this knowledge in a project they were working on. A biology participant stated that:

> Data management across courses has been beneficial to my preparation in the field of biology. It connects with subjects like bioinformatics and statistics, enhancing my ability to analyze and interpret biological data. This skillset will be crucial for my future studies in genetics or genomics.

It seemed that some participants found the connection between Data Management and their STEM studies to be very straightforward.

A participant majoring in Business and Information Technology shared their experience learning Data Management:

> [It] allowed me to explore the connection between data management and other disciplines, such as business, information technology, and statistics. Through this course, I learned about key concepts like data cleaning and data analysis, which are also applied in other fields.

Another participant suggested incorporating “[p]latforms like Excel, Google Sheets, Tableau, or Python programming for data analysis.” The use of technology in Data Management was beneficial and well received by some participants. Some expressed a desire to explore even more technological tools through this course.

However, some participants felt that there was insufficient cross-curricular content in the course. A participant from Chemistry noted that Data Management “[e]nhanced my logical thinking ability.” A student from Mathematics and Statistics shared that Data Management helped them in a way that it “[c]onnected with preparation for first-year courses, as well as planning my educational pathway and GPA, such as selecting courses based on averages and statistical success.” This participant appeared to use the knowledge gained from Data Management to assist with career-related decisions, such as understanding GPA and selecting programs and courses, rather than directly applying it to their STEM studies in university. They also suggested that the Data Management curriculum should “[m]ake it clearer how the two [cross-curricular contents and Data Management] are connected. Without this survey, I wouldn’t have realized all the cross-curricular connections. Having this knowledge earlier might have helped me better understand the course material.”

A student from Health Sciences mentioned that the mathematical content in their studies “[c]onsists of addition, subtraction, multiplication, and division to calculate medication dosages and pump rates.” They added that they “[d]o not have to use statistical data or calculus/vectors.” It seemed that these students struggled to connect their current studies with the knowledge they learned from Data Management in high school.

The topic of Counting and Probability includes the contents of “probability of events,” “permutations and combinations” (Ontario Ministry of Education, 2007, p. 113). This topic received a relatively higher score in effectiveness of its cross-curricular contents (3.61). However, the qualitative responses seemed to suggest otherwise. This topic was only mentioned by a participant from Chemistry, who stated: “[c]ross-curricular content did not seem very developed in the Data Management curriculum. Very rarely did the content relate to other fields of study. For example, most probability and counting problems related to cards and poker hands, which were not used anywhere else academically.” Participants appeared to overlook the connection between this topic and other STEM-related fields when discussing Data Management. In reality, probability is widely applied in various STEM disciplines. For instance, it is used in genetic inheritance studies in biology (Conte et al., 2012), determining treatment effectiveness in health science (Mazur & Hickam, 1991), and modeling particle collisions in physics (Je et al., 2022).

The topic of Probability Distributions includes discrete and continuous probability distributions, representing them numerically, graphically, and algebraically, and identifying their key features (Ontario Ministry of Education, 2007). The cross-curricular content in this section received the lowest score in learning experience (3.22) among all topics in Data Management but achieved a relatively higher score in effectiveness ratings (3.63).

A student from Computer Science noted that Data Management was “very important for courses such as data science and economics, especially the topics of probability distribution. Probability is also important in computer science (such as AI-related topics) and finance as well.” They added that the cross-curricular “[p]roblem statements sound boring. It may be better to present these problems in … more realistic and applied settings, such as financial modeling.” They were referring to an example question from the survey: “In July of 2000, 38% of the population of Canada lived in Ontario. Design a simulation to estimate the expected number of residents of Ontario included in a random survey of 25 people in Canada." This problem relates to population statistics. Taking Western University as an example, their Finance program includes six statistics courses. The first Statistics course requires students to learn about descriptive statistics, probability, hypothesis testing, analysis of variance, correlation and regression, time series forecasting, and survey techniques (Western University, n.d.). The contents of this course demonstrate the importance of statistics in finance.

Another student from Health Science mentioned that "[p]robability distributions specifically were very helpful in [preparing] for my statistics course in university. I found it really [provided] the foundational [knowledge] needed to keep up in this class."

Additionally, this topic can be useful for students to understand their own grades, similar to the Mathematics and Finance student mentioned earlier. Studying normal distributions can help students interpret their performance relative to their classmates. For example, bell curves are sometimes used in universities to adjust grades to fit a normal distribution. Understanding these concepts can help students perform better and succeed in their future studies.

The topic of Organization of Data for Analysis includes understanding the role of data in statistical studies, the principles of primary data collection, and collecting and organizing data to solve problems. Organization of Data for Analysis is a topic where most qualitative responses expressed a desire for more cross-curricular content. The cross-curricular content in this topic received a score of 3.66 in learning experience, which is relatively high compared to other topics, but a 3.44 in effectiveness, which is lower than other topics.

A participant from computer science thought that "for [computer] science, [this] knowledge [is] good to have but not necessary. However, I do think the cross-curricular questions can be engaging and spark interest." They suggested that:

> [D]ata management [could be integrated] with database and system design courses in the computer science curriculum. I think it is good to think about how data is collected, how we clean it up, and then process and analyze it. Just [providing] some background context could lay a good foundation for learning computer science. Also, since this is the age of big data, these [concepts] can be applicable to other fields as well.

This reflects an application of Organizing Data for Analysis. It seemed like this participant considered the cross-curricular content in this section to be sufficient. Another participant from Computer Science also felt that "Data management helps me store and process computer data more effectively and fully utilize the power of data." They expressed a hope for more "practical opportunities" to apply these skills.

The topic of Statistical Analysis includes expectations for students to analyze and interpret one- or two-variable data, as well as understand "the applications of data management used by the media and the advertising industry, and in various occupations" (Ontario Ministry of Education, 2007, p. 120). The cross-curricular content in this topic received a relatively lower score in learning experience (3.37) but a relatively higher score in effectiveness ratings (3.61) compared to other topics in Data Management. However, very few qualitative responses specifically mentioned this topic.

A participant in Mathematics and Statistics, Engineering, and Physics mentioned that this topic helped them "analyze the distribution of [data over] a certain time [period], intuitively [visualize] the [progress] of project data, and [identify] future development directions." They suggested adding content such as "analyz[ing] the specific data of an event or the sales [performance] of a store through field visits, and analyz[ing] how to [plan] for the future."

Within Data Management, university STEM participants seemed to be most satisfied with their experience completing the culminating data management investigation, with a rating of 3.68. They were also most satisfied with how they applied these skills in their STEM studies.

The culminating data management project focuses on “designing and carrying out a culminating investigation” (Ontario Ministry of Education, 2007, p. 122) and “presenting and critiquing the culminating investigation” (Ontario Ministry of Education, 2007, p. 122). The culminating investigation includes posing problems, designing study plans, gathering and interpreting data, and drawing conclusions from data analysis (Ontario Ministry of Education, 2007, p. 122). This topic seems to combine the abilities students learned about data processing and management throughout the course and focuses on applying them to real-life situations.

Culminating data management investigation can be broadly used in STEM university studies, especially in experiments. For example, a lab instruction in engineering, focusing on studying thermodynamics, includes “demonstrations, ‘cookbook’ type experiments, guided inquiry exercises, and independent/design projects” (Shepard, 2021, p. 1), which is similar to culminating investigation. A participant from Mathematics and Statistics and Biology thought that “analyzing, collecting, storing, [and] applying data from multiple perspectives is very helpful for learning skills.” They also wished that “provid[ing] internship opportunities for students and apply[ing] them in practice” could make cross-curricular content more effective in this section.

For the overall course Data Management, a participant provided some suggestions to enhance the cross-curricular content in data management:

1. Practical project practice: Let students apply cross-curriculum knowledge to real scenarios through real data management projects.
2. Group cooperative learning: Organize students to solve data management problems in groups to develop teamwork and communication skills.

3. Industry expert sharing: Invite professionals in the field of data management to share experiences and understand the cross-curriculum content in practical applications.
4. Interdisciplinary research: Encourage students to participate in interdisciplinary research projects, broaden their horizons, and integrate knowledge from different fields.

This student proposed several pedagogical strategies for teaching Data Management. However, the curriculum itself, which often serves as a guide for teachers, could also address these aspects. For example, the topic of "Organization of Data for Analysis" could be structured around a financial project-based approach, where students tackle a real financial challenge. For instance, they could identify outliers in datasets to address a specific financial problem. These example problems could be based on real-world financial situations. Curriculum developers might find similar sample problems in textbooks used in university finance programs.

A student from Health Science suggested that Data Management "could prepare students better with more realistic life mathematics such as how to do your taxes, or how to get a mortgage. Preparing more for real life than equations we never see in our lifetime again." This topic is currently covered in the Ontario curriculum course Mathematics for Work and Everyday Life, Grade 11 (MEL3E), Mathematics for Work and Everyday Life, Grade 12 (MEL4E), Foundations for College Mathematics, Grade 11 (MBF3C), and Foundations for College Mathematics, College Preparation, Grade 12 (MAP4C) (Ontario Ministry of Education, 2007). However, it is not explicitly included for students taking 4U courses, which are designed as university preparation courses.

Incorporating practical content like filing income taxes could be an excellent project for Data Management, bridging the gap between theoretical knowledge and real-world application.

It should be noted that courses such as MCR3U and MCF3M already cover topics like annuities (Ontario Ministry of Education, 2007), which lay the groundwork for understanding financial concepts, including mortgages. That said, the connection to mortgages is not explicitly made, and the limited time allocated to these topics can make it challenging to explore their practical applications in depth. This underscores the importance of strengthening the link between theoretical concepts and real-world scenarios in the curriculum.

To summarize, participants are generally satisfied with their learning experience regarding the cross-curricular content in Data Management and how it prepares them for university STEM studies, based on their qualitative responses compared to two other mathematics courses. Participants also appreciated the use of technology in this course. Some found the content beneficial because they could apply the knowledge outside of their studies or learned valuable logical thinking skills. However, some participants struggled to see how topics like counting and probability connect to their STEM studies. Additionally, some suggested that the cross-curricular content could be made more engaging by incorporating real-world applications, such as financial modeling and realistic income tax filing.

4.3.4 Data Analysis on responses to the Optional questions

The optional question section includes these two questions:

Please comment on the overall cross-curricular contents in *Ontario Grade 12 University-level Mathematics curriculum*; Have you been introduced to progressivism, constructivism, and experiential learning or any educational philosophies or theories during your study of cross-curricular content in Grade 12 mathematics? Please name them and share your experience of applying for them.

Regarding the first question, most of the responses are positive, with participants expressing satisfaction with the cross-curricular content in the Ontario Grade 12 university-level mathematics curriculum. Many also wished for even greater incorporation of cross-curricular content. A Biomedical Science student said: "I think I was exposed to a great deal of cross-curricular contents in Grade 12 Math, which helped me in my further education. I think the curriculum should at least maintain or perhaps even increase the amount of cross-curricular content to help students apply math to the real world." A participant from Mathematics and Statistics also expressed satisfaction with the cross-curricular content in the Ontario Grade 12 mathematics curriculum:

> The *Ontario Grade 12 university[-]level Mathematics [C]urriculum* incorporates cross-curricular content by emphasizing the application of mathematical concepts in various real-world contexts. … One of the key aspects of cross-curricular content in Grade 12 [m]athematics is the integration of mathematical concepts with other subjects such as science, business, and social sciences … Furthermore, the curriculum incorporates cross-curricular activities and projects that require students to use mathematics in authentic, real-life scenarios. … Another aspect of cross-curricular content in Grade 12 [m]athematics is the use of technology and digital tools.

The real-world applications and the use of technology in the Ontario Grade 12 university-level mathematics curriculum were also highlighted by other participants.

However, there are some responses suggested that more cross-curricular contents can be added in Ontario Grade 12 university-level mathematics curriculum. A Chemistry student said:

> I feel like overall, more math content could be related to other academic fields, like sciences. I feel like … the different applications of each mathematical field could be explored more. Often, certain applications of mathematics [are] not very readily apparent without being taught.

A computer science student also said:

> I think we do lack … cross-curricular content in Ontario Math class, but this could be done intentionally. I have the feeling that [this] content should be 'advanced' questions, meaning that people should start with pure math questions, and then, as they progress, we

> can incorporate other knowledge in to see how math concepts [can] be applicable to other fields.

A Biology student noted that the cross-curricular content was:

> Minimal for my initial year of undergrad. It was beneficial for understanding the [theory] behind analytical chemistry in year[s] 2 and 3. [It was] non[-]existent for health course-related post-secondary education. Statistics at a university level would have been more beneficial [at] a high school level than calculus for real-world applications over the last 20 years or so of my working life.

Based on quantitative responses categorized by programs and participants' qualitative responses, it is evident that students in Chemistry, Biology, and Health Science tend to see fewer connections between the Grade 12 university-level mathematics curriculum and their studies compared to students in Mathematics, Engineering, and Physics. Among the three courses, Calculus and Vectors is the one where this disconnect is more pronounced. Incorporating more cross-curricular content related to Chemistry, Biology, and Health Science could help address this issue and allow students to better understand why they study the Grade 12 university-level mathematics curriculum before entering their chosen the STEM field. Additionally, cross-curricular content can help "ring a bell" when students encounter related topics in their university studies. For example, when studying the population growth of bacteria, students should be able to recall their knowledge of rates of change from Calculus and Vectors and apply it to their biology studies.

A computer science participant recognized the challenges of adding more cross-curricular content to Ontario's Grade 12 math curriculum. They specifically noted that they preferred the curriculum "to be relatively cross[-]curricular, but because of the depth of the material, it is hard to connect with other subjects in a fully applicable way." This is an important factor to consider when making the curriculum more cross-curricular.

Regarding the second question about participants' experience with educational theories related to cross-curricular learning, most participants skipped it or said they had never learned about these educational theories. The following responses are from the few participants who were introduced to them. A Mathematics and Statistics participant said: "During my 12th grade math studies, I learned about educational theories like Progressivism, Constructivism, and Experiential Learning. These theories helped my learning by encouraging active participation, hands-on experiences, and building knowledge."

Constructivism was the most discussed theory in this section. One participant explained that constructivism "emphasizes that individuals build their own knowledge and understanding through interaction with the environment and by communicating with the people or things around them." Another student shared their experience:

> [I]n Grade 12 math, I was often encouraged to build my math knowledge through group discussions, problem-solving, and hands-on work. This way of learning not only gave me a deeper understanding of mathematical concepts but also improved my critical thinking and problem-solving skills.

Constructivism aligned with what most participants wanted in this survey, more cross-curricular content and interesting applications in Ontario's Grade 12 math curriculum. It was most discussed in Calculus and Vectors, as participants found derivatives and integrals difficult to understand and wished for real-life applications from other the STEM field to help them grasp the concepts better.

A student from Mathematics and Statistics, Physics, and Engineering shared their experience with experiential learning: "I had the opportunity to participate in experiential learning, which my brother introduced to me. The whole process was guided by the tutor, allowing us to experience different situations, reflect on them, and share our thoughts to achieve better results." In Data Management, participants expressed dissatisfaction with textbook sample problems pertaining to real-life applications. They wanted more practical experience, such as real financial modelling cases, which align with the principles of experiential learning.

To summarize, participants who responded to the first optional question expressed overall satisfaction with the cross-curricular content in the Ontario Grade 12 university-level mathematics curriculum. However, some participants from Biology, Chemistry, and Health Science backgrounds did not clearly recognize the connection between the mathematics curriculum and their fields of study. One participant raised concerns that adding more cross-curricular content to the curriculum might make it overly challenging for students to comprehend.

Regarding the second optional question, most participants indicated limited familiarity with educational theories. Among the few who had been exposed to such theories, constructivism and experiential learning were mentioned as being applied in their studies. These theories align closely with the participants' suggestions in the survey, which included incorporating more real-life STEM applications into the curriculum and emphasizing project-based learning.

Chapter Five: Discussion

This chapter addresses the research questions outlined in Chapter 1, focusing on students' overall perceptions of the cross-curricular content in the Ontario Grade 12 university-level mathematics curriculum and its effectiveness in preparing them for future STEM studies. Additionally, the chapter examines whether the Ontario Grade 12 university-level mathematics curriculum sufficiently prepares students for university STEM programs, drawing on survey responses and a review of existing literature related to teachers' instructional supports.

The discussion also includes an analysis of the nature of hypothetical example problems, potential solutions, and whether integrating STEM cross-curricular content might overcomplicate the curriculum for students. Additionally, the limitations of this research are explored. Finally, the chapter concludes with a summary of the survey results, including quantitative responses, data analysis, and a review of qualitative feedback provided by participants.

5.1 Addressing the Research Questions

This section addresses the research questions outlined in Chapter 1. The research questions were:

1. How do current undergraduate students in STEM fields from Ontario universities perceive the cross-curricular content in the Ontario Grade 12 university-level mathematics curriculum in terms of preparing them for future STEM studies? For those who found the cross-curricular content sufficient, how did they apply this knowledge? For those who found it insufficient, what specific cross-curricular topics do they wish had been included in the Ontario Grade 12 curriculum?

2. What insights can be derived from students’ feedback to guide curriculum developers in potential modifications for a revised Ontario Grade 12 curriculum?

Based on the quantitative results, current Ontario STEM university students who participated in the survey generally hold positive perceptions of the learning experience with STEM cross-curricular content in the Ontario Grade 12 University-level curriculum. They also view this content as beneficial in preparing them for their STEM university studies. This phenomenon is evident by average scores above 3 (the midpoint on a 1–5 Likert scale) and mode scores of 4 for both experience and effectiveness ratings across the three courses. However, the results also indicate room for improvement in the integration of cross-curricular content within the curriculum.

Participants expressed varying perceptions regarding the sufficiency of cross-curricular content in the Ontario Grade 12 curriculum. Some found the content sufficient, compared to other participants, and highlighted its applicability to their university studies. For example, a Mechanical Engineering student emphasized the importance of Exponential and Logarithmic Functions in understanding radioactive decay, while Engineering students considered Calculus and Vectors central to their field. A Health Science student noted that probability distributions were particularly helpful in preparing for their statistics course. On the other hand, some students, such as those in Nursing and Biochemistry, felt that certain topics, like Calculus and Vectors, did not significantly contribute to their university studies. A Chemistry student also mentioned that counting and probability were unrelated to their field. Despite these differences, some participants valued the courses for fostering mathematical thinking, problem-solving skills, and introducing technologies like Excel, even if they did not directly prepare them for their specific STEM disciplines.

Regarding the second research question, the feedback from these 95 participants, who covered all topics in the Ontario Grade 12 University-level curriculum, provides valuable insights for curriculum developers. The qualitative responses reflect participants' feelings on most topics and offer guidance for potential modifications to the curriculum. For instance, participants suggested incorporating more STEM project-based and activity-based learning, integrating additional technologies to enhance cross-curricular learning, and inviting professionals to discuss real-world STEM scenarios. These suggestions, along with the detailed qualitative analysis in Chapter 4, highlight areas where the curriculum could be revised to better align with the needs of diverse STEM disciplines. By addressing these insights, curriculum developers can create a more inclusive and effective Grade 12 curriculum that better prepares students for their future STEM studies.

5.2 Discussion

5.2.1 Student Perceptions of the Connection Between STEM Cross-Curricular Content and Their Studies

Quantitative survey responses indicate that there is room for improvement in the integration of cross-curricular content within the Ontario Grade 12 university-level mathematics curriculum, with the average ratings for each course ranging from 3.36 to 3.71 out of 5. Participants rated their experience with all three courses as statistically similar, according to the ANOVA test. However, the ANOVA test on effectiveness ratings revealed significant differences in how participants perceived the value of cross-curricular content across the courses. This ANOVA test result suggests that students had varying views on how well the cross-curricular content prepared them for their later studies.

Discrepancies between qualitative and quantitative responses for some of the topics further highlight this inconsistency. For example, Calculus and Vectors received the highest average effectiveness rating (3.71), yet many non-Engineering and non-Mathematics participants questioned its relevance to their studies. Similarly, the topic of counting and probability in Data Management received a moderate effectiveness rating (3.61), but participants expressed confusion about its connection to their studies. Conversely, while participants qualitatively appreciated the effectiveness of the Organization of Data for Analysis topic, it received the lowest effectiveness rating (3.44) among Data Management topics.

These findings suggest that participants perceived the value of cross-curricular content differently, depending on the topic and their individual experiences. While cross-curricular connections may exist, some participants recognized them, while others overlooked, or could not recall them entirely. This disconnection could stem from differences in academic programs, learning experiences, or the way cross-curricular content is presented and emphasized in the curriculum. Some participants may have missed the connections due to a lack of explicit examples or real-world applications, while others may have been influenced by their specific STEM disciplines or personal interests.

Many participants expressed a desire for greater incorporation of STEM cross-curricular elements. This sentiment may stem from a genuine need for more STEM-focused content in the curriculum. Additionally, qualitative data analysis from the previous chapter suggests that participants often applied knowledge from the Ontario Grade 12 university-level mathematics curriculum—particularly from Advanced Functions, Calculus and Vectors, and Data Management—without fully recognizing they were doing so. This was most evident in areas such as trigonometric and polynomial functions in Calculus and Vectors, as well as counting and probability in Data Management.

A notable finding was that non-Engineering and non-Mathematics STEM students did not perceive Calculus and Vectors as significantly beneficial to their studies. Many of these students reported having only a superficial understanding of the subject, with concepts like rate of change and derivatives proving particularly challenging. Strengthening the connection between Calculus and Vectors and the non-Engineering and non-Mathematics STEM fields could increase students' interest in the subject, foster a deeper understanding of its concepts, and enable them to recall and apply Grade 12 university university-level mathematics content in their future studies. For instance, derivatives are widely used in fields like chemistry to describe reaction rates, where the rate of change of a reactant or product's concentration is expressed as a derivative with respect to time. Similarly, in pharmacology, drug absorption can be modeled using derivative functions (Thanou et al., 2001). However, these pharmaceutical students might not realize that they are applying the knowledge of derivatives in this process.

A similar scenario applies to Advanced Functions. Although Advanced Functions serves as a foundational subject for other STEM disciplines—for instance, using average or secant slopes as a precursor of instantaneous or tangent slope that defines the derivative graph may lead students to focus on the derivative rather than the precursor knowledge—it is often perceived as less effective than Calculus and Vectors or Data Management in preparing participants for STEM studies. Many participants seemed to overlook the connections between Advanced Functions and their subsequent coursework (including the Calculus and Vectors course). This perception may arise from the longer time gap between studying Advanced Functions and applying its concepts in later courses, compared to the other two subjects.

Among the topics in Advanced Functions, exponential and logarithmic functions were recalled by Earth Science students as particularly useful. However, trigonometric functions were primarily deemed effective in preparing students for later studies by mathematics students. This result is surprising, given that periodic functions—often modeled using sine and cosine functions—are widely applicable across other STEM-related fields. For example, in physics, trigonometric functions are used to describe wave phenomena such as sound and light, while in engineering, they are essential for analyzing alternating current circuits. One possible explanation for this disconnect is that, for example, when physics students derive functions from oscillators, the resulting formulas are often complex combinations of functions (such as Fourier series), calculated using computers, rather than perfect sine or cosine waves. As a result, students may overlook the connection between these real-world applications and the precursor trigonometric functions they studied in Advanced Functions.

The topic of counting and probability also faces similar challenges. Concepts like event probability, permutations, and combinations are often introduced using examples involving poker, dice, and card games. While some participants acknowledged that studying Data Management strengthened their mathematical thinking and improved their understanding of what numbers represent, they struggled to see the relevance of this topic for their future studies. However, event probability is widely applied across various fields. For instance, in biology, it is used to predict genetic outcomes, and in finance, it helps assess risk and uncertainty in investments. Similarly, permutations and combinations are essential tools in other STEM disciplines.

In computer science, the concepts are used in algorithms for sorting and optimization, while in chemistry, they help determine the number of possible molecular arrangements (i.e., the number of isomers). These applications highlight the practical importance of counting and probability in real-world problem-solving. Despite these applications, the survey responses suggest a missing link between permutations, combinations, and event probability, and their applications in students' studies. Thes responses indicates a need for more STEM-focused cross-curricular content in the curriculum, moving beyond traditional examples like cards and poker, to help students better recall and connect these concepts to their fields of study.

In conclusion, participants' responses highlight opportunities to strengthen the integration of STEM cross-curricular contents in the Grade 12 university-level mathematics curriculum. For instance, Calculus and Vectors could include more content relevant to the non-Engineering and non-Mathematics STEM fields, while topics like Trigonometric Functions and Polynomial and Rational Functions in Advanced Functions could be more explicitly linked to real-world STEM applications. Similarly, in Data Management, the topic of counting and probability could be better connected to other STEM disciplines. These improvements could be achieved by incorporating straightforward problems or projects rooted in real-world STEM applications, as demonstrated in earlier examples. Such enhancements would help students better appreciate the relevance of these mathematical concepts to their future studies and careers.

Participants expressed a strong desire to have been exposed to more cross-curricular content while studying the Grade 12 university-level mathematics university curriculum. They felt that such connections would have helped them better understand the relevance of mathematics to their future studies. Additionally, they emphasized that these cross-curricular links should be more closely aligned with the content they encounter in university, as this would bridge the gap between high school and post-secondary education. The feedback from these participants highlights a clear need for more STEM cross-curricular content, particularly for students pursuing the non-Engineering and non-Mathematics STEM fields.

With the research revealing various needs, the question arises whether teachers have resources that can facilitate making these changes or whether there is a need for resources to support the changes. The issue is that changing the curriculum can work if supports for teachers to make the changes already exist. If, however, resources do not currently exist then changing the curriculum will not be sufficient because supports would need to be developed simultaneously to support instructional changes.

5.2.2 STEM Instructional Supports

The articles in section 2.2.3 STEM instructional supports for Mathematics teacher in Ontario, revealed that less than 20 articles are connected to STEM field out of 1276 viewed instructional supports articles for Ontario Mathematics teachers (neglecting the repeating ones). Many articles applied technologies in Mathematics teaching. The application of technology in mathematics education is closely tied to STEM cross-curricular learning, as it fosters a deeper understanding of existing mathematics content within the curriculum. However, many studies appear to reverse the purpose and outcomes of cross-curricular learning, focusing more on using technology to enhance mathematics education rather than exploring how mathematics can be applied to other STEM-related fields. As a result, these studies fall outside the scope of this research.

There remains a significant gap in the literature regarding STEM cross-curricular content in Grade 12 mathematics education. The limited number of studies addressing this topic highlights the need for more research and curriculum development to effectively prepare students for interdisciplinary STEM challenges in their future academic and professional pursuits.

The scarcity of studies on cross-curricular content in these mathematics journals may stem from traditional educational structures and the challenges of implementing cross-curricular initiatives. “The differential status (and available resources) of the various school subjects derive from their origins in the separate educational sectors which preceded comprehensivation” (Goodson, 2013, p. 4). “Curriculum integration” and implementation of cross-curricular contents in this case, experience problems that are “not with the disciplines of knowledge themselves but with their representation in the separate-subject approach to the curriculum” (Beane, 1995, p. 1). Beane called “for an end to the separate-subject approach to school curriculum organization” (Beane, 1995, p. 2) in 1995, however, this model remains the dominant structure in education. The traditional, compartmentalized curriculum, where teachers work independently and are not accountable for students’ performance in other subjects, creates significant barriers to cross-curricular integration. This structure may discourage researchers and educators from exploring interdisciplinary connections in depth. Additionally, developing and implementing cross-curricular content requires collaboration across disciplines, alignment of learning objectives, and substantial resources. These challenges are further compounded by the difficulty of evaluating the effectiveness of cross-curricular initiatives.

A study on the effectiveness of cross-curricular collaboration, faced the difficulties of “cross-curricular collaboration at a more superficial level can take place anytime, hence making it too difficult to trace and observe, let alone evaluate its effectiveness” (Lo, 2015, p. 447), and that “actual effectiveness has not been empirically evaluated before, probably because of its ambiguous nature and the difficulty in disentangling it from other variables” (Lo, 2015, p. 457).

These journals also present a challenge in that they focus exclusively on mathematics. For example, "*A Framework for Computational Thinking Dispositions in Mathematics Education*," (Pérez, 2018) one of the few articles related to STEM, primarily discusses how computational thinking can enhance mathematics education. If a mathematics teacher or researcher seeks information on cross-curricular connections to biology, they might need to consult a separate journal tailored for biology educators, where access to relevant content may be limited or unavailable.

The limited availability of resources on cross-curricular content poses significant challenges for curriculum developers seeking to integrate more interdisciplinary material into the curriculum. If more studies were conducted to demonstrate the effectiveness of STEM cross-curricular learning—through comparisons between groups, for example—and to provide specific guidance on implementing such approaches in mathematics curricula, curriculum developers would face fewer obstacles when incorporating STEM cross-curricular content.

The traditional educational system, with its compartmentalized subject structure, further exacerbates this issue by failing to interconnect curricula across STEM disciplines. For instance, when high school students study bacterial growth in biology and calculate growth rates, there are no explicit prompts in the curriculum to encourage them to recall their knowledge of exponential and logarithmic functions from Advanced Functions. While the curriculum is designed to facilitate transfer, and biology teachers often contextualize these mathematical concepts rather than teaching them from scratch, this approach may still lack the "ring a bell" effect that would help students recognize they are applying concepts from the Ontario Grade 12 university-level mathematics curriculum. For such recognition to occur, students need a deeper and more explicit connection between disciplines, which is often missing due to another problem: the example problems provided in textbooks tend to be overly hypothetical and disconnected from real-world applications. Strengthening these links could help students appreciate the relevance of their mathematical knowledge to other STEM-related fields.

5.2.3 Hypothetical cross-curricular problems in curriculum

The survey used a variety of examples of cross-curricular problems and some participants commented about the hypothetical problems. As an example, a comment from a computer science student regarded the following example question from the survey: "In July of 2000, 38% of the population of Canada lived in Ontario. Design a simulation to estimate the expected number of residents of Ontario included in a random survey of 25 people in Canada." The student noted that the cross-curricular "[p]roblem statements sound boring" and suggested that such problems would be more engaging if presented in "more realistic and applied settings, such as financial modeling." The problem sets up a hypothetical scenario and provides only the information necessary to solve it, making it feel artificial and disconnected from real-world applications.

The issue is not isolated because many problems focus solely on mathematics with limited grounding in real-world contexts. For example, questions like "[f]ind f'(x)" (Crippin et al., 2009, p. 74) are common, requiring students to mechanically apply product, quotient, or chain rules without understanding what they are calculating. A simple adjustment, such as defining f(x) as a displacement function in a motion problem and asking students to find f'(x) as a velocity function, could provide meaningful context. This type of questions with more contexts, would clarify the concept of derivatives and help students understand the purpose behind their calculations.

Hypothetical example problems are prevalent not only in mathematics but across various curricula and textbooks. Due to limited access to laboratories and resources, it is challenging to incorporate many real-life problems into the curriculum. Many participants suggested potential solutions to improve cross-curricular content, emphasizing the need for more practical and engaging approaches. Among these, activity-based and project-based learning were highlighted as effective methods. These approaches allow students to tackle real-life problems step by step, fostering deeper understanding and application of concepts. While activity-based and project-based learning represent the optimal way to implement STEM cross-curricular learning, they are also highly time-intensive. Given the volume of material and learning objectives in the current Ontario Grade 12 curriculum, many projects may only be feasible once per term. When designing cross-curricular activities and projects, it is optimal to keep them short and focused. For example, a project on Benford's law could be incorporated into the topic counting and probability in Data Management. Students could use a random number generator and Excel to create a table (Sibbald & Veres, 2019), demonstrating how Benford's law applies to finance. This project could be introduced in class and completed outside of class within a week, making it an appropriate length for a cross-curricular activity.

Some participants expressed a desire to learn practical skills, such as how to file taxes, rather than solving hypothetical problems, in the Ontario Grade 12 university-level mathematics curriculum. While this content is currently covered in courses like Mathematics for Work and Everyday Life, Grade 11 (MEL3E), Mathematics for Work and Everyday Life, Grade 12 (MEL4E), and Foundations for College Mathematics, Grade 12 (MAP4C) (Ontario Ministry of Education, 2007), university-level students also highlighted the need for such topics to be included in the university-stream mathematics curriculum.

Some participants suggested “[i]nviting professionals in the field of data management to share their experiences and demonstrate how cross-curricular content is applied in practical settings.” These professionals could bring real-world laboratory experiences into the classroom, encouraging high school students to consider how such problems can be solved using concepts from the Ontario Grade 12 university-level mathematics curriculum. However, simply listening to these examples may not leave a lasting impression on students, as they might perceive them as no different from the hypothetical problems in textbooks.

This approach could be enhanced using technology. If professionals or teachers supplement their explanations with pictures, videos, or simulations of STEM cross-curricular applications related to the curriculum, students are likely to develop a deeper understanding and connection to the material. For instance, when studying events and probabilities, a simple model of moving molecules in ideal gas could be presented alongside an explanation of their relevance to topics like Boltzmann-Maxwell distributions. These topics could spark interest in students pursuing chemistry, motivating them to engage more deeply with derivatives, counting and probability. Later, during their university studies, they might recall these visuals and apply their knowledge of probability in chemistry contexts. Such materials could also be integrated into the curriculum, leveraging advancements in technology to make cross-curricular connections more accessible and impactful.

5.2.4 Will implementation of more cross-curricular content make curriculum difficult?

A participant raised a concern, stating they preferred the curriculum “to be relatively cross-curricular, but because of the depth of the material, it is hard to connect with other subjects in a fully applicable way.” The perceived difficulty of the Ontario Grade 12 university-level mathematics curriculum has elicited mixed perceptions. Some students find the current curriculum too challenging, while others advocate for the inclusion of more advanced topics, such as integration. Integration, historically part of the Grade 13 curriculum, was often mentioned as a topic students wished to see reintroduced. It is likely beneficial for students pursuing STEM studies at the university level, as it can deepen their understanding of derivatives. However, there is no doubt that adding integration would increase the difficulty of the curriculum.

However, integration is not part of cross-curricular content. The addition of cross-curricular, based on the existing topic, generally is not inherently tied to increasing the difficulty of the curriculum. Students often perceive a course as difficult when they experience stress, which may come from a variety of causes, such as unsatisfactory assessment scores, rather than exclusively the content itself. Therefore, while implementing more cross-curricular elements, it is crucial to ensure that these additions do not overcomplicate the curriculum for Grade 12 students—they should be demonstrative and accessible. The goal of integrating cross-curricular content is not to overwhelm students with additional material but to enhance their understanding of existing concepts by connecting them to real-world applications and other disciplines.

Importantly, cross-curricular content should not increase the difficulty of the curriculum. Instead, it should provide context and relevance, making the material more engaging and facilitating understanding by interpreting the context. For example, when teaching exponential growth, students could be shown pictures of bacteria growing in a Petri dish, along with an estimation of the bacterial count after one hour, two hours, and three hours, to align with exponential calculations. To keep the example accessible, more complex factors like contamination from other bacteria can be omitted, ensuring the scenario remains straightforward and focused. By emphasizing meaningful connections rather than adding volume or complexity, cross-curricular integration can enhance the learning experience without overwhelming students or creating unnecessary stress.

Beyond helping students understand mathematics better, STEM cross-curricular content can also play a crucial role in helping students discover their interests earlier. A study of how mathematics interest, self-efficacy, and anxiety predict STEM career choices in emerging adulthood "suggest that maths anxiety and maths interest in adolescence independently predict STEM career choices in emerging adulthood" (Ferdinand et al., 2024, p. 5). By integrating STEM subjects into mathematics courses, students can develop an interest in the STEM field or gain clarity earlier on whether they are genuinely interested in pursuing STEM careers, which can significantly influence their future career decisions.

However, research on students developing STEM interest within mathematics classes is far less prevalent compared to studies on interest developed outside of class. Students often cultivate their interest in STEM through extracurricular activities, such as scientific movies, summer camps, or visits to science centers. A study that explored the connection between Out-of-School Time (OST) activities and STEM career interest shows that:

> [T]hose respondents who reported participating in OST clubs/competitions and reading/watching science activities at least a few times a year were more likely to report a career interest in a STEM discipline in university than those respondents who did not participate in these OST science activities at least a few times a year. (Dabney et al., 2012, p. 72)

The implementation of STEM cross-curricular content in the Ontario Grade 12 university-oriented mathematics curriculum can serve as an invaluable opportunity to introduce students to other STEM disciplines and expose them to real-world applications of mathematics. By incorporating examples and problems from fields like biology, physics, engineering, or computer science, the curriculum can spark curiosity and engagement, helping students see the interconnectedness of STEM subjects. This approach not only enriches their understanding of mathematics but also provides a foundation for exploring potential career paths in STEM, addressing the gap between classroom learning and real-world aspirations.

5.3 Limitations

The online survey research method sometimes yielded a lower-than-expected response rate. Nearly one-third of the participants did not proceed to complete the survey after filling out the participant information section. Some participants were not Ontario University STEM students who had experienced the Ontario Grade 12 university-level mathematics curriculum, meaning they did not meet the eligibility criteria for the survey. Although recruitment letters were distributed to STEM professors and student unions (for distribution to STEM students), this approach had limitations. For instance, there were delays in circulating the survey, and challenges such as identifying active faculty (e.g., those not on sabbatical) and ensuring the survey reached contract instructors or teaching assistants. Additionally, based on the number of responses received relative to the number of professors and STEM student unions contacted, many of them overlooked the recruitment letter. These issues highlight the inherent limitations of relying on third-party distribution for participant recruitment in online surveys.

There may also have been an issue with the wording of the reward eligibility criteria, which stated that the reward would be given to "participants who complete at least one section of the survey," as outlined in the form of consent. Some participants might have interpreted this question to mean that completing only the Participant Information section would qualify them for the reward. To avoid confusion in future studies, the reward eligibility criteria could be clarified or removed from the form of consent.

Responses such as “N/A” or “no” were frequently observed in mandatory open-ended questions in this survey. These types of responses provided limited value and contributed little to the analysis. Participants appeared more willing to complete Likert-scale questions than open-ended questions, as evidenced by their tendency to complete multiple Likert-scale sections while leaving open-ended questions unanswered. “The length of online questionnaires should be kept to a minimum and they should be easy to complete” (Lefever et al., 2007, p. 581). Online participants tend to prefer questions that are less time-consuming and straightforward. For future research, online surveys could include fewer open-ended questions and instead incorporate more multiple-choice or Likert-scale questions.

Open-ended questions, if included, could be designed as short-answer prompts, allowing participants to briefly explain their selections from multiple-choice or Likert-scale questions. This approach may help reduce the number of meaningless or incomplete responses, as shorter and simpler questions are likely to encourage greater engagement. Additionally, while not explored in this study, conducting interviews could be an effective way to gather more detailed and nuanced insights, complementing the quantitative data collected through surveys.

The survey responses provided valuable insights into participants' experiences with the Ontario Grade 12 university-level mathematics curriculum and their perspectives on how it supported their later studies. However, these perceptions may have been influenced by the time elapsed between completing the courses and participating in the survey, as some details may have been forgotten or misremembered. For example, Advanced Functions, being a prerequisite for Calculus and Vectors, had a longer time gap for participants compared to the other courses, which might explain its lower experience and effectiveness ratings.

The most common response to the question, “Which year did you complete high school?” was 2022, indicating that many participants had been away from the curriculum for approximately two years at the time of the survey. Analysis of Likert-scale results based on graduation years showed that participants who graduated in 2020 provided the lowest average ratings among those who graduated between 2020 and 2023, suggesting that the time gap influenced their perceptions. However, participants who graduated in 2019 gave the highest average ratings, which may be attributed to the timing of the COVID-19 pandemic, which began in early 2020 and disrupted subsequent academic experiences.

There were two versions of the survey: the original survey which included a non-bot verification feature and the updated survey. A comparison between the two surveys revealed that the non-bot verification had a minimal impact on the survey results and the percentage of analyzable responses. However, it is possible that some participants completed both surveys. Since the questions in both surveys were identical, there was no meaningful reason for participants to complete the survey twice unless their intention was to increase their chances of winning the award. Additionally, since students could use multiple email addresses to enter the award draw, comparing emails alone was not a reliable method to identify duplicate responses.

To identify potential duplicates, a comparison was conducted based on participants reported high school graduation year, university entry year, and program of study. This analysis revealed two participants who appeared in both surveys and shared identical details: one was a biology student who graduated high school in 2022 and entered university the same year, while the other selected all program options as their primary university program, graduating high school and entering university in 2015. Although their Likert-scale and open-ended responses differed, and they used different email addresses for each survey, it cannot be conclusively determined whether they were distinct participants or the same individual completing the survey twice. As a result, there is a possibility of duplicate responses when combining the data from both surveys. On the other hand, the reward was small and the timing between the original and updated surveys was short, so it seems unlikely that there would be any duplication, certainly not to an extent that would alter the conclusions.

The survey design had a significant issue with the question, “Please indicate the primary university program you are currently enrolled in or have completed,” which allowed multiple selections. The initial intention was to accommodate students in interdisciplinary programs, such as Biochemistry, by providing appropriate options. However, many participants appeared to misinterpret the question, selecting multiple programs as if they were listing individual courses rather than identifying their primary program. For instance, several participants selected all available options, including “Mathematics and Statistics,” “Chemistry (excluding health sciences),” “Biology (excluding health sciences, but including botany, zoology, microbiology),” “Physics,” and “Health Sciences.” It is unlikely that these participants were enrolled in all these programs simultaneously, suggesting either a misunderstanding of the question or an attempt to avoid disclosing their actual primary program.

This issue posed a challenge for analyzing responses based on participants’ programs, as such cases had to be excluded from program-specific data analysis. As a result, there were insufficient responses for most programs; only Health Sciences, Biology, and Mathematics and related programs had enough data for meaningful comparison. For future research, it would be advisable to restrict this question to a single selection and include additional options, such as

“Biochemistry,” “Mathematical Physics,” and other common STEM programs offered at Ontario universities, to better capture participants’ primary programs accurately.

5.4 Conclusions

The survey, titled “Assessment of cross-curricular content in the Ontario Grade 12 University-Level Mathematics Curriculum,” asked participants to evaluate their learning experience with the cross-curricular content in each topic of the *Ontario Grade 12 University-Level Mathematics curriculum* (Advanced Functions, Calculus and Vectors, and Data Management) and to assess how much this content aided them in their STEM university studies. Each topic included an example problem to remind participants of its content. The questions were designed as Likert-scale items, ranging from 1 to 5. For experience ratings, a 1 indicated very limited cross-curricular content, and a 5 indicated abundant cross-curricular content. For effectiveness ratings, 1 meant ‘did not provide preparation, and 5 meant provided substantial preparation.’ Examination of data reveals that approximately one-third of participants exited the survey during or after completing the Participant Information section.

I hypothesized that this trend might be linked to the non-bot verification process and released an updated version without the non-bot verification, and the original survey was also modified to remove this feature. The results from both surveys indicate that the non-bot verification had a negligible impact on participants' responses and the overall completion rate. Consequently, the data from both surveys were combined for analysis. In total, 364 responses were collected, with 95 of these being valid and suitable for further analysis.

The analysis of the Likert-scale results revealed that Calculus and Vectors received the highest ratings for both experience and effectiveness, followed by Data Management and then

Advanced Functions. These results suggest that while the cross-curricular content in Ontario Grade 12 university-level mathematics courses is generally viewed positively, there is still room for improvement to enhance its breadth and impact on students' preparation for STEM studies.

The ANOVA test results indicate that there are no statistically significant differences in the experience ratings among the three courses. However, statistically significant differences were found in the effectiveness ratings of the three courses. To further investigate, three T-tests were conducted: Advanced Functions compared to Calculus and Vectors, Calculus and Vectors compared to Data Management, and Advanced Functions compared to Data Management. The results reveal that the effectiveness ratings of the cross-curricular content in Advanced Functions are significantly lower than those of the other two courses.

The data analysis based on participants' programs yielded limited responses for certain programs, such as environmental science, earth science, general science, physics, and nursing. Among the programs with sufficient data, health science participants rated the experience and effectiveness of cross-curricular content highest for Data Management and lowest for Advanced Functions. In contrast, biology participants assigned higher ratings to the experience and effectiveness of cross-curricular content in Advanced Functions. Participants from Mathematics and Statistics programs provided very similar scores for both the learning experience and effectiveness of cross-curricular content across all three courses.

The analysis based on participants' graduation years from high school revealed notable trends in their ratings. Participants who graduated from high school in 2020 provided the lowest average experience and effectiveness ratings, among participants that graduated from 2019 to 2023. In contrast, participants who graduated in 2019 gave the highest average experience and effectiveness ratings.

The qualitative responses aligned with the quantitative findings, revealing mixed feedback on the cross-curricular content in Advanced Functions. While exponential and logarithmic functions received positive comments, polynomial and rational functions were not mentioned, and participants called for more real-world applications. In Calculus and Vectors, Engineering and Mathematics students gave high ratings, but students from other programs struggled with concepts like rates of change and derivatives, partly due to disruptions from the COVID-19 pandemic. Vectors were notably absent from discussions outside of mathematics and engineering. For Data Management, most participants found topics like probability distributions and data organization helpful for their studies, with many appreciating the integration of technology. Some highlighted its practical benefits, such as developing logical thinking skills, though others questioned the relevance of topics like counting and probability to the STEM fields.

In conclusion, the qualitative and quantitative survey responses highlight both the strengths and areas for improvement in the cross-curricular content of the Ontario Grade 12 university-level mathematics curriculum. While many participants found certain topics beneficial for their future studies, others struggled to see the connections between their studies and the cross-curricular content in the curriculum. Participants also emphasized the importance of incorporating more real-world, STEM-focused problems and fostering greater engagement with cross-curricular material. However, concerns were raised about the potential challenges of expanding the curriculum, given its current complexity and scope. These findings suggest that thoughtful revisions, balancing real-world relevance with the curriculum's rigor, could enhance the overall learning experience and better prepare students for their future endeavors in the STEM fields.

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Appendix A

Letter of Consent

Survey topic: Assessing the Impact of cross-curricular content in Grade 12 Mathematics Curriculum

Preamble: The survey will be in plain text. The logic of the survey will be in Italics. For example, the consent form of the survey is stated below.

Consent form: This consent form will be presented to the participants as an integral part of the online survey, but before they start the survey.

Title of Survey: Assessment of cross-curricular content in the Ontario Grade 12 University-Level Mathematics Curriculum

Investigator: Qiye Huang

Introduction: You are invited to participate in a research survey focused on assessing cross-curricular aspects of the *Grade 12 University-Level Mathematics Curriculum* in Ontario, Canada. This survey aims to gather information about your experiences with the curriculum to improve its effectiveness. The research has been reviewed and approved by the Nipissing University Research Ethics Board under protocol – To be added when approved. Please read the following information carefully before deciding to participate.

Purpose of the Survey: The goal of the research is to understand how the cross-curricular content in the curriculum has prepared students for university-level studies, particularly in STEM (science, Technology, Engineering, and Mathematics) fields. The participants of the survey are University students who are in STEM programs in Ontario, and who have previously taken Ontario high school math courses. Your valuable input will help inform future curriculum development and enhance educational outcomes. Thank you, in advance, if you choose to share your experiences and insights.

Study Procedures: If you agree to participate, you will be asked to answer questions related to your age, year of university, program of study, and your experiences with Grade 12 mathematics. If you would like to enter a draw to win a $25 Indigo gift card, then your email address will be needed (but you can complete the survey without entering the draw).

Confidentiality: Your responses will remain confidential, and if you provide your email address it will only be used for prize distribution. Your individual responses will be used by the researcher (Qiye Huang) and thesis supervisor (Dr. Timothy Sibbald) and will not be shared further. Results of the research will be reported in an aggregated and anonymized format. It's important to note that participants will remain anonymous if you choose not to enter the draw and do not provide your email address.

Voluntary Participation: Participation in this survey is entirely voluntary. You may choose not to participate or to withdraw at any time without penalty. Please do not complete the survey if you are one of Dr. Sibbald's students.

Potential Risks and Benefits: There are no known risks associated with this survey. By participating, you will contribute to the improvement of mathematics education. You may receive a prize (an Indigo $25 gift card) for participating if you complete a survey section about a Grade 12 course and provide your email. To protect the information of the participants, the name of the winner of the prize will not be disclosed. An overall summary of the responses and some feedback will be available at Dr. Timothy Sibbald's page at https://uts.nipissingu.ca/timothys/ after the data are analyzed. If the survey's content creates an unintended concern, please consider accessing counselling services at your university or resources and referral services on the

Canadian Mental Health Association (Ontario) website at https://ontario.cmha.ca/provincial-mental-health-supports/.

Contact Information: If you have questions about the survey or its procedures, you may contact the researcher Qiye Huang at [Qiye’s email]. Alternatively, you may contact Dr. Timothy Sibbald, Qiye’s thesis supervisor, at [Dr. Sibbald’s email] or [Dr. Sibbald’s phone] or the Nipissing University Research Ethics Board at ethics@nipissingu.ca.

Right to Withdraw: You have the right to withdraw from the survey at any time without providing a reason. Your decision to participate, or not, will have no affect on your relationship with the investigator or your university.

Draw for Gift Card: If you meet the criteria to participate in the survey and complete it regarding one of the three courses it focuses on then you may choose to provide an email address and be entered in a draw to win a $25 Indigo gift card. Only one participant that has completed at least one section of the survey will receive the prize. There is no obligation to provide an email address and you do not have to enter the draw. You will remain anonymous if you choose not to enter the draw and provide your email address.

Consent: By clicking the "I agree to participate" button below, you indicate that you are at least 18 years of age, understand the purpose of the survey, and voluntarily consent to participate.

[ ] I agree to participate

Appendix B

Research Survey

Survey for University Students: Assessing the Impact of Grade 12 Mathematics Curriculum. Elements in italics represent commentary about the survey or the pathway through the survey based on the response to a question.

The following section is the basic information of the survey.

Section 1: Participant Information

1. High school Study experience (*Multiple Choice*): Have you completed Grade 12 in Ontario?
    - Yes
    - No: *Goes to the End page for those who could not complete the survey.*
    - Currently enrolled in Grade 12 in Ontario: *Goes to the End page for those who could not complete the survey.*
    - Others: Please specify: *Goes to the End page for those who could not complete the survey.*
2. University Study experience (*Multiple Choice*): Are you currently enrolled or have attended Ontario university?
    - Yes, I am currently enrolled in an Ontario University
    - Yes, I have attended an Ontario University in the past
    - No, I am enrolled or have been enrolled in a university outside of Ontario (Please specify, country, Province/state)
3. Year of completion of high school (*Short answer*): Which year did you complete high school?
4. Year you began university (*Short answer*): Which year did you start university?
5. University Programs (*Multiple Choice*): Please indicate the primary university program you are currently enrolled in or have completed:
    - Mathematics and Statistics
    - Chemistry (exclude health sciences)
    - Biology (exclude health sciences, but including botany, zoology, microbiology)
    - Physics
    - Health Sciences
    - Engineering
    - Other programs that are not a STEM program: *Goes to the End page for those who could not complete the survey, since they are not the target participants of the survey.*
    - Other programs that is a STEM program (Please specify):
6. University Year (*Multiple Choice*): Select your current university year. If you are unsure, please select the response indicating what year most of your courses belong to:
    - Year 1
    - Year 2
    - Year 3

    - Year 4
    - Year 5 and above
7. Curriculum Source (*Multiple Choice*): Were your Grade 12 Mathematics courses part of the Ontario curriculum?
    - Yes and grade 12 was the final year
    - Yes and I completed OACs or Grade 13, as well
    - No, I followed a different curriculum (e.g., AP, IB, private school, etc.): *Goes to the End page for those who could not complete the survey.*
    - Other curriculum or unsure (Please specify): *Goes to the End page for those who could not complete the survey.*
8. Mathematics Courses (*Multiple Choice*): Please select the Grade 12 Mathematics course(s) you completed:
    - Advanced Functions (MHF4U): *Goes to Section I: Advanced Functions Curriculum.*
    - Calculus and Vectors (MCV4U): *Goes to Section II: Calculus and Vectors Curriculum.*
    - Data Management (MDM4U): *Goes to Section III: Data management Curriculum.*
    - Mathematics for College Technology, College Preparation (MCT4C)
    - Foundations for College Mathematics, College Preparation (MAP4C)
    - Mathematics for Work and Everyday Life, Workplace Preparation (MEL4E)
    - Other (Please specify):

The sample problems and the questions

To avoid bias, if the participant selected more than one course in the previous question, the order of the sections will be randomized.

Section I: Advanced Functions Curriculum

The survey will ask questions after giving some examples. Examples of the cross-curricular contents in each topic: *(There will be questions related to these examples after the example section)*

Exponential and Logarithmic Functions
The pH or acidity of a solution is given by the equation pH = – logC, where C is the concentration of $[H^+]$ ions in multiples of M = 1 mol/L. You are given a solution of hydrochloric acid with a pH of 1.7 and asked to increase the pH of the solution by 1.4. Determine how much you must dilute the solution. Does your answer differ if you start with a pH of 2.2? (Ontario Ministry of Education, 2007, p. 88)

Trigonometric Functions
A clock is hanging on a wall, with the centre of the clock 3 m above the floor. Both the minute hand and the second hand are 15 cm long. The hour hand is 8 cm long. For each hand, determine the equation of the cosine function that describes the distance of the tip of the hand above the

floor as a function of time. Assume that the time, t, is in minutes and that the distance, is in centimetres. Also assume that t=0 is midnight. (Kirkpatrick et al., 2008, p. 362)

Polynomial and Rational Functions
A group of students have volunteered for the student council car wash. Janet can wash a car in “m” minutes. Rodriguez can wash a car in “m – 5” minutes, while Nick needs the same amount of time as Janet. If they all work together, they can wash a car in about 3.23 minutes. How long does Janet take to wash a car? (Kirkpatrick et al., 2008, p. 309)

Characteristics of Functions
According to Statistics Canada, Canada’s population reached 30.75 million on July 1, 2000—an increase of 256 700 from the previous year. The rate of growth for that year was the same as the rate of growth for the year before. Both Ontario and Alberta, however, recorded 1.3% growth rates in 2000. a) Create algebraic and graphical models for the population growth of Canada. Assume that the percent rate of growth was the same for every year. b) How does the growth rate for Canada’s population compare with the growth rate reported by Ontario and Alberta? (Kirkpatrick et al., 2008, p. 574)

Questions:

1. Please rate your experiences of cross-curricular content in the Advanced Functions curriculum from 1 (very limited cross-curricular content) to 5 (abundant cross-curricular content). *(Likert scale)*
2. Rate the effectiveness of this type of cross-curricular question or content in preparing you for your academic pursuits, from 1 (did not provide preparation) to 5 (provided substantial preparation). *(Likert scale)*
3. Provide examples of how the cross-curricular content in Advanced Functions either aided or did not aid in your preparation for your academic field. Mention any other subjects it interacted with and the connections it made to your future studies. *(Long Answers)*
4. Suggest improvements that could enhance the cross-curricular content in Advanced Functions. Include any materials or activities you believe should be incorporated or alternative methods for teaching cross-curricular content. *(Long Answers)*

These questions will be shown for each topic, after each example problem above.

End of Advanced functions:

Would you like to continue this survey for another Grade 12 mathematics courses you have taken?

- Yes. *Proceed to the next section according to their previous selections. If they picked Advanced Functions, Calculus and Vectors, and Data Management, they would go to either Section II or III (randomized).*
- No. *Goes to the optional questions.*

Section II: Calculus and Vectors Curriculum

The survey will be given after providing some examples from the curriculum. Examples of the cross-curricular contents in each topic:

Rate of Change
A pellet is shot into the air. Its position above the ground at any time, *t*, is defined by $s(t) = 45t - 5t^2$m. For what values of *t*, $t \geq 0$, is the upward velocity of the pellet positive? For what values of t is the upward velocity zero and negative? Draw a graph to represent the velocity of the pellet. (Crippin et al., 2009, p. 156)

Derivatives and their Applications
A bird is foraging for berries. If it stays too long in any one patch it will be spending valuable foraging time looking for the hidden berries, but when it leaves it will have to spend time finding another patch. A model for the net amount of food energy in joules the bird gets if it spends t minutes in a patch is $E = 3000t/(t+4)$. Suppose the bird takes 2 min on average to find each new patch, and spends negligible energy doing so. How long should the bird spend in a patch to maximize its average rate of energy gain over the time spent flying to a patch and foraging in it? Use and compare numeric, graphical, and algebraic strategies to solve this problem. (Ontario Ministry of Education, 2007, p. 106)

Geometry and Algebra of Vectors
The width of a rectangle increases at 2 cm/s, while the length decreases at 3 cm/s. How fast is the area of the rectangle changing when the width equals 20 cm and the length equals 50 cm? (Crippin et al., 2009, p. 569)

Questions (same as previous):

1. Please rate your experiences of cross-curricular content in the Calculus and Vectors curriculum from 1 (very limited cross-curricular content) to 5 (abundant cross-curricular content). *(Likert scale)*
2. Rate the effectiveness of this type of cross-curricular question cross-curricular content in preparing you for your academic pursuits, from 1 (did not provide preparation) to 5 (provided substantial preparation). *(Likert scale)*
3. Provide examples of how the cross-curricular content in Calculus and Vectors either aided or did not aid in your preparation for your academic field. Mention any other subjects it interacted with and the connections it made to your future studies. *(Long Answers)*
4. Suggest improvements that could enhance the cross-curricular content in Calculus and Vectors. Include any materials or activities you believe should be incorporated or alternative methods for teaching cross-curricular content. *(Long Answers)*

These questions will be shown for each topic, after each example problem above.

End of Calculus and Vectors:

Would you like to continue this survey for other Grade 12 mathematics courses you have taken?

- Yes. *Proceed to the next section according to their previous selections. If they picked Advanced Functions, Calculus and Vectors, and Data Management, they would go to either Section I or III (randomized).*
- No. *Goes to the optional questions.*

Section III: Data Management curriculum

The survey questions are provided after a few examples from the curriculum. Examples of the cross-curricular contents in each topic:

Counting and Probability
Of 150 workers surveyed in an industrial community, 65 worked in the paper mill and 30 worked in the water-treatment plant. a) What is the probability that a worker surveyed at random works i) in either the paper mill or the water treatment plant? ii) somewhere other than the paper mill or the water-treatment plant? b) What assumptions must you make in part a)? (Zimmer, 2003, p. 360)

Probability Distribution
In July of 2000, 38% of the population of Canada lived in Ontario. Design a simulation to estimate the expected number of residents of Ontario included in a random survey of 25 people in Canada. (Zimmer, 2003, p. 409)

Organization of Data for Analysis
Suppose you are designing a remote control that uses short, medium, or long pulses of infrared light to send control signals to a device. a) How many different control codes can you define using i) three pulses? ii) one, two, or three pulses? b) Explain how the multiplicative and additive counting principles apply in your calculations for part a). (Zimmer, 2003, p. 261)

Statistical Analysis
A phosphorescent material can glow in the dark by absorbing energy from light and then gradually re-emitting it. The following table shows the light levels for a phosphorescent plastic.

Time (h)	Light Level (lumens)
0	0.860
1	0.695
2	0.562
3	0.455
4	0.367
5	0.305
6	0.247

a) Create a scatter plot for the data. b) Perform a quadratic regression. Record the equation of the curve of best fit and the coefficient of determination (also called the r-squared). c) Repeat part b) for an exponential regression. d) Compare how well these two models fit the data. e) According to each model, what will be the light level after 10 h? f) Which of these two models is superior for extrapolating beyond 6 h? Explain. (Zimmer, 2003, p. 215)

Culminating Data Management Investigation
Select four of the topics below. Then, brainstorm sub-topics and construct a mind map for each of your four topics. Try to include several levels for your mind maps.
AUTOMOBILES
MUSIC
MOVIES
SPORTS
DANCE

FASHION
TRAVEL
OCCUPATIONS RISK (Zimmer, 2003, p. 485)

Questions (same as previous):

1. Please rate your experience of cross-curricular content in the Data Management curriculum from 1 (very limited cross-curricular content) to 5 (abundant cross-curricular content). *(Likert scale)*
2. Rate the effectiveness of this type of cross-curricular question cross-curricular content in preparing you for your academic pursuits, from 1 (did not provide preparation) to 5 (provided substantial preparation). *(Likert scale)*
3. Provide examples of how the cross-curricular content in Data Management either aided or did not aid in your preparation for your academic field. Mention any other subjects it interacted with and the connections it made to your future studies. *(Long Answers)*
4. Suggest improvements that could enhance the cross-curricular content in Data Management. Include any materials or activities you believe should be incorporated or alternative methods for teaching cross-curricular content. *(Long Answers)*

These questions will be shown for each topic, after each example problem above.

End of Data Management:

Would you like to continue this survey for other Grade 12 mathematics courses you have taken?

- Yes. *Proceed to the next section according to their previous selections. If they picked Advanced Functions, Calculus and Vectors, and Data Management, they would go to either Section I or II (randomized).*
- No. *Goes to the optional questions.*

Optional questions

(Optional) Please comment on the overall cross-curricular contents in *Ontario Grade 12 University level Mathematics Curriculum*.

(Optional) Have you been introduced to progressivism, constructivism, and experiential learning or any educational philosophies or theories during your study of cross-curricular content in Grade 12 mathematics? Please name them and share your experience of applying for them.

(Optional) You have a chance to win a 25$ gift card! If you wish to be entered in the draw, please enter your email address for the purpose of the survey rewards. If you do not wish to, that is fine.

Goes to the End page for those who completed the survey.

End page for those who completed at least one section of the survey.

Thank you for participating in this survey. Your responses will help us better understand the impact of Grade 12 mathematics curriculum on university students. A summary of the findings from this survey will be posted at [redacted] after the data analysis (hopefully by the summer of 2024).

End page for those who could not complete the survey.

We appreciate your interest in our survey, but you do not fit the criteria required for this research. If you happen to know university STEM students who studied Grade 12 math in Ontario, please feel free to share the survey link with them. *link of survey will be added*. Thank you!

Appendix C

Letters of Recruitment

The contents of the emails for recruitment

Subject: Request for Participation in Research on Grade 12 Mathematics Curriculum

For: FYMiC and other students' unions:

To whom it may concern,

I am Qiye Huang, a grad student from Nipissing University and I am currently researching the Impact of Grade 12 mathematics Curriculum. I have a survey that I would like Ontario university STEM students to complete. I am interested in understanding how the cross-curricular content in the Grade 12 curriculum has prepared students for university-level studies in STEM (science, technology, engineering, and mathematics) fields. The participants of the survey are University students who are in STEM programs in Ontario, and who have previously taken Ontario high school math courses. Their valuable input will help them self-reflect on their Grade 12 mathematics education and to think about how the cross-curricular contents help them with their studies and will contribute to informing future curriculum development and enhance educational outcomes. The survey will take them 20-50 minutes to complete.

The survey has received approval from my thesis supervisor, Dr. Timothy Sibbald ([Dr. Sibbald's email]), professor at Nipissing University and the Nipissing University Research Ethics Board (REB) (approval number will be added after approval). Please do not complete the survey if you are or have been one of Dr. Sibbald's students. The participants will be asked to answer questions about their experiences with Grade 12 mathematics. The information needed from them is, for example, their year of university, program of study, and your experiences with Grade 12 mathematics. If the participant is interested in winning a $25 Indigo gift card reward then their email address will be required. Their responses will remain confidential, and their email address will only be used for addressing the prize. It's important to note that participation will remain anonymous for those who choose not to enter the draw and do not provide their email address.

Please circulate the survey link to university students, and other faculty who may also be able to circulate it, which is: [link to be added]

I can be contacted at [Qiye’s email] if you have any questions. There is no set deadline for the survey. The link will be closed once enough responses have been collected.

Thank you so much for your consideration.

Regards,

Qiye Huang

For: University STEM departments and professors:

Dear [department name] Faculty and Administrators or [professor name],

My name is Qiye Huang and I am a graduate student at Nipissing University conducting research on the impact of the Grade 12 mathematics Curriculum in Ontario. I am reaching out to request your support and assistance in gathering valuable insights from your university's STEM students. The purpose of my research is to assess how the cross-curricular content within the Grade 12 mathematics Curriculum has prepared our students for university-level studies, particularly in STEM (science, technology, engineering, and mathematics) fields. The participants of the survey are University students who are in STEM programs in Ontario, and who have previously taken Ontario high school math courses. The outcomes of this research will play a crucial role in shaping future curriculum development and enhancing educational outcomes for our students.

The survey has received approval from Dr. Timothy Sibbald ([Dr. Sibbald's email]), professor at Nipissing University, and the Nipissing University Research Ethics Board (REB) (approval number will be added after approval). Please do not complete the survey if you are or have been one of Dr. Sibbald's students.

Participants in this study will be asked to share their experiences with Grade 12 mathematics, including their year of university, program of study, and insights into how the curriculum has helped, hindered, or influenced their university studies. The participants will have the opportunity to enter a draw for a $25 Indigo gift card. It's important to note that participation will remain anonymous for those who choose not to enter the draw and do not provide their email address. Their responses will remain confidential. To access the survey and learn more about the research, please find the attached survey link (link to be added).

Your support in disseminating this survey to students and other faculty within your department is greatly appreciated. I believe that the collective input of our students will provide valuable insights into the curriculum's effectiveness.

If you have any questions or require further information, please do not hesitate to reach out to me at [Qiye's email]. Thank you in advance for your support.

Regards,

Qiye Huang

Post on general social media:

Dear [university name] community,

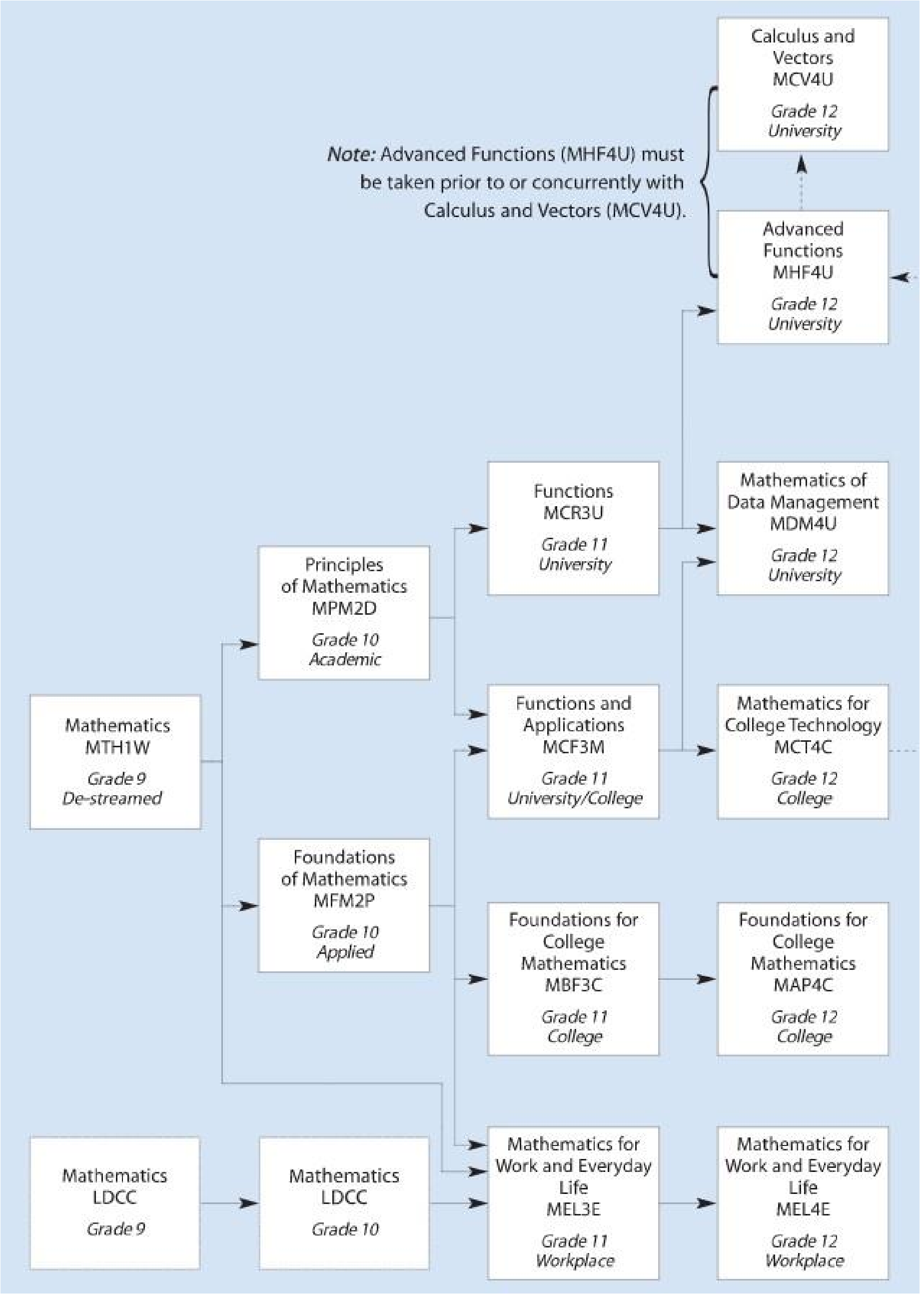
I am excited to invite STEM students, who studied Ontario Grade 12 mathematics following the Ontario curriculum, to participate in an important research study conducted by Qiye Huang, a graduate student at Nipissing University. This research aims to assess the influence of the Grade 12 mathematics curriculum in Ontario on university preparedness and STEM education. The participants of the survey are University students who are in STEM programs in Ontario, and who have previously taken Ontario high school math courses.

This study seeks to understand how the Grade 12 mathematics curriculum has prepared our students for university-level studies, particularly in STEM-related fields. The survey has received approval from Dr. Timothy Sibbald ([Dr. Sibbald’s email]), professor, Nipissing University and the Nipissing University Research Ethics Board (REB) (approval number will be added after approval). Please do not complete the survey if you are or have been one of Dr. Sibbald’s students. You will be asked to share your experiences with Grade 12 mathematics, including your year of university, program of study, and insights into how the Grade 12 curriculum has helped, hindered, or influenced your university studies. All responses will be kept confidential, and email addresses will only be needed if you wish to enter a draw for a $25 Indigo gift card reward. It's important to note that participation will remain anonymous for those who choose not to enter the draw and do not provide their email address. If you are interested, please follow this link to the survey (link to be added). There is no deadline for the survey. The survey will be closed once there are enough participants.

If you have any questions or require further information, please do not hesitate to reach out to me at [Qiye’s email]. Thank you in advance for your interest!

Appendix D

Grade 12 Mathematics Curriculum Pathways



Ontario Ministry of Education. (2021d). Prerequisite chart for mathematics, Grades 9–12. Queen's Printer for Ontario. https://www.dcp.edu.gov.on.ca/en/course-descriptions-and prerequisites/mathematics

Appendix E

List of Universities Emailed Recruitment Requests

Brock University
Carleton University
McMaster University
Nipissing University
Ontario Tech University
Queen's University
University of Guelph
University of Toronto
University of Waterloo
University of Windsor
Western University
Wilfrid Laurier Universit
York University

Appendix F

Letters of Recruitment After the Removal of the Non-bot Verification

Dear STEM professors from Ontario Universities,

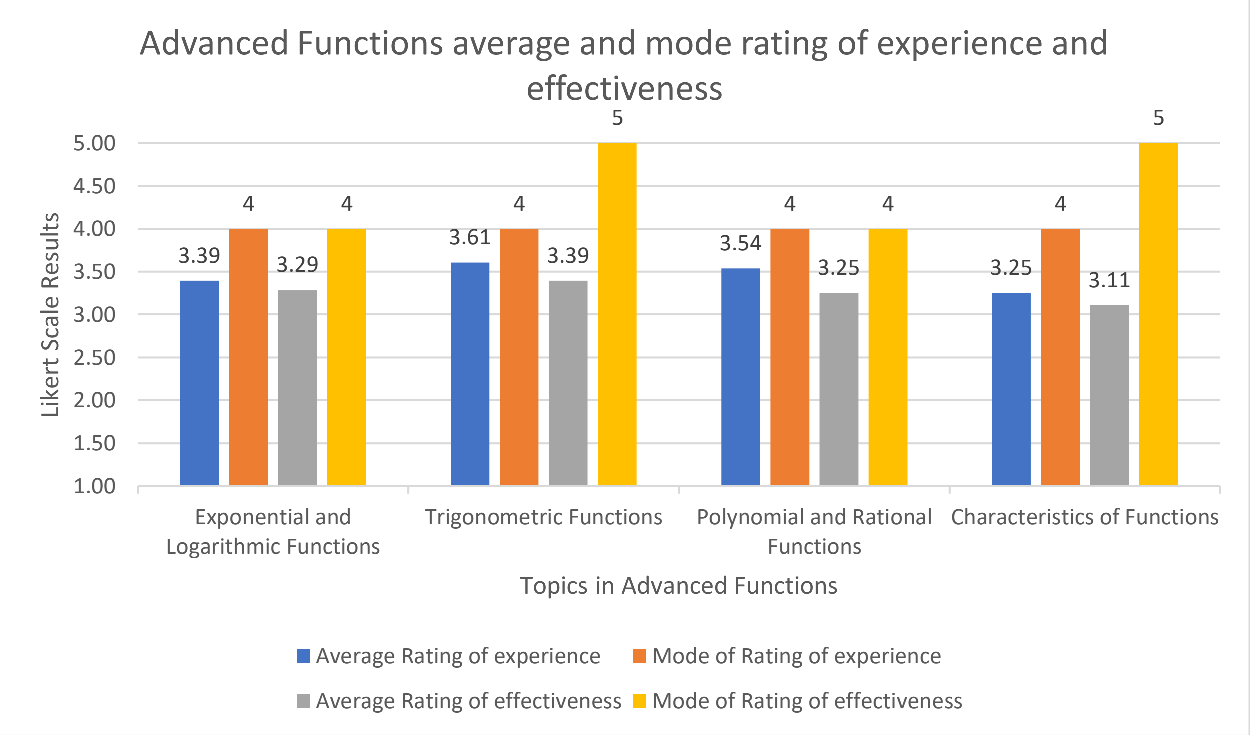
I appreciate your help with the circulation of the survey in support of my thesis. I have noticed that my survey's non-bot verification (CAPTCHA) may have caused problems for some participants. I have removed it, and a new link to the survey is: [redacted](note the old link still works, this is just preferred). Please find an updated PowerPoint slide attached to simplify distributing the survey to your students. I appreciate your help and understanding.

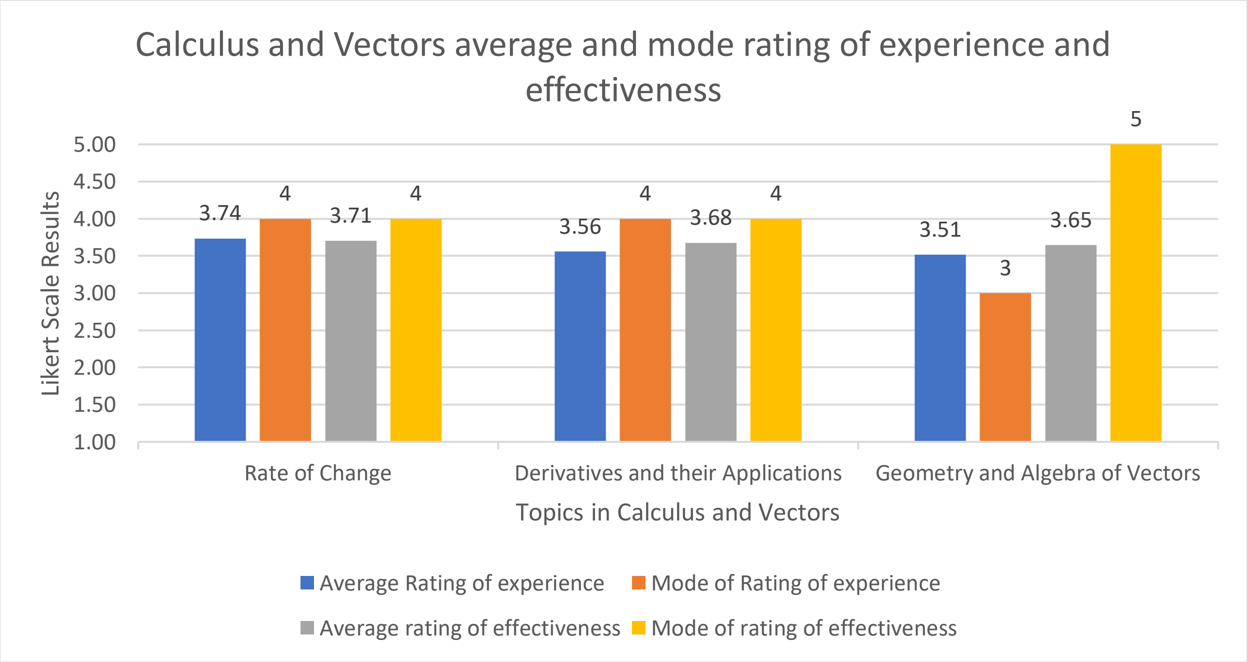
Qiye Huang

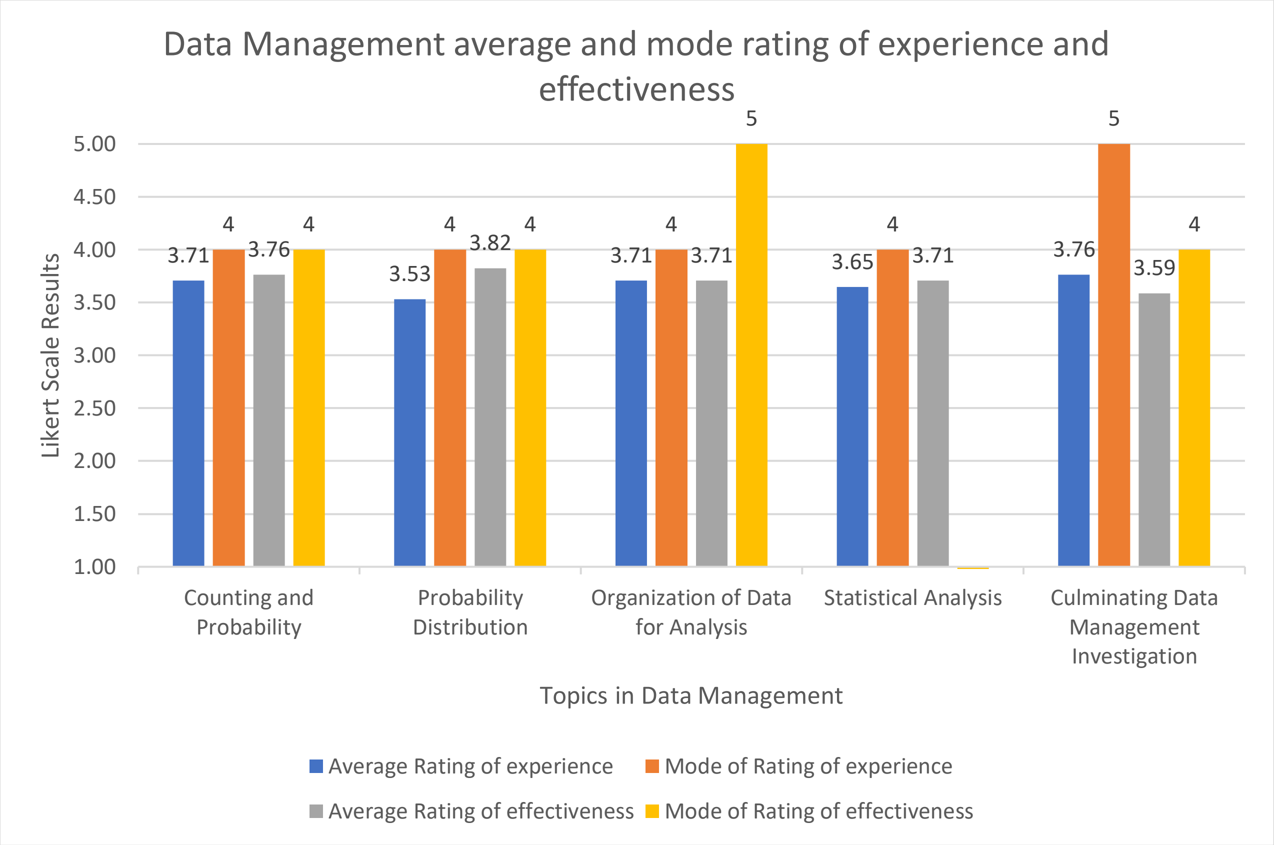
Appendix G

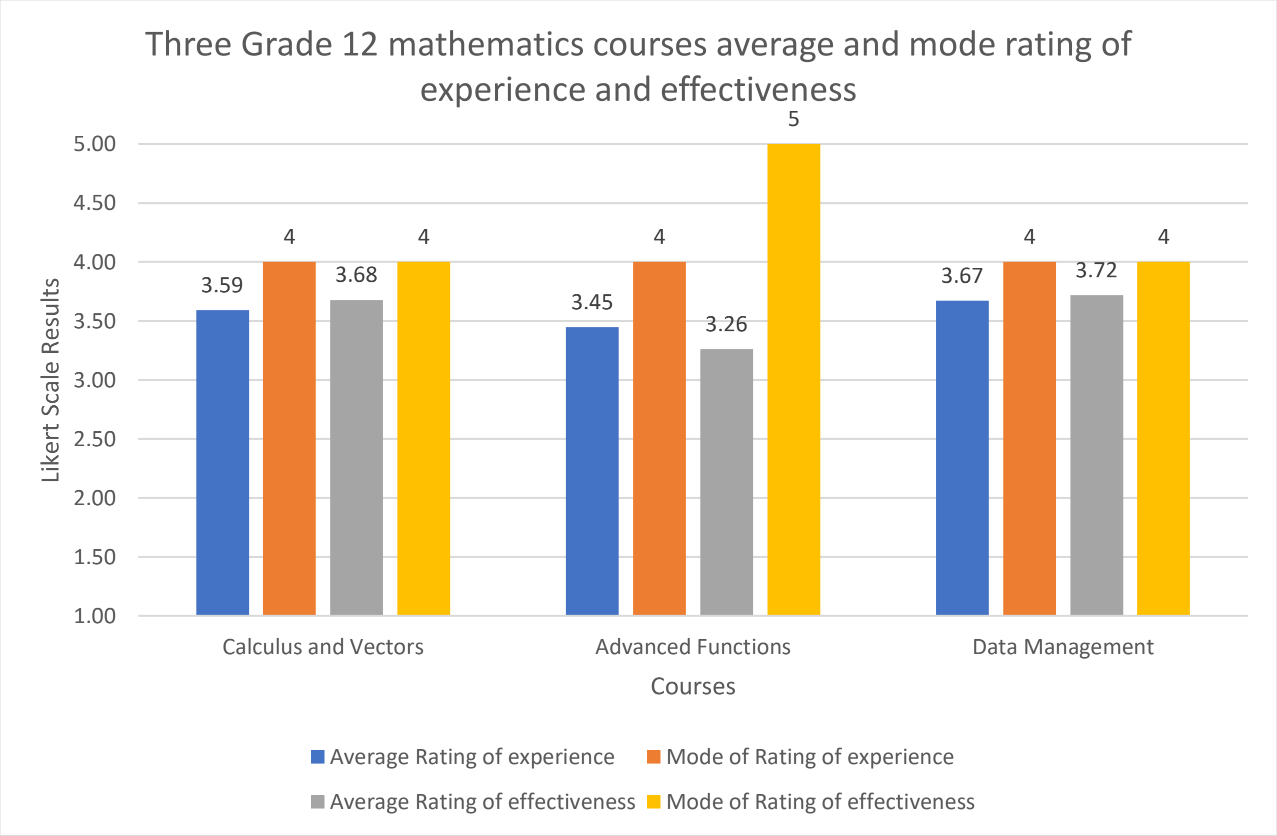
Graphs of Average and Mode Ratings of Participants' Cross-Curricular Content Experience and Effectiveness by Topic and Course

Part 1: The original survey's average and mode rating of experience and effectiveness for each topic of the three courses

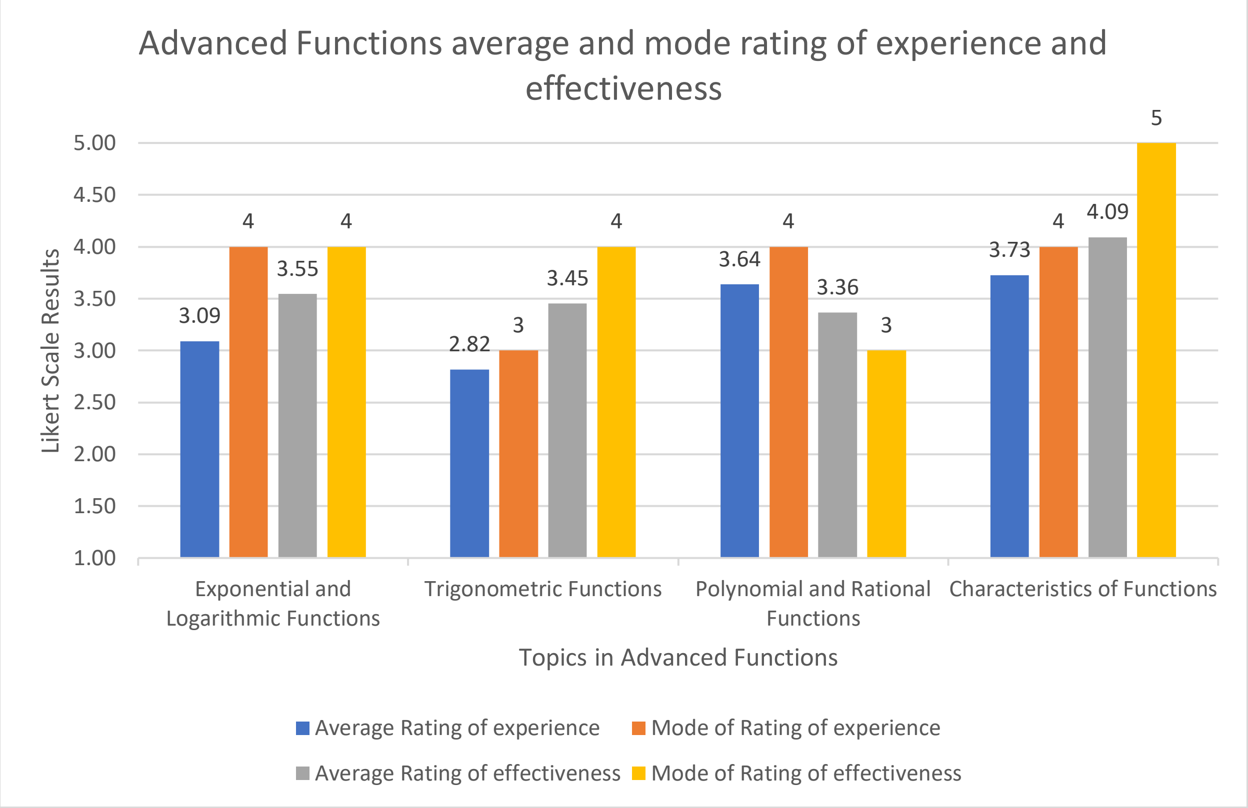


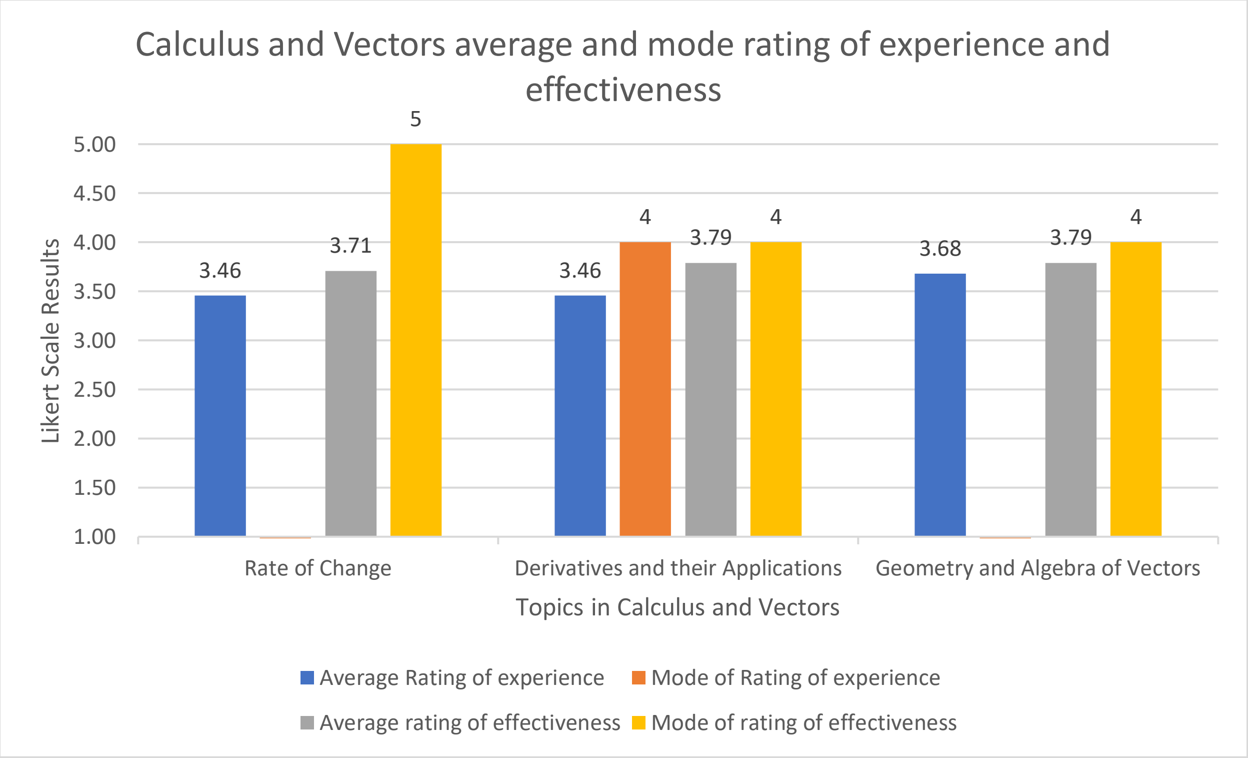


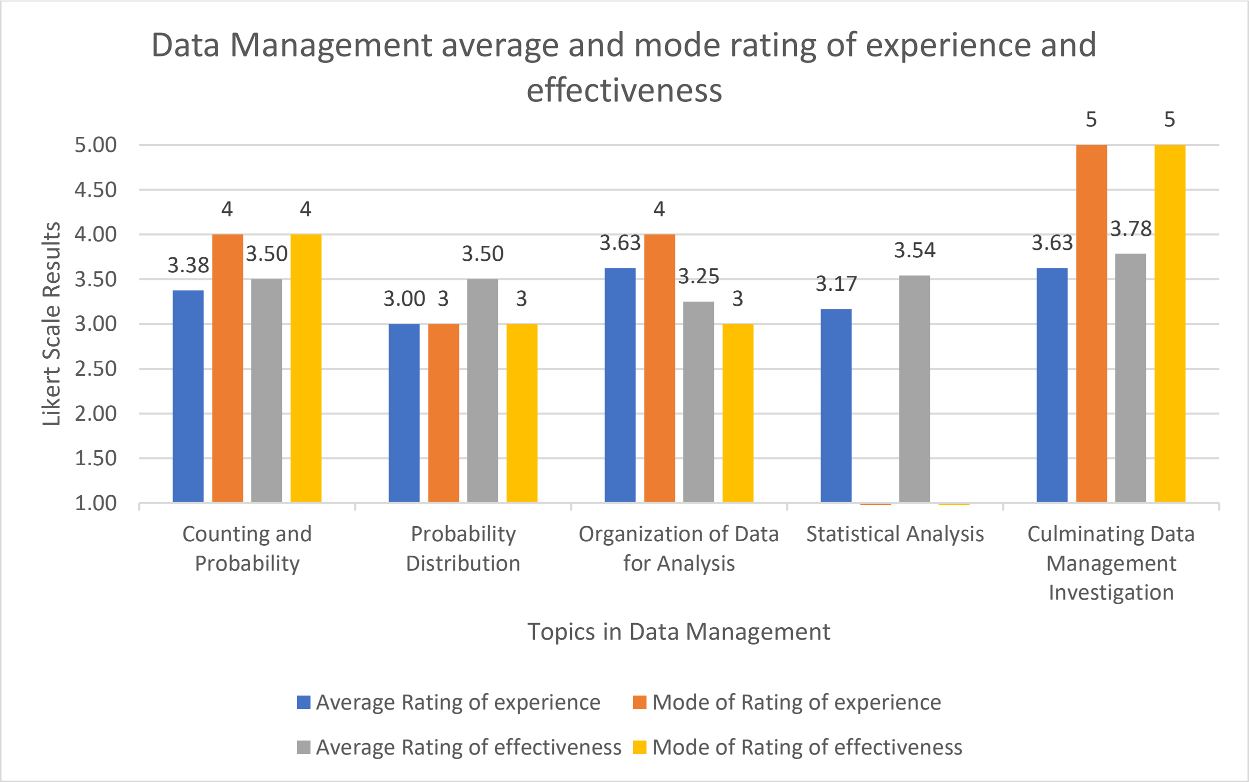

Data Management average and mode rating of experience and effectiveness
Likert Scale Results
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
3.71
4
3.76
4
3.53
4
3.82
4
3.71
4
3.71
5
3.65
4
3.71
3.76
5
3.59
4
Counting and Probability
Probability Distribution
Organization of Data for Analysis
Statistical Analysis
Culminating Data Management Investigation
Topics in Data Management
Average Rating of experience
Mode of Rating of experience
Average Rating of effectiveness
Mode of Rating of effectiveness

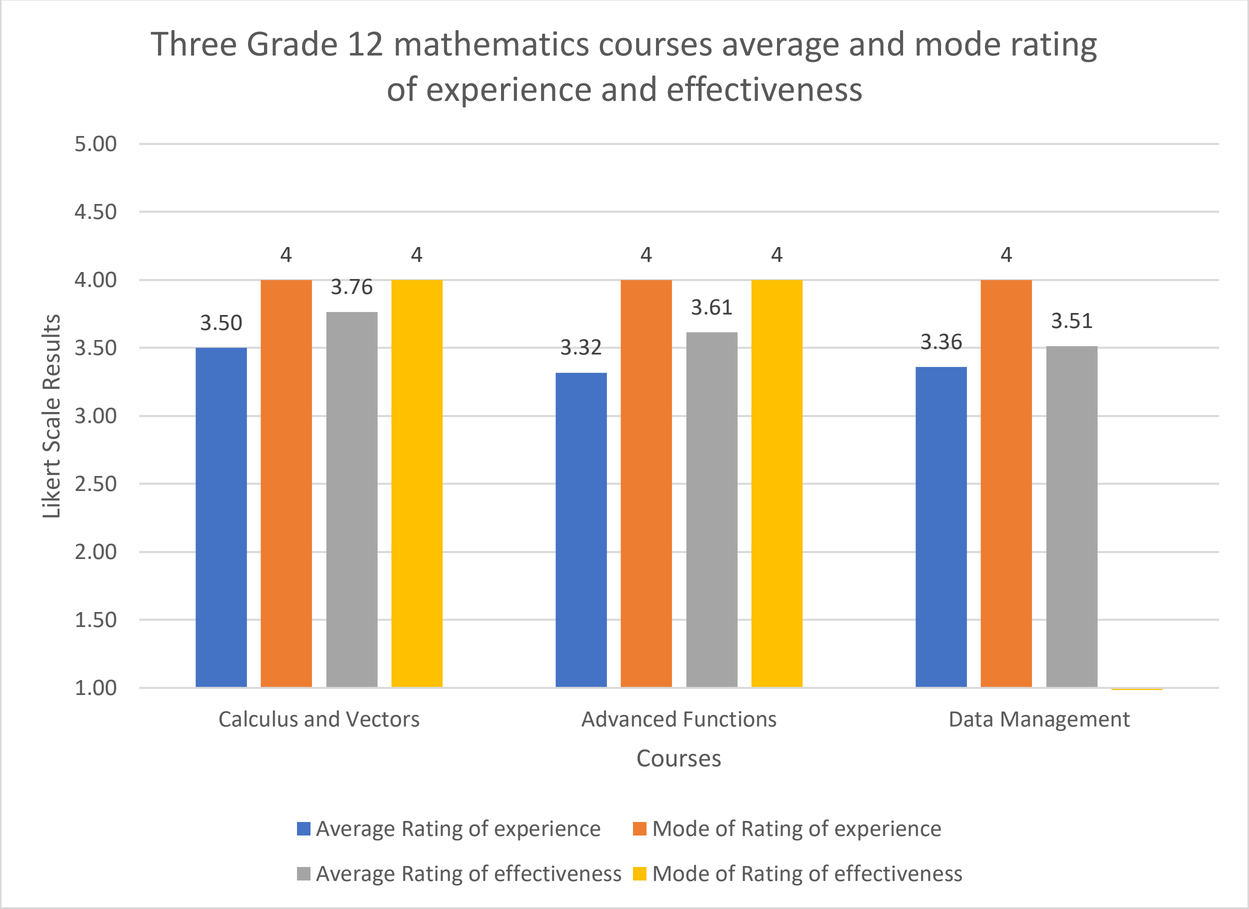

Three Grade 12 mathematics courses average and mode rating of experience and effectiveness
Likert Scale Results
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
3.59
4
3.68
4
3.45
4
3.26
5
3.67
4
3.72
4
Calculus and Vectors
Advanced Functions
Data Management
Courses
Average Rating of experience
Mode of Rating of experience
Average Rating of effectiveness
Mode of Rating of effectiveness

Part 2: The updated survey's average and mode rating of experience and effectiveness for each topic of the three courses

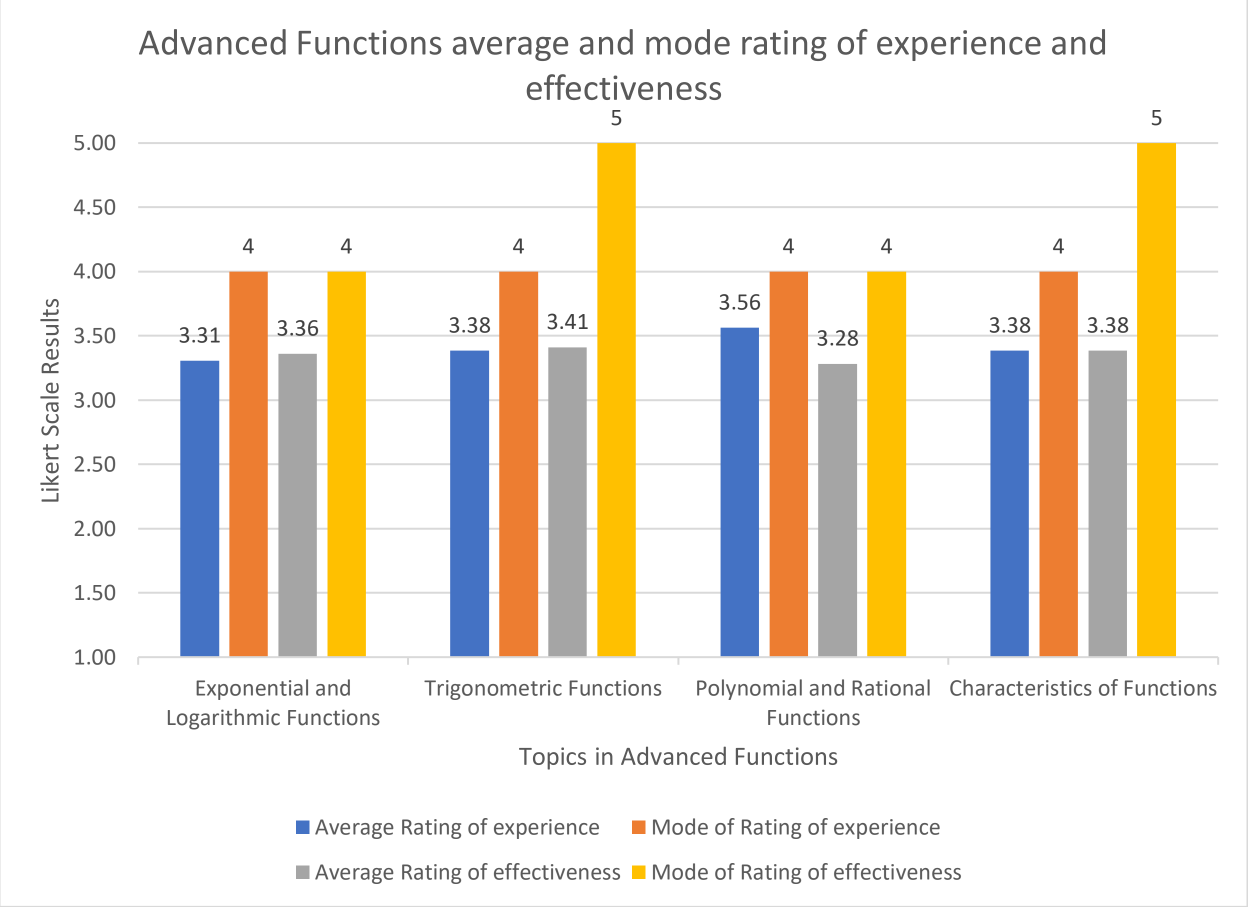


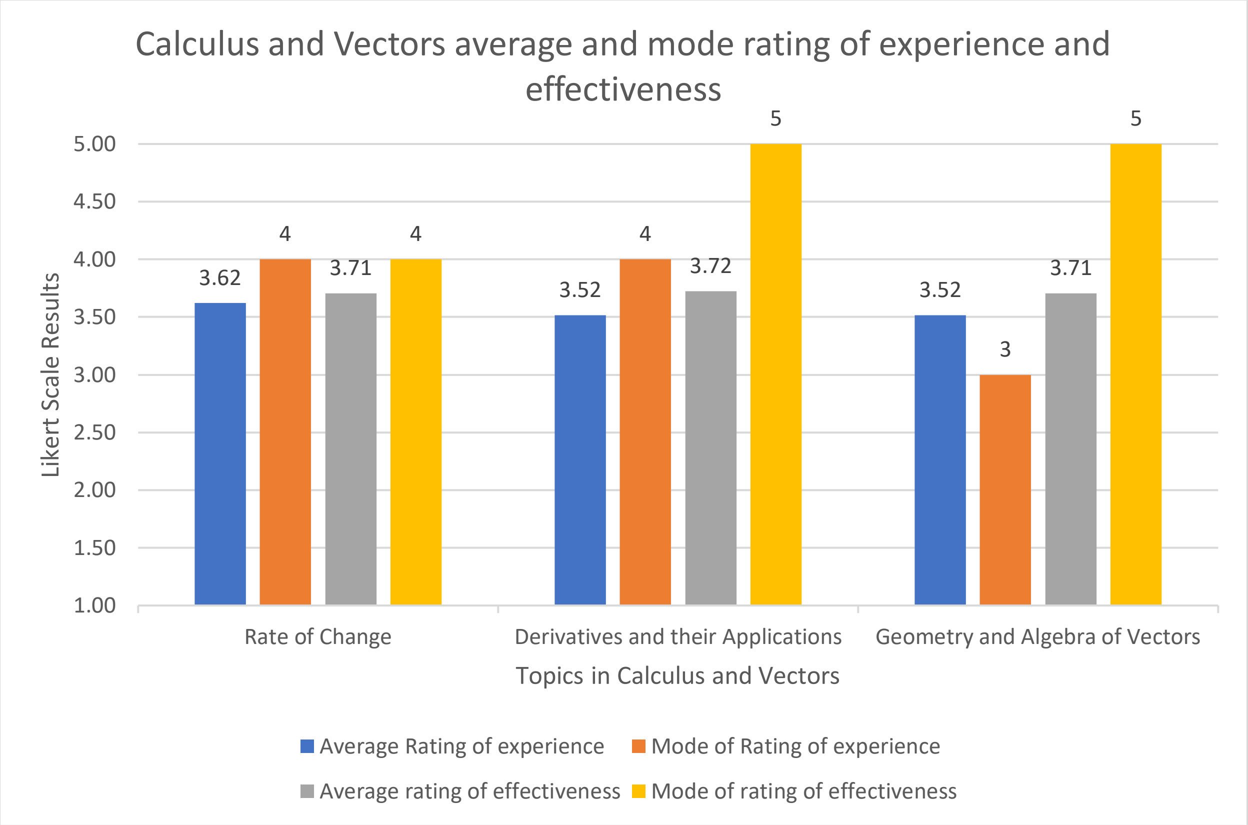


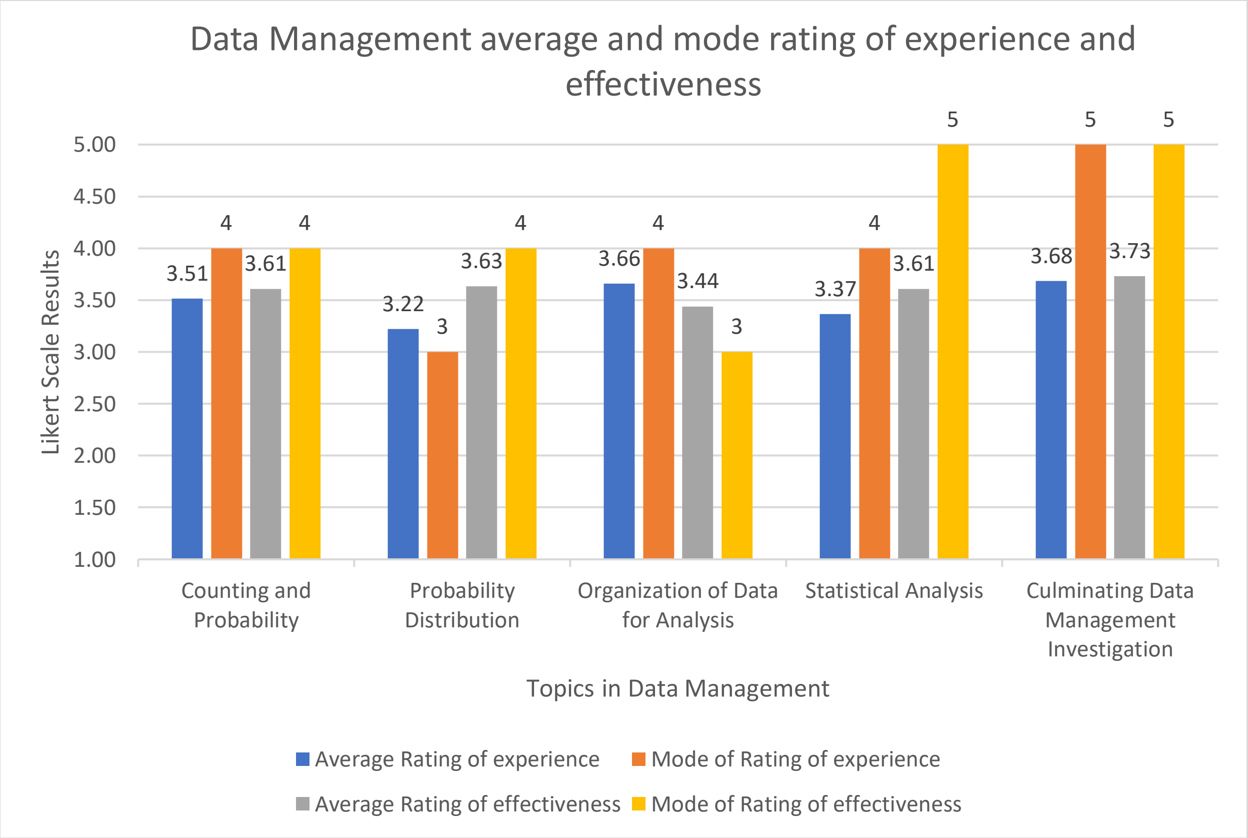

Data Management average and mode rating of experience and effectiveness
Likert Scale Results
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
3.38
4
3.50
4
3.00
3
3.50
3
3.63
4
3.25
3
3.17
3.54
3.63
5
3.78
5
Counting and Probability
Probability Distribution
Organization of Data for Analysis
Statistical Analysis
Culminating Data Management Investigation
Topics in Data Management
Average Rating of experience
Mode of Rating of experience
Average Rating of effectiveness
Mode of Rating of effectiveness


Three Grade 12 mathematics courses average and mode rating of experience and effectiveness
Likert Scale Results
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
3.50
4
3.76
4
3.32
4
3.61
4
3.36
4
3.51
Calculus and Vectors
Advanced Functions
Data Management
Courses
Average Rating of experience
Mode of Rating of experience
Average Rating of effectiveness
Mode of Rating of effectiveness

Part 3: The combined survey's average and mode rating of experience and effectiveness for each topic of the three courses



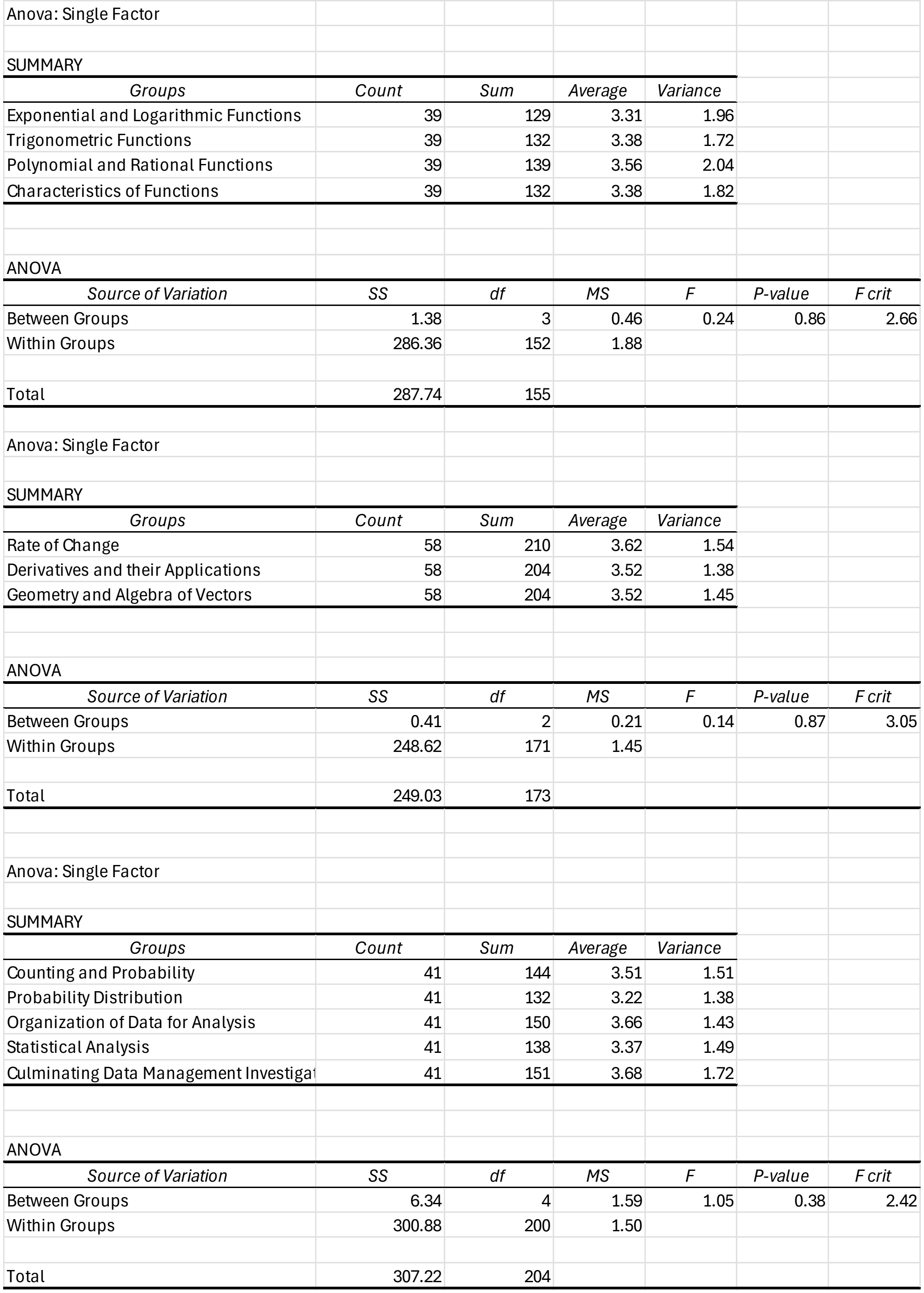

Calculus and Vectors average and mode rating of experience and effectiveness
Likert Scale Results
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
3.62
4
3.71
4
3.52
4
3.72
5
3.52
3
3.71
5
Rate of Change
Derivatives and their Applications
Geometry and Algebra of Vectors
Topics in Calculus and Vectors
Average Rating of experience
Mode of Rating of experience
Average rating of effectiveness
Mode of rating of effectiveness


Data Management average and mode rating of experience and effectiveness
Likert Scale Results
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
3.51
4
3.61
4
3.22
3
3.63
4
3.66
4
3.44
3
3.37
4
3.61
5
3.68
5
3.73
5
Counting and Probability
Probability Distribution
Organization of Data for Analysis
Statistical Analysis
Culminating Data Management Investigation
Topics in Data Management
Average Rating of experience
Mode of Rating of experience
Average Rating of effectiveness
Mode of Rating of effectiveness

Appendix H

ANOVA Test Results for Topic Comparisons Within Mathematics Courses

Part 1: ANOVA Test Results for Experience Ratings by Topic Across Mathematics Courses (Advanced Functions, Calculus and Vectors, and Data Management, in order)



Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Exponential and Logarithmic Functions	39	129	3.31	1.96
Trigonometric Functions	39	132	3.38	1.72
Polynomial and Rational Functions	39	139	3.56	2.04
Characteristics of Functions	39	132	3.38	1.82

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.38	3	0.46	0.24	0.86	2.66
Within Groups	286.36	152	1.88			
Total	287.74	155				

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Rate of Change	58	210	3.62	1.54
Derivatives and their Applications	58	204	3.52	1.38
Geometry and Algebra of Vectors	58	204	3.52	1.45

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.41	2	0.21	0.14	0.87	3.05
Within Groups	248.62	171	1.45			
Total	249.03	173				

Anova: Single Factor

SUMMARY

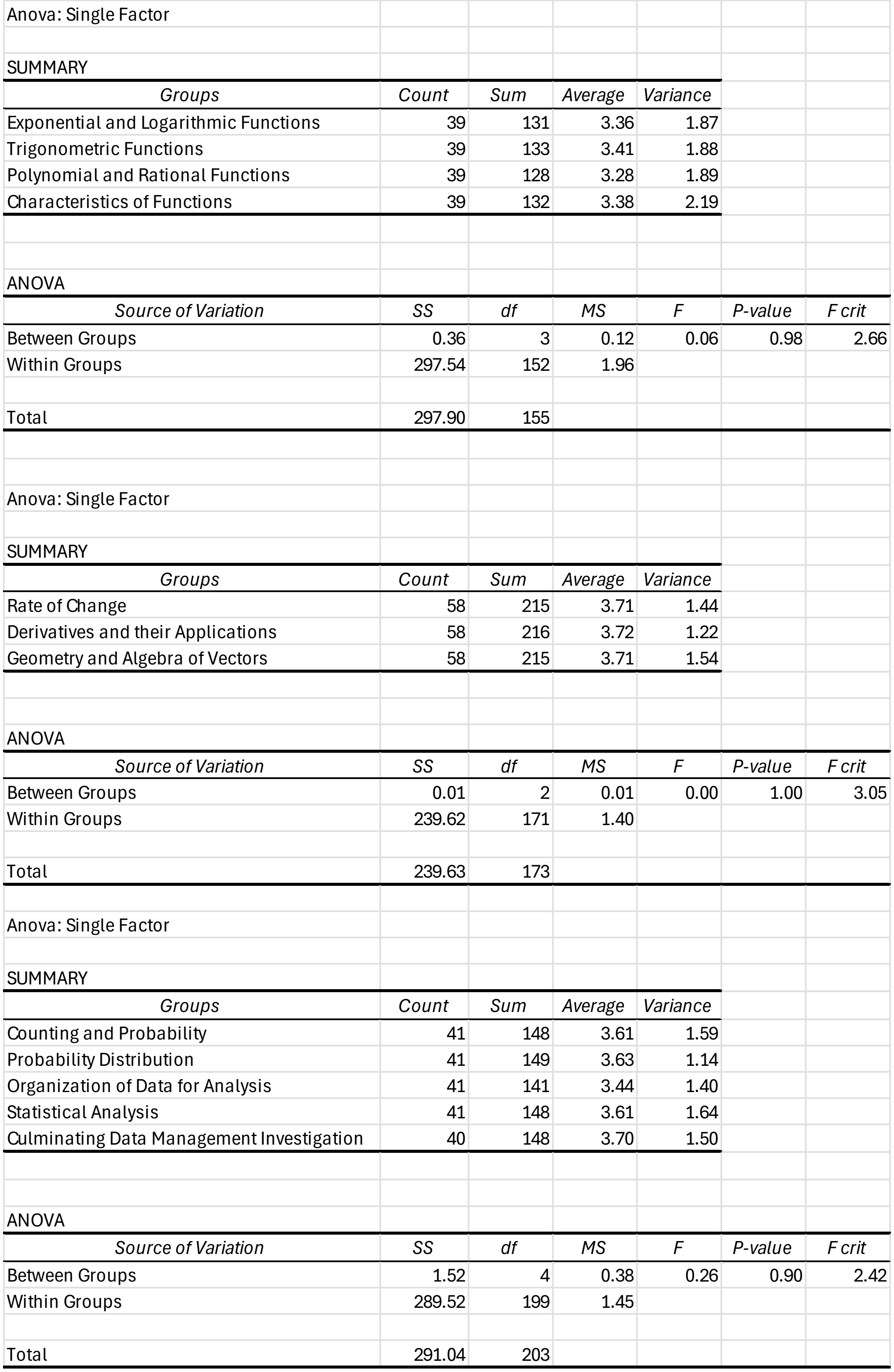
Groups	Count	Sum	Average	Variance
Counting and Probability	41	144	3.51	1.51
Probability Distribution	41	132	3.22	1.38
Organization of Data for Analysis	41	150	3.66	1.43
Statistical Analysis	41	138	3.37	1.49
Culminating Data Management Investigat	41	151	3.68	1.72

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	6.34	4	1.59	1.05	0.38	2.42
Within Groups	300.88	200	1.50			
Total	307.22	204				

Part 2: ANOVA Test Results for Effectiveness Ratings by Topic Across Mathematics Courses

(Advanced Functions, Calculus and Vectors, and Data Management, in order)



Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Exponential and Logarithmic Functions	39	131	3.36	1.87
Trigonometric Functions	39	133	3.41	1.88
Polynomial and Rational Functions	39	128	3.28	1.89
Characteristics of Functions	39	132	3.38	2.19

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.36	3	0.12	0.06	0.98	2.66
Within Groups	297.54	152	1.96			
Total	297.90	155				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Rate of Change	58	215	3.71	1.44
Derivatives and their Applications	58	216	3.72	1.22
Geometry and Algebra of Vectors	58	215	3.71	1.54

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.01	2	0.01	0.00	1.00	3.05
Within Groups	239.62	171	1.40			
Total	239.63	173				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Counting and Probability	41	148	3.61	1.59
Probability Distribution	41	149	3.63	1.14
Organization of Data for Analysis	41	141	3.44	1.40
Statistical Analysis	41	148	3.61	1.64
Culminating Data Management Investigation	40	148	3.70	1.50

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.52	4	0.38	0.26	0.90	2.42
Within Groups	289.52	199	1.45			
Total	291.04	203				

Appendix I

Summary of Experience and Effectiveness Ratings by University Program

Health Sciences and Medical Science

Ratings	Experience			Effectiveness		
Courses	Advanced Functions	Calculus and Vectors	Data Management	Advanced Functions	Calculus and Vectors	Data Management
Average	2.94	3.10	3.60	2.50	2.90	3.93
Percent of 1	25%	19%	7%	25%	24%	0%
Percent of 2	6%	10%	7%	25%	19%	13%
Percent of 3	19%	24%	27%	25%	14%	7%
Percent of 4	50%	38%	40%	25%	29%	53%
Percent of 5	0%	10%	20%	0%	14%	27%
Samples	14					

Biology

Ratings	Experience			Effectiveness		
Courses	Advanced Functions	Calculus and Vectors	Data Management	Advanced Functions	Calculus and Vectors	Data Management
Average	3.75	3.67	3.48	3.70	4.00	3.60
percent of 1	15%	0%	20%	20%	0%	12%
percent of 2	5%	11%	8%	0%	11%	12%
percent of 3	0%	11%	8%	0%	11%	16%
percent of 4	50%	78%	32%	50%	44%	24%
percent of 5	30%	0%	32%	30%	33%	36%
samples	10					

Chemistry

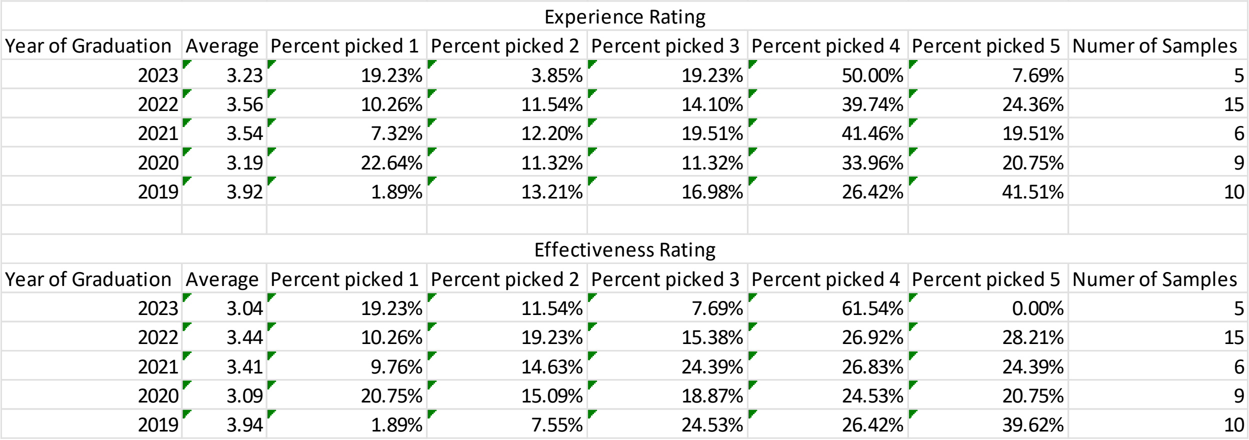
Ratings	Experience			Effectiveness		
Courses	Advanced Functions	Calculus and Vectors	Data Management	Advanced Functions	Calculus and Vectors	Data Management
Average	2.50	3.67	3.10	2.92	4.11	3.25
percent of 1	25%	0%	5%	17%	0%	0%
percent of 2	42%	33%	40%	17%	0%	30%
percent of 3	8%	0%	15%	33%	22%	35%
percent of 4	8%	33%	20%	25%	44%	15%
percent of 5	17%	33%	20%	8%	33%	20%
samples	6					

Mathematics and related programs (finance, computer science)

Ratings	Experience			Effectiveness		
Courses	Advanced Functions	Calculus and Vectors	Data Management	Advanced Functions	Calculus and Vectors	Data Management
Average	3.00	3.56	3.40	3.38	3.59	3.80
percent of 1	13%	3%	0%	4%	3%	0%
percent of 2	25%	23%	28%	17%	15%	16%
percent of 3	17%	15%	20%	25%	23%	24%
percent of 4	42%	33%	36%	46%	38%	24%
percent of 5	4%	26%	16%	8%	21%	36%
samples	15					

Appendix J

Summary of Experience and Effectiveness Ratings by Participants' Graduation Years from High School



Experience Rating

Year of Graduation	Average	Percent picked 1	Percent picked 2	Percent picked 3	Percent picked 4	Percent picked 5	Numer of Samples
2023	3.23	19.23%	3.85%	19.23%	50.00%	7.69%	5
2022	3.56	10.26%	11.54%	14.10%	39.74%	24.36%	15
2021	3.54	7.32%	12.20%	19.51%	41.46%	19.51%	6
2020	3.19	22.64%	11.32%	11.32%	33.96%	20.75%	9
2019	3.92	1.89%	13.21%	16.98%	26.42%	41.51%	10

Effectiveness Rating

Year of Graduation	Average	Percent picked 1	Percent picked 2	Percent picked 3	Percent picked 4	Percent picked 5	Numer of Samples
2023	3.04	19.23%	11.54%	7.69%	61.54%	0.00%	5
2022	3.44	10.26%	19.23%	15.38%	26.92%	28.21%	15
2021	3.41	9.76%	14.63%	24.39%	26.83%	24.39%	6
2020	3.09	20.75%	15.09%	18.87%	24.53%	20.75%	9
2019	3.94	1.89%	7.55%	24.53%	26.42%	39.62%	10