Montessori Grade 9 Students and Their Use of an Online Concept Mapping Website: A Case Study Exploration

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Abstract

This study investigated the impact of an online concept mapping website (Concept Maps for Learning, or CMfL) designed to provide targeted formative feedback to students. The aims of this study were to determine the usefulness of CMfL for both teachers and students, as a tool for instruction and self-regulated learning. Additionally, the impacts of CMfL on supporting student learning were observed. This research site of this study was a Montessori high school, and the participating students were enrolled in the Ontario Grade 9 Academic Mathematics course. The educational philosophies deployed at the research site offered independence and flexibility to students with respect to how the Ontario Grade 9 Academic Mathematics course was approached, and therefore matched the self-regulated learning components of the study.

This study measured student achievement across three milestones over the data collection period to analyse any cognitive impact that CMfL had on the participating students. Metacognitive impacts, as well as the students' perception of usefulness of CMfL, were measured through surveys that were administered at the milestone points. Usefulness of CMfL from the teacher's perspective was determined through interviews with the teacher. The participating students and teacher were also provided with the opportunity to provide feedback on how CMfL could be improved through the aforementioned surveys and interviews, respectively.

The evidence collected over the study suggests that CMfL can be a useful tool for teaching and learning in a self-regulated environment, and that frequent engagement with CMfL may can support student learning. However, there is room for improvement that may increase student adoption and aid teaching strategy.

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Introduction

The Ontario Curriculum for Grades 9 and 10 Mathematics, revised most recently in 2005, asserts that “students will need to adapt to changing conditions and learn independently” (Ontario Ministry of Education, 2005, p. 3) due to the pace of change in the world. The curriculum document further explains that “procedural mathematics” such as complex calculations can now be completed quickly and easily thanks to advances in technology, which therefore allows students to focus on understanding mathematics concepts instead of on executing mathematics procedures. Linking independent learning and conceptual understanding of mathematics as two of the key pillars in designing a mathematics course that aligns with the curriculum document, students’ metacognition becomes an emergent theme with respect to success in mathematics. Metacognition can be defined as one’s knowledge of their own skills regarding information processing or learning, as well as knowledge of the nature of cognitive tasks, and coping strategies for these tasks (Schneider & Artelt, 2010). Exploring the theme of metacognition further, self-assessment of one’s own learning skills and reflection upon which strategies are working to support learning (and which strategies are not working) are key factors that students would need to be aware of, and engage in, to ensure that conceptual understanding occurs. Research from both theoretical (Bransford, Brown, & Cocking, 1999) and practical (Donovan & Bransford, 2005) perspectives suggests that metacognition is an important component in promoting deeper understanding of mathematics concepts for students. For educators, Bransford et al. (1999) suggests that “a ‘metacognitive’ approach to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them” (Bransford et al., 1999, p. 18). A metacognitive approach to instruction can be defined based on the context or scenario in which the approach is being deployed. If independent learning is considered the primary concept around which a mathematics course is designed, the metacognitive approach from the teacher's perspective could simply be monitoring of progress. The teacher could make a number of learning tools or strategies available to students, and then leave the students to grow their metacognitive skills by deciding which learning tools or strategies are either most useful for increasing understanding, most useful for aiding in learning or achievement, or some combination of these measures. However, this metacognitive approach may require some precedent regarding students' metacognitive awareness and ability to self-regulate their learning for positive results (such as increased student understanding or achievement) to occur. For students who may be struggling, a metacognitive approach to instruction may be more involved. The teacher may need to provide guidance or structure to students, thereby supporting the students' abilities to understand which learning strategies and tools can support their learning. For students who lack an understanding of their learning processes, schoolwork may be frustrating and unproductive. A metacognitive approach to instruction may help increase student understanding of learning processes and reduce frustration (Hoyt & Sorensen, 2001; Peverly, Brobst, & Morris, 2002).

The framework for building mathematics courses that is introduced in the curriculum document aligns to recently popularized "exploration" or "discovery" style of mathematics and science instruction and learning has been impacting the teaching styles of math educators in Ontario, as well as their interpretations of the curriculum they are expected to adhere to by the provincial government (Brown & Rushowy, 2013). As such, many Ontario teachers have introduced what can be considered "alternative" methods of teaching mathematics in both primary and secondary schools, with varying degrees of success. While there are many methodologies and tools that can be utilized by educators to implement exploratory mathematics into their teaching styles, the overall goal remains to increase student learning. One method of increasing student learning is the frequent use of formative assessment (Clark, 2010). Formative assessment, defined, is the practice in which student achievement is elicited and interpreted by a teacher, learner, or peer from some form of evidence (e.g., a quiz) to make an informed decision about the next steps in instruction. In theory, the information derived from the evidence by the teacher would lead to instructional decisions that would be better than the decisions that would have been made in the absence of said evidence (Black & William, 2009). In action, formative assessment is a collaborative process that engages both students and teachers; participation in a formative engagement process can help with the understanding of students' strengths and weaknesses, their conceptual understanding of a subject, and can aid teachers in improving their instructional methods and help students deepen their understanding and improve their achievement (Andrade & Cizek, 2010, p. 6-7). Two methods of formative assessment that may be used in classrooms are assessment "for" learning and assessment "as" learning. Assessment "for" learning is typically teacher-driven and can be used by teachers to provide descriptive feedback to students. In the assessment "for" learning process, teachers use the assessment information collected to make instructional decisions to support student learning. Assessment "as" learning is student-driven, where descriptive feedback is typically provided to one's self. The purpose of assessment "as" learning is for a student to be able to determine what to do next to support or improve their own learning. The long-term goal of assessment "as" learning is to become a reflective learner, a learner who is able to understand what strategies and tools support their learning process. As such, assessment "as" learning may be considered as a component of a metacognitive approach to instruction.

Researchers have identified consistency and frequency as important to ensuring student success through the use of formative assessment, which has been successfully utilized in mathematics courses for a variety of age groups (Ingec, 2009; Phelan, Choi, Vendlinski, Baker, & Herman, 2011; Wilson, Lyons, & Quinn, 2013). However, time limitations can prevent instructors from being able to effectively utilize formative assessment (Hudesman, Crosby, Flugman, Isaac, Everson, & Clay, 2013; Phelan, et al., 2011). This is particularly true for traditional classes that have set time slots for each class. Some Montessori schools, however, differ in structure from standard schools in public and Catholic schoolboards in Ontario in that students are offered more freedom with respect to timetables. As such, a private secondary school built on the philosophies of Maria Montessori, and associated with the Canadian Council of Montessori Administrators (CCMA) was chosen as the research site for this study.

Dr. Maria Montessori's *Method* is the educational philosophy she developed while working with cognitively disabled orphans in Italy. Her experiences led her to founding a school called The Children's House, where instruction was provided in mixed-age classrooms. These experiences led to her conclusion that her *Method* applied to all children, and the resulting successes she experienced would lead to what is now formally known as The Montessori Method (Colgan, 2016). The foundations of Montessori's *Method* are: (i) that learning be cultivated through use of materials and tools rather than instruction, (ii) that students are free to move about the classroom whilst engaging with materials and instruction, and (iii) that students should have choice in which materials they engage with during learning, and that learning occur at the student's pace (Colgan, 2016). Although freedom of movement and pace were encouraged, Montessori had some limitations in how these facets of her *Method* were to be implemented. Unsystematic or "play-based" experiences were discouraged. Montessori felt that structure was required in early cognitive development. She also believed that independent learning, as opposed to group- or social-based structure, was important. Montessori theorized that independent learning at an early age would develop concentration skills in her students, and that this would, in turn, decrease dependency on teachers, parents, or peers (Colgan, 2016).

Montessori's research and utilization of her *Method* have been documented by many researchers as being beneficial for early childhood education. Gopnik (2009) cited Montessori's research as the basis for discoveries regarding how integral connections between action, perception, and cognition were to childhood development. In fact, Montessori's findings have informed Gopnik's own work in the fields of neuroscience and developmental psychology regarding children in their infant and toddler years. In the sphere of education, case studies, (Cohen, 2016; Corrie, 2015), quantitative analyses (Phillips, 2017, Korfmacher, Spicer, Fitzgerald, Love, Raikes, & Robinson, 2002) and qualitative analyses (Corrie, 2015), have all shown that students that participate in an educational program that is developed in the Montessori tradition show higher than average achievement in academic measures such as standardized tests (Corrie, 2015). However, most of the research centers on students in the early childhood education years (ages 3 to 5). Some studies focus on students in the elementary years, however the age limit for these studies tends to end at 12 years old, which is the top age limit for the "Upper Elementary" category of Montessori students (ages 9 to 12). Since the research site of this study is Ontario, I reviewed the programs offered by Montessori schools in the province by visiting the CCMA website (http://www.ccma.ca/). Most accredited Montessori schools in the region accommodate students up to age 12. The application of Montessori philosophies to secondary school-aged students (defined as ages 13 to 18 for this study) seems to be a combination of a recent development, as well as a niche market given the Montessori school's better-established brand as an alternative option for early childhood education. This begs some broader philosophical questions. Montessori is well documented in her belief that her *Method* can be applied to all students (Montessori, n.d., Colgan, 2016, Seldin & Epstein, 2003), but to this point there has not been much documentation with regards to its success in students of secondary school age. In establishing a secondary school in the Montessori tradition, which of the philosophies should one adapt? All of them? Is that even possible, given the requirements of the curriculum, outlined by the Ontario provincial government, that schools and teachers need to meet? Can Montessori's philosophies of independent learning and systemic approaches to learning be reconciled with the modern "discovery model" of mathematics education?

At the school that data collection took place in the present study (referenced from this point as the "research site"), elements of constructivist and "discovery model" learning theories (foundational pieces of Montessori's Method) dictate the educational philosophy. The constructivist learning theory suggests that learning is an active process that requires individuals to build new concepts through environmental interaction (vonGlaserfeld, 1991). Some of the assumptions of constructivist learning theory are that future learning is influenced by existing ideas and understanding, and that learning is most effective when experiences are contextual and interactive. Literature indicates that use of the constructivist learning theory can encourage self-awareness of learning amongst students, places learning into relevant contexts, and can shift the agency of knowledge construction to students (Cardellini, 2006; vonGlaserfeld, 1991; Yilmaz, 2008). The components of increased self-awareness and agency for students with respect to learning links directly to metacognition, as students are empowered to think critically about their learning practices and processes. Regarding teaching practices, constructivist theory suggests that effective teaching within the constructivist paradigm must take these pre-existing conceptions into account. Further, if these existing ideas are actually misconceptions that are never corrected, students may hold these misconceptions into adulthood (Carre, 1993). If misconceptions can be surfaced through the teaching style of the teacher, or through the learning process of the student, they can be used as a starting point during the teaching or learning process. However, it is important to note that knowledge cannot be directly transmitted from the teacher to the student. Active construction of knowledge needs to occur and may take many different forms. At the research site, students learn concepts from working with materials and tools, researching, or in objective-based scenarios rather than receiving direct instruction as much as possible. This aligns with many of Montessori's philosophies (Seldin & Epstein, 2003). Based on the teacher's professional judgement, and in correlation with the mandates of the curriculum, students are provided with instruction through a variety of media and can submit assignments in non-traditional manners. For example, an English unit may focus on podcasts, and students' homework assignments may take the form of audio or video responses to the subject matter (as opposed to something written). Lessons in standard Grade 9 subjects (such as Mathematics, Science, English, and Geography) are offered, but pre-scheduled open blocks of time are available through specific days of the week to work on assignments and explore interests as students wish. These blocks of time are structured in one- to three-hour sessions based on student progress, and are formally know as Independent Work Periods. Independent Work Periods are monitored, in that students must have completed certain requirements in other subjects (determined by the teachers of these subjects) before moving on to working on their desired assignments or hobbies. By offering Independent Work Periods, the research site offers students freedom of choice in how they learn, and the opportunity to move at their own pace, but also adheres to a structure that ensures that students are working through their academic requirements in a systematic manner.

The components of independence, student-driven learning, and tool-based learning, suggested by constructivism contribute to the make up the Montessori philosophy. These constructivism components, alongside learning theories and teaching practices that utilize formative assessment and support the development of metacognition, make up the educational philosophy of the research site. As such, I suggested that an online concept mapping website be explored as a novel teaching/formative assessment tool to engage students in an exploratory learning style, whilst adhering to the following pre-defined criteria:

(i) Ensure that use of the website does not negatively impact students from attaining of government-regulated curriculum expectations with respect to mathematics

(ii) Ensure that students have the freedom necessary to continue adhering to Montessori philosophies

Use of Concept Maps as Instructional Tools

Over the past several decades, concept maps and concept mapping have been shown to be useful as a methodology for research and instruction. Novak, Gowin, and Johansen (1983), through the basis of Ausbelian learning theory (Fitzgerald, Ausbel, & Kuhlen 1963), proposed that “a key factor for potential success in meaningful learning is the framework of relevant concepts or propositions the [learner] possesses” (p. 625). Meaningful learning, in this context, refers to a deeper understanding of the subject at hand; in other words, the ability to take knowledge in its conceptual form, and apply it. Concept maps are technically defined as a series of concept or ideas (represented by a word or phrase), with linkages connecting concepts that the author of the concept maps perceives to be related. These linkages are labeled with prepositions, providing context for the relationship being illustrated. However, subsequent research has considered concept maps more generally to include any node-link knowledge representations (Trumpower & Sarwar, 2010; Turns, Altman, & Adams, 2000; Bramwell-Lalor & Rainford, 2014; Buldu & Buldu, 2010). This more general consideration of concept maps is what I have adhered to for my study.

Whether teacher-created (Jacobs-Lawson & Hershey, 2002) or student-centred (Buldu & Buldu, 2010), what makes the use of concept maps effective is that they require the learner to critically consider the organization of the knowledge, the relationships between concepts, and to assimilate this new knowledge into their existing understanding of the subject being studied. Utilization of concept maps as a learning tool discourages rote memorization, or fragmented conceptualization due to traditional unit or chapter conclusions that appear commonly in textbooks. Construction of concept maps can allow for meaningful, relevant learning to occur. Instead of reiterating or restating facts, creating concept maps requires students (and teachers) to interact with the subject through exploration of the relationships that exist between concepts. Concept relationships can be questioned and probed, and students may be afforded the opportunity to explain their thinking. This potential discourse between student and teacher may encourage learning autonomy amongst students; students can pose their hypotheses regarding their understanding of concept relationships, and teachers can assess the depth of a student’s understanding by challenging these hypotheses. Requiring students to explain their thinking or reassess their understanding provides an avenue for instruction and assessment in mathematics that is different from the standard assignment/quiz/test cycle. In this way, concept maps can act as a crossroads between conceptual and applied knowledge, while also fitting into the category of “alternative” teaching methods and “exploration” learning. By providing a visual, organized structure within which students can strive to achieve deeper understandings of the relationships between concepts that create a subject, the assumption is that students will be able to apply their knowledge. In other words, students will be able to transfer their learning from a classroom environment into other applicable, real-life contexts. Meaningful understanding of relational, conceptual knowledge will allow for students to solve diverse problems, many of which may be in a mathematical context. Concept maps have been shown to be a flexible learning tool, and the literature indicates that student achievement increases when concept maps are utilized as part of the learning process (Turns, Atman, & Adam, 2000; Koc, 2012; Bramford-Lalor & Rainford, 2014). Figure 1 is a concept map explaining the theoretical basis of concept maps.

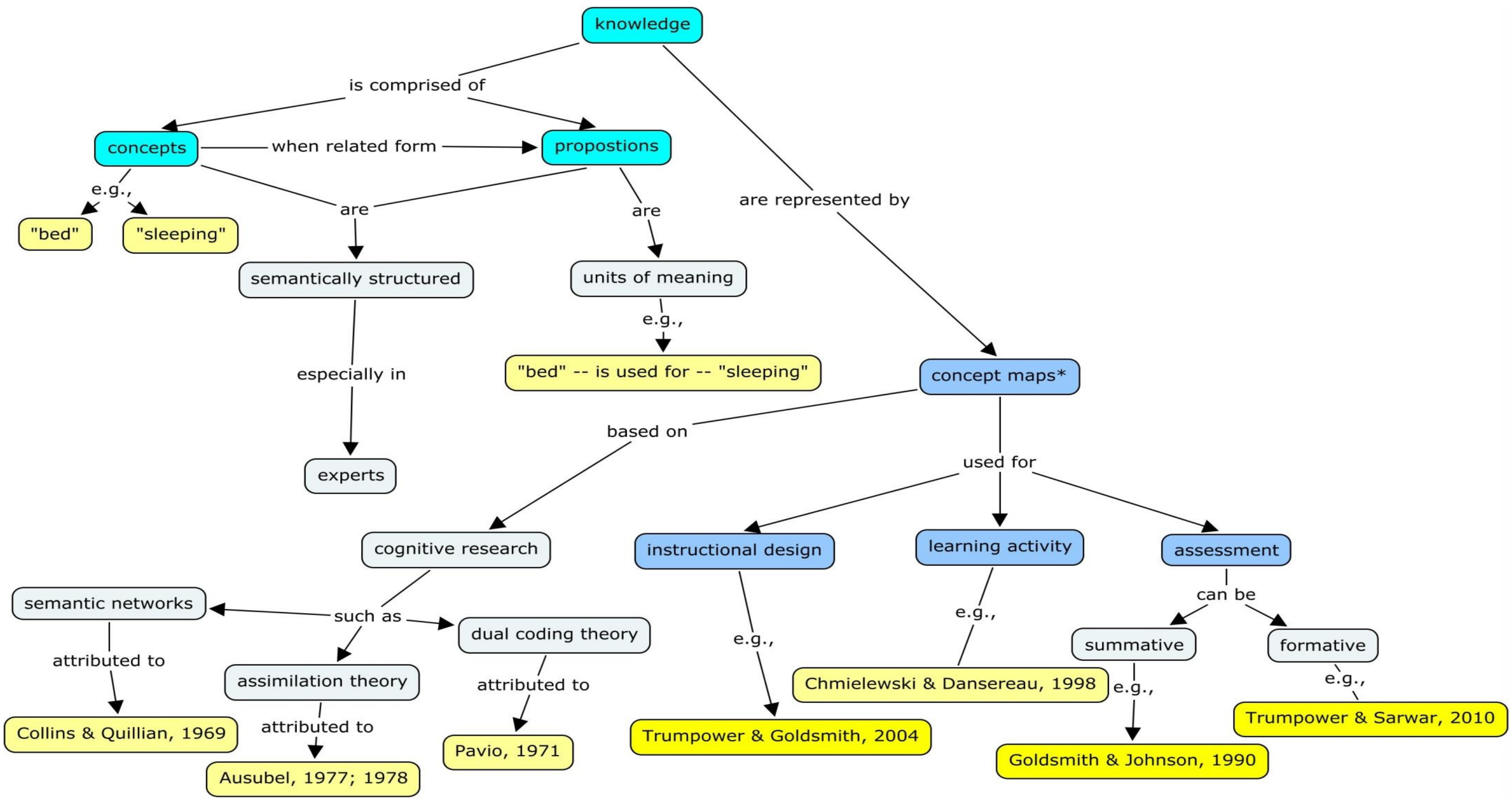

Figure 1 - Concept map describing the theoretical basis of concept maps.

Reprinted from "Formative Structural Assessment: Using Concept Maps in Assessment for Learning," by D. Trumpower and G.S. Sarwar, 2011, *Assessment and Evaluation in the Contemporary Society: Issues and Promises conference*, p. 10

The Concept Maps for Learning (CMfL) Website and the Pathfinder Scaling Algorithm

The Concept Maps for Learning (CMfL) website (http://conceptmapsforlearning.com/index.php) was chosen as the method by which formative feedback would be provided to students using concept maps. CMfL provides students with the ability to have concept maps be automatically generated, based on their understanding of the relationship between pairs of concepts within a subject. CMfL was originally developed as a resource for teachers but is primarily being used as a research tool (Filiz, Trumpower, Ghani, Atas, & Vanapalli, 2015). CMfL is a website, but can be described as an educational technology or tool to support student learning due to the way it is used in this study. The "engine" of CMfL is the Pathfinder Scaling Algorithm. This algorithm is programmed into the website and drives the automated generation of a Pathfinder network based on student inputs. The Pathfinder network, in the context of CMfL, is actually the concept map itself. This methodology allows for a complete concept map to be created, ensuring that all concepts are considered and accounted for in the structure of the map, and removing the temptation to have the map be visually appealing as students do not participate in the actual "sketching."

The Pathfinder Scaling Algorithm adheres to the Pathfinder Network Scaling structural modeling technique. The technique was originally developed for proximity data analysis in psychology by Schvaneveldt, Dearholt and Durso (1988). Generally, Pathfinder algorithms take estimates of the proximities between pairs of items as inputs, and determine which links are deemed to be important based on these proximities. The proximities that will be utilized must be defined by the researcher. In this study, the proximities used to develop the concept map(s) are programmed into the browser-based CMfL website based on the inputs made by the students (their ratings of concepts). Once the most important links are determined through the Algorithm, the concept map (a Pathfinder network consisting of a series of nodes and links) is generated. Nodes are connected links, indicating a relationship. As mentioned, the inputs for the Pathfinder Scaling Algorithm are the ratings that students have entered. These inputs are based on pairs of concepts the students are presented with. The proximities have been translated into relatedness ratings, where students rate pairs of concepts based on scale of 1 (completely unrelated) to 5 (highly related). Once the students have completed the relatedness rating exercise, their concept map is automatically generated.

The Pathfinder algorithm is utilized in this instance to determine the strength of the relationship between concepts. This can be represented through proximity between concepts, weight of the arc that connects concepts, or a combination of the two. The Pathfinder algorithm is also advanced enough that secondary relations can be represented. The algorithm calculates how related pairs of concepts are based on the pairwise relatedness ratings entered by the students. To reiterate, students rated pairs of concepts from a subject on a Likert scale of 1 to 5. In this scale, 1 referred to the pair of concepts being completely unrelated, while 5 meant that the concepts are strongly related. The Pathfinder scaling algorithm took all of the ratings for concept set that the students had entered and built a structural representation of the students' knowledge in the form of a concept map. Concepts that (according to the students' ratings relative to each other in the concept set) were related were connected by a solid line. The CMfL website would then compare the student generated concept map to a pre-loaded referent concept map. Links that were generated on the referent map, but were missing on the student concept map, were represented as dotted lines. This is the "secondary relation" that was mentioned earlier.

CMfL provided a final output, which was a comparison between the concept maps generated by each student. Theoretically, this quantitative data should have revealed improvement. Initial studies in the use of relatedness ratings to produce Pathfinder networks (concept maps) with the purpose of providing feedback have shown positive results (Trumpower & Sarwar, 2010), so I had posited that concept maps that are generated using the same Pathfinder Scaling Algorithm for a Grade 9 mathematics class will result in similar findings.

Purpose of this study

In this study, I analyzed the use of an online, automated concept mapping website (CMfL) as a novel tool for providing on-demand formative feedback in a Montessori grade 9 mathematics class. CMfL was chosen for its accessibility and ability to provide formative feedback on-demand, which is in agreement with Montessori philosophies regarding independent learning and discovery. CMfL was used independently by the students, allowing for them to dictate the pace of their learning, once again in agreement with Montessori philosophies. Since the students decided how they would be engaging with CMfL in terms of how they used it as a learning aid, there was an inherent metacognitive factor at play. In theory, as the students grew more comfortable with CMfL, they would have been able to determine how to most effectively deploy it during their individual learning practices. This study focused on mathematics because this subject contains a balance between conceptual and theoretical learning, as well as the application of this knowledge in the form of mathematics-based problem solving. The configuration of the formative feedback provided by CMfL allowed for the effectiveness of concept maps as a learning tool for both theory and application to be measured in this study. CMfL was also chosen due to the research site’s emphasis on independence and exploration as a learning approach for students. The intersection between the philosophies of the research site and the design of CMfL, along with how CMfL was leveraged, provided the opportunity to analyze the following research questions:

(i) How does the use of an online concept mapping tool for formative feedback support student learning in a Grade 9 mathematics class that emphasizes independent study?

(ii) To what extent is the participating teacher able to use the students' digital concept maps to assess student strengths and weaknesses, and how does the teacher use this assessment information?

The *Design and Methods* portions of this thesis will address how these questions are answered. These questions are relevant in the context of the modern education landscape for several reasons. Although this study took place in an environment where independent study and exploration of a subject is specifically emphasized, the emergence of online courses at both high school and post-secondary educational levels, as well as the popularity of self-study resources such as Khan Academy (Smith & Harvey, 2014) and YouTube (Fralinger & Owens, 2009) suggests that the traditional learning cycle of lecture-study-test is being disrupted by students' ability to access different types of learning resources on demand. Like Khan Academy and YouTube, the CMfL website can be accessed by students at any time. However, CMfL has the advantage of being able to provide specifically designed formative feedback to students, something that a resource like a generic YouTube instructional video cannot provide.

From the teacher's perspective, the ability to track student progress and assess strengths and weaknesses are imperative to ensure that appropriate intervention is being applied when necessary. If students are engaged in a primarily independent program, it can be difficult to track their progress outside of scheduled class hours or frequent assignments, quizzes, or tests. CMfL provides the teacher with the ability to track students' progress in several ways. Firstly, the website can help the teacher track a student's sequential progress through a course. By having a map (or maps) for each unit of study, the teacher can ensure that a student is covering the prescribed material. The teacher can also use the concept mapping website to monitor a student's understanding of the material. This can be done by assessing the maps that a student has generated, both before and after the student has engaged with the automatic feedback.

Conceptual Framework

The conceptual framework of this study centres around supporting student learning. It has been established that independent learning and conceptual understanding are pillars for building mathematics courses in Ontario based on the current mathematics curriculum document published by the Ministry of Education in Ontario. With that said, to support student learning alongside these pillars, students must be able to demonstrate metacognitive skills. One way that teachers and students themselves can support the development of metacognitive skills is through formative assessment, specifically assessment "for" learning and assessment "as" learning (Siegesmund, 2016). A novel way of deploying formative assessment may be through the use of educational technology. This study proposed the use of the Concept Maps for Learning (CMfL) website as an educational technology that can support independent learning through formative assessment. A Montessori School whose teaching and learning philosophies are focused on independent and self-regulated learning was chosen as the research site for this study. Figure 2 is a summary of this conceptual framework.

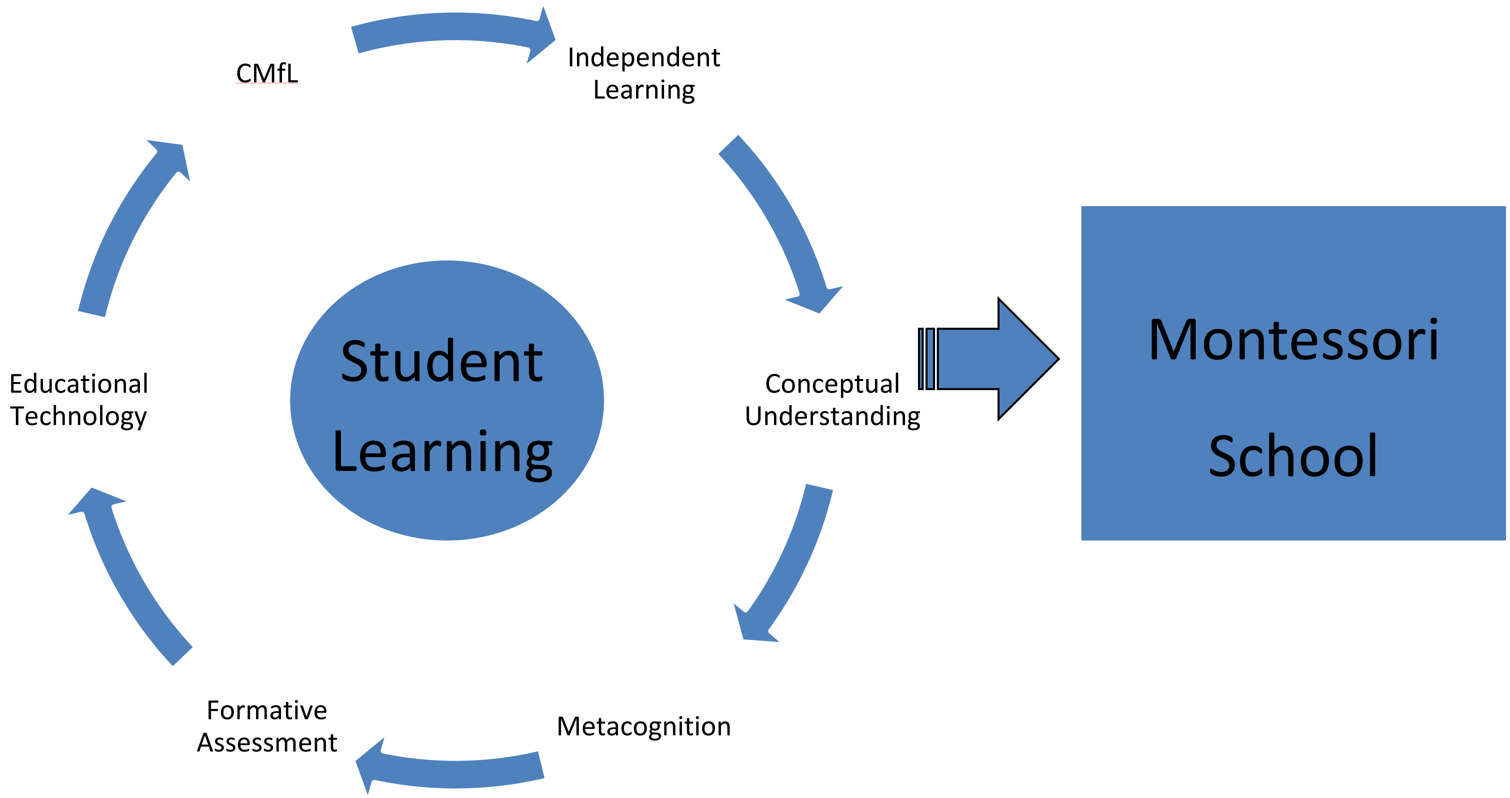

Figure 2 - Conceptual framework of this study

Literature Review

This literature review is structured to establish relationships between mathematics education, formative assessment, and self-regulated learning, to provide evidence for the usage of formative assessment to improve student achievement, and to illustrate the ways in which formative assessment can be integrated into classroom instruction as formative feedback. The purpose of articulating these relationships is to show the adaptability with which formative assessment can be utilized in the classroom setting. Extending this concept of adaptable formative assessment, I have presented evidence of how formative assessment can be used with self-regulated (or independent) learning. This evidence strengthens my assertion that intervention through formative assessment that is embedded within CMfL may improve student achievement, and also act as a useful tool for supporting the development of students' metacognitive skills, while simultaneously augmenting teacher instruction.

While there are numerous examples that illustrate the relationship between at least two (and often all three) of mathematics education, formative assessment, and self-regulated learning, using concept maps to support all three of these ideas to build a cohesive relationship is comparatively unique. The literature review describes how concept maps can be used for mathematics education, how concept maps can be used as a method of formative assessment, and how concept maps can support self-regulated learning. The purpose of illustrating the relationship that concept maps have with mathematics education, formative assessment, and self-regulated learning is to support my assumptions of how CMfL can act as a vehicle to bring these concepts together to build the previously described cohesive relationship. The literature review also shows that concept maps have proven to be valuable as a teaching and learning tool in a variety of school subjects, and that concept maps have been successfully used as formative feedback. Additionally, students who use concept maps as part of a study strategy often perform better in terms of academic achievement. My assumption here is that CMfL can be considered analogous to traditional concept maps such as those drawn with pencil and paper. CMfL as it was deployed in this study, was configured to be used by students as they saw fit. The students determined the value of CMfL to their learning practice. My intention is to show that through CMfL, concept maps can act as a tool that, at least, lead to the same previously established positive relationships between mathematics education, formative assessment, and self-regulated learning, and at most can strengthen or enhance these relationships in regards to usefulness for both teaching and learning. Usefulness, defined for my study, refers to student learning, either as indicated by measures of achievement, student perceptions of learning, teacher perceptions of student learning, and/or teacher perceptions of how well instructional strategy is informed. In the following sections, I summarize the literature that examines the intersection of mathematics education, formative assessment, and metacognition; formative assessment and technology; and concept maps and assessment to support learning and teaching.

Mathematics Education, Formative Assessment, and Metacognition

There are well established links between academic achievement and the use of formative assessment for teaching and learning. Paul Black and Dylan William published a synthesis of 250 studies of formative assessment establishing the finding, and their work remains amongst the most cited when discussing formative assessment as a positive teaching and learning strategy (Black & William, 1998a, 1998b, 2009). When formative assessment is utilized as a regular part of instruction in a classroom, it can result in improved learning with respect to curriculum-based measurement (Fuchs, 1995; Zimmerman & DiBenedetto, 2008).

Specific to mathematics education, many researchers have presented evidence that formative assessment interventions have resulted in positive outcomes for students and teachers across grade levels, and into post-secondary education (Duckor, Holmberg, & Becker, 2017; Rakoczy, Pinger, Hockweber, Klieme, Shutze, & Besser, 2019; Hudesman, Carson, Flugman, Clay, & Isaac, 2011). These "positive outcomes" can be linked to usefulness for both students and teachers. For example, Duckor, Holmberg, and Becker (2017) found that academic achievement improved for a seventh-grade mathematics class when the teacher ("Sevan") integrated a series of formative assessment strategies known as "FA moves" (e.g., "priming" by asking a question that drives discussion, "binning" to categorize student responses, then asking to see which responses more students think are correct) into his/her instructional strategy. Sevan's experiences show that formative assessment has the potential to increase student understanding from the perspective of the teacher, and to help teachers revise their instructional strategies to better meet their students' needs. Essentially, formative assessment can be very useful for both teachers and students, but the conclusions reached in this study required Sevan to be an active participant, analyzing and revising his/her teaching methods, and documenting student responses. This finding is consistent with other research indicating the usefulness that teachers perceive in the ability of formative assessment to support student learning (Bramwell-Lalor & Rainford, 2014; Buldu & Buldu, 2010; Haiyue & Khoon Yoong, 2010).

While Duckor, Holmberg and Becker (2017) showed a teacher's perspective on the value of formative assessment, Rakoczy, Pinger, Hockweber, Klieme, Shutze, and Besser (2019) have shown that students' perception of the usefulness of formative feedback can improve student "self-efficacy" and academic achievement. Self-efficacy of students can be linked to metacognition, in that a student's belief in their ability to be successful may be related to growth in metacognitive skills. However, validation of this growth in metacognitive skills would still be required to definitively state that it had occurred. Rakoczy, et al.'s (2019) study was structured such that at pre-determined intervals, students were given a diagnostic assessment to determine their understanding of the subject at that point in time, as well as a questionnaire to measure the students' feelings about their self-efficacy and the usefulness of the teacher's feedback. Students were divided into an experimental group and a control group. In the experimental group, a formative assessment intervention was administered in response to student-submitted work, while the control group did not receive tailored intervention. At the end of the study period, the same assessment was administered to students in both groups to measure achievement. Analysis of student achievement showed that students in the experimental group generally performed better than those in the control group. Additionally, students in the experimental group felt that the teachers' feedback was more useful than those in the control group. The conclusions of the study suggest that formative assessment in Grade 9 mathematics can be a beneficial form of instruction, and that when implemented correctly students feel that it is useful and are more confident in their ability to perform well academically. Improvement in student achievement suggests that these students' feelings of self-efficacy are linked to growth in metacognitive skills. This finding is consistent with other literature supporting the relationship between student achievement and positive feelings of self-efficacy (Hudesman, Crosby, Flugman, Isaac, Everson, & Clay, 2013; Zimmerman, 2006; Cheung & Slavin, 2013).

Duckor et al.'s (2017) findings regarding usefulness of formative feedback for teachers for informing instruction (assessment "for" learning), and Rakoczy et al.'s (2019) findings regarding usefulness of formative feedback for students to support their learning (assessment "as" learning) align with my assumptions that CMfL can be useful for both teachers and students. Rakozcy et al.'s conclusions about student self-efficacy, supported by increased student achievement, also suggest that effective utilization for formative feedback can enhance metacognitive skills. However, across both studies, it should be noted that active participation from both teachers and students is required to realize positive results.

Establishing that formative assessment intervention is useful from both the teacher and student perspective and that formative assessment can improve student achievement in the right context leads to the question of how independent or self-regulated learning has been used within the appropriate context. Zimmerman (1990, 2000, 2002, 2006), Hudesman, Carson, Flugman, Clay, and Isaac (2011) and Hudesman, et al. (2013) have documented improved academic achievement through the utilization of formative feedback to support independent or self-regulated learning. Hudesman, Crosby, Ziehmke, Everson, Isaac, Flugman, and Moylan (2014) specifically investigated use of formative assessment and self-regulated learning to improve mathematics achievement of students enrolled in baseline developmental mathematics courses in two-year colleges. Data was collected using quizzes that were administered at least once a week. On each quiz, students were asked to predict their quiz grade and enter the amount of time they had spent preparing for the quiz. After that, they were asked to review each question and make a judgement regarding how confident they were about their ability to solve the question (self-efficacy). After completing a problem, students were again asked to judge how confident they were that they had correctly solved the problem. Instructors would grade the quizzes, taking into account students' responses about self-efficacy and study time, provide feedback to students on the quizzes, and use the student comments to change their instruction based on trends in students' perceptions of their understanding and ability. In this study, formative assessment could have been leveraged by teachers to alter instructional strategies, and for students to alter learning strategies and time (assessment “for” learning and assessment “as” learning, respectively). The students’ comments provided teachers with the opportunity to analyze the relationship between the students’ abilities in mathematics and their metacognitive skill levels. Results showed that 79.2% of students passed the class in the semester in which this study occurred, whereas the previous semester saw a pass rate of 63.5%. Additionally, the experiment semester saw a mean grade of 5.2, while the previous semester’s mean grade was 4.1.

Hudesman, et al. (2014) have shown that formative assessment and self-regulated learning can successfully function in concert, but that both instructors and students should be engaged in the process. Teachers need to be able to analyze student work and provide valuable formative feedback, while simultaneously assessing student progress and class-wide trends so that instructional strategies can be modified to meet students’ needs. At the same time, students need to be able to synthesize the formative feedback being provided by teachers to improve their learning practice. A reoccurring theme in some of the highlighted literature is that students need to revise their study strategies based on the formative feedback they receive. In other words, students need to increase their metacognitive awareness.

Formative Assessment and Technology

While the use of formative feedback and independent or self-regulated learning in mathematics has now been shown to yield positive results regarding student achievement, the introduction of technology as the vehicle for delivering the formative assessment has been relatively unexplored to this point. My study is focused on the utilization of technology to deliver formative feedback through concept maps, a subsection of the broader area of technology for delivery of formative assessment. Despite the relatively unexplored nature of using technology to deliver formative assessment, frequency of use of digital learning tools in education has been rising (Hwang & Tsai, 2011; Sung, Chang, & Liu, 2016). Additionally, there is some evidence that suggests that digital learning tools may improve the effectiveness of formative assessment activities in classrooms (Cheung & Slavin, 2013). Faber, Luyten, and Visscher (2017), for example, used a digital formative assessment tool called Snappet to measure mathematics achievement and student motivation in Grade 3 classes.

The Snappet tool is a tablet. Immediately after an assignment is completed on the Snappet, simple feedback is provided to students through the tablet, with adaptive assignments being assigned as follow-up work based on the scores that students achieve. Each time an assignment was completed, the Snappet recalculated the students' achievement and recommended a follow-up assignment. Teachers were able to monitor student progress through their own Snappet tablets. In this way, teachers were able to monitor each of their individual students' progress against specified learning goals. In addition to student achievement, student motivation was measured through the frequency that students utilized their Snappet tablets. Initially the experimental group performed worse than the control group. However, results showed that as the study period continued, the experimental group outperformed the control group. Additionally, within the experimental group, students that engaged with Snappet more frequently outperformed those that used it more infrequently. As this combination of researchers concluded, formative assessment in mathematics education, alongside self-regulated learning (where students' cognitive and metacognitive learning processes were altered) and technology, can aid in student achievement. This finding is consistent in literature (Atas, Trumpower, & Filiz, 2013; Cheung & Slavin, 2013; Coutinho & Bottentuit, 2008)

Concept Maps and Assessment to support learning and teaching

Another major facet of this thesis study is the use of concept maps as a tool specifically for assessment to support learning and teaching. Establishment of use of concept maps to aid student understanding and/or inform teaching strategy is important for my study; my assumptions regarding CMfL and its ability to support student learning or provide value to the teacher as an assessment tool rely on concept maps being able to meet student and teacher needs. The value of the use of concept maps for assessment is featured in abundance in literature. Fields as varied as teacher education (Schall, 2010, Coutinho & Bottentuit, 2008, and Himangshu, Iuli & Venn, 2008), secondary level biology (Bramwell-Lalor & Rainford, 2014), and Grade 8 level mathematics (Haiyue & Khoon Yoong, 2010) have all shown that academic achievement for students increases with the use of concept maps as some form of assessment. I am considering academic achievement a measure of student learning within this context.

Haiyue and Khoon Yoong (2010), for example, posit that concept maps can be used to represent mathematics ideas, since mathematics concepts are inherently interconnected. Their study specifically explored whether the use of concept maps to teach students about the theory behind triangle concepts in geometry is an effective instruction method. In the study, students were given training sessions on effective use of concept maps. Students had been previously instructed in triangle concepts using traditional classroom- and textbook-based teaching methods, and were asked to create concept maps on the subject using blank pieces of paper and a list of pre-determined triangle concepts. Students could add concepts as they saw fit, and the maps could be hierarchical or non-hierarchical. A conceptual understanding test was administered to students one day prior to their completion of the actual concept mapping task, and a correlation between achievement on the conceptual understanding test and the accuracy of the students' maps was found. The concept maps, thus, provided a way for teachers to assess students' understanding regarding the connectedness of concepts, thereby acting as a predictor for areas that may cause struggle as well.

Bramwell-Lalor and Rainford (2014) evaluated the use of concept maps as an alternative assessment tool in advanced level biology classes. In their mixed-methods study, quantitative data came from a researcher-developed standard biology test, and qualitative data came from interviews with students and teachers as well as students' documents (e.g., practice concept maps). The quantitative findings of the study indicated that creation of concept maps as part of the students' study strategy led to statistically significant gains in student achievement on lower- (multiple choice) and higher-order (application questions) cognitive items on the test that was administered. The qualitative data revealed that students and teachers considered concept maps to be an engaging and effective method for conveying information, and that teachers considered concept maps an effective alternative method for assessing understanding. The structure and findings of Bramwell-Lalor and Rainford's (2014) study mirror those of Haiyue and Khoon Young's (2010) study, reinforcing the findings that suggest that concept maps can aid in positive student achievement, and that both teachers and students find concept maps useful.

Coutinho and Bottentuit (2008) utilized concept maps in a post-graduate level education course on research methods for active teachers. The participants in this case were tasked with creating concept maps about course readings using a computer-based tool (CmapTools Software), as opposed to being provided with them. After being trained to use CmapTools, participants created concept maps as part of the course work, and the professor created concept maps as part of their instructional method. Concept maps were shared amongst participants through the course website, where comments and discussion were encouraged by the professor.

The participants' feelings regarding the use of the concept maps were assessed through an online questionnaire that was completed at the end of the semester. The findings from the questionnaire showed that 54% of participants were familiar with concept maps and had utilized them at some point, but that 46% were familiar with concept maps but had not used them. Specific feedback from participants found concept maps to be a motivating tool, and one that allowed them to effectively reflect on their own learning. Although the findings of this study align with those of Bramwell-Lalor and Rainford (2014) and Haiyue and Khoon (2010), I have included it in the literature review due to Coutinho's and Bottentuit's (2008) use of computer-based tool to create concept maps.

Buldu and Buldu (2010) used concept maps as a tool for formative assessment of student teachers. The researchers were investigating the development of participant thinking processes during concept mapping tasks. This method placed the onus of learning on the participants themselves and therefore ties into the independent learning aspects of my study. Rather than exerting control over participant learning, researchers placed the emphasis on group dialogue, negotiation, and knowledge building, with the concept maps used as a discussion catalyst. Researchers assessed students' understanding of conceptual relationships based on their comments during the discussions and provide feedback and reasoning for relationship linkages on the concept maps as part of the discussion. Participants responded to a questionnaire that measured profile, usefulness, and satisfaction. Reconciliation of results of the data collected by the researchers showed that participants found that concept mapping was a satisfactory tool in terms of value, but also that it was useful in reducing learning barriers, stimulating reflective thinking, and increasing participant involvement and dialogue. Buldu and Buldu (2010) concluded the concept maps could inform both students and teachers about potential adjustments in learning and teaching strategies, respectively, when implemented as a formative assessment tool.

The purpose of highlighting several studies that share the same basic finding, that concept maps support student learning, was to show the flexibility of concept maps to act as a tool for formative assessment delivery. Haiyue and Khoon (2010) and Bramwell-Lalor and Rainford (2014) both conducted studies in the middle school to high school age groups (Grade 8 and Grade 12, respectively), but in very different subjects. Haiyue and Khoon (2010) investigated the use of concept maps in a mathematics class, and Bramwell-Lalor and Rainford (2014) conducted their study in a biology class. Both sets of researchers recorded positive results, indicating that concept maps may support student learning in a variety of contexts, which is discussed further in the *Implications for the Field* section of this thesis. Coutinho and Bottentuit (2008) and Buldu and Buldu (2010) investigated use of concept maps with students at the post-secondary level. Once again, both sets of researchers recorded positive results. These findings suggest that concept maps may be useful for formative assessment across many age groups or levels of study. Cutinho and Bottentuit's (2008) method involved a computer-based tool for concept map creation, therefore also suggesting that concept maps can be created (or even just viewed) in different formats while still supporting student learning. Buldu and Buldu (2010) studied the value of concept maps for formative assessment for both students and teachers; the inclusion of how concept maps could affect teaching strategy was unique amongst this collection of literature, which is why Buldu and Buldu (2010) were included.

The literature indicates that concept maps can be used as formative assessment regardless of format and can be valuable for supporting student learning and informing teaching strategy (Schall, 2010, Coutinho & Bottentuit, 2008, Buldu & Buldu, 2010, Bramwell-Lalor & Rainford, 2014, Martinez, Pérez, Suero, & Pardo, 2013, and Turns, Altman, & Adams, 2000). As such, I have assumed that the CMfL can perform similarly. CMfL will generate a concept map based on student inputs, and compare the generated map to a pre-loaded expert concept map. Missing links with the concept maps will be highlighted, and clicking on them will provide instant formative feedback, allowing the student to tackle misunderstandings immediately. The formative feedback provided will be approved by the teacher, ensuring that it is consistent with his teaching strategies. CMfL can be accessed at any time, so the student can receive formative feedback and any time. This provides the student with the opportunity to synthesize the feedback independently before seeking assistance. I believed that CMfL can aid in the teacher's analysis of students' strengths and weaknesses, allowing for teaching strategy changes as deemed necessary. In combination with the conclusions previously outlined regarding the relationships between mathematics, formative assessment, and self-regulated learning (which may result in growth of students' metacognitive skills), I believed that CMfL could act as a bridge between all of these factors that can contribute to positive student and teacher experiences.

Design and Methods

This study was designed as a case study, and used the methodology outlined by Yin (2002). This study required various data collection instruments, and there were several types of data that were analyzed and were used to reach my conclusions. Given the amount of data that needed to be synthesized, Yin's definition of a case study as a "comprehensive research strategy" (Yin, 2002, p.14) was appealing. Yin's case study methodology allows for the investigation of a particular situation that encompasses "variables of interest" rather than interpreting results based on a set of data points. This methodology allowed for me to build my study with the flexibility I required to collect and analyze data but provided the structure I required to keep my results organized.

Adhering to Yin's definition of a case study, each design decision that I made in building my study can be linked to a precedent established by other researchers, as outlined in the *Literature Review* section. The subject of this case study was the introduction of CMfL as a tool for students to receive formative feedback in a self-regulated manner. This study was bounded by time and place, as it occurred over a fixed duration during that data collection period entirely at the research site. Stake has characterized case studies as being intrinsic, instrumental, and/or collective (Stake, 1995), which can be utilized to describe my study. My study began as an intrinsic study, which seeks to learn about a unique phenomenon. In my case, the unique phenomenon was the introduction of CMfL as a tool for supporting student learning at the research site. However, my study developed into an instrumental case study, in which a specific case is used to gain a broader understanding of an issue or phenomenon. My study used the specific phenomenon of the introduction of CMfL to gain an understanding of how CMfL did (or did not) support independent student learning, how CMfL affected formative assessment from the perspective of the teacher, how CMfL impacted teaching practices, and how CMfL may drive growth of metacognitive skills of students.

In this study, my research questions are "how" questions, aligning to Yin's suggestion that case study methodology is best suited to "how" or "why" questions. Yin also suggests that in these scenarios, the researcher has little or no control over behavioural events, and that the boundaries between the phenomenon and the context may not be clearly evident. Therefore, it may be impossible to make generalizations (Yin, 2012). In this study, I had little control over the behaviour and actions of the participating students and teacher. The study was designed so that the students and teacher used CMfL as they saw fit. This study had multiple units of analysis: students' concept maps produced through CMfL, student achievement scores, student survey responses, and teacher interview responses. As such, findings could be drawn through triangulation across multiple data sources. The research design around the qualitative data (open-ended student survey responses and teacher interview responses) was an open-ended, naturalistic, bounded system approach with a thematic analytic component. As there were multiple data sources in this single case study, this research design provided a descriptive single embedded case study design of how six Grade 9 students and their teacher used CMfL to support student learning and inform teaching instruction.

Participants

The participants in this study consisted of two groups: the "expert group" and the student participants. The expert group was made up of one active mathematics and science teacher (who was also the instructor of the course during this study), one former mathematics and science teacher (who will be referred to as the "expert-participant"), and myself. The expert group had all achieved a minimum of a Bachelor's of Education degree at a Canadian post-secondary institution, and had some degree of experience teaching the Grade 9 academic mathematics course in Ontario.

The former mathematics and science teacher in the study was originally the teacher of the Grade 9 mathematics class, but left the research site before data collection began. He remained a part of the study by providing feedback on which concepts would be valuable to include in the pairwise ratings exercise for the development of concept maps, and by participating in the pairwise ratings exercise to help establish the referent maps. The expert-participant also facilitated in transitioning the role of the teacher in the study by helping to communicate what the expectations of the teacher in the study were.

The teacher joined the research site shortly before data collection began. His role included providing feedback on the concepts that would be used in the pairwise ratings exercise, participating in the pairwise ratings exercise to establish the referent maps, and to interact with the students that were participating in the study. Interaction with the students included assigning generic usernames and passwords for the CMfL website to the students, reviewing their maps at his discretion to see if any information could be gleaned that would aid his teaching strategies, and administering and collecting surveys to students after pre-determined intervals during the data collection period.

My role in the expert group was to contribute my own ratings through the pairwise ratings exercise, compile the ratings, and calculate the averages that would be used to generate the referent maps. My ratings were entered first, prior to collecting the contributions of the teacher and expert-participant. None of the three expert group members was aware of the others' ratings.

The student participants in this study were the Grade 9 students at the research site, a Montessori high school in Ontario, Canada. The class consisted of seven students that were progressing through the Ontario Grade 9 academic level mathematics course at an independent pace, with common milestone goals. A milestone is roughly defined as an assessment of some kind, whether formative or summative. In this case, the milestones were a quiz, a unit test, and the final exam. How students spend the time within the unit, prior to the test, studying and learning is primarily their decision. The teacher acts more as a guide or coordinator, stepping in to provide lessons or specific feedback based on student-driven requirements. Of the seven students in the Grade 9 class, six participated in the study.

Consent to conduct the study was received from the School Director, as well as the former science and mathematics teacher, who at the time was the lead teacher at the research site and was going to fulfill the teacher role. The active teacher and expert-participant signed consent forms, agreeing to participate in the study. These forms outlined the expectations regarding their roles, and their respective duties. The letters of information regarding the purpose of the study, consent forms for parents, and assent forms for students, were all distributed to the students by the teacher. The students and their parents were given two weeks to review the letters of information, the consent forms, and the assent forms. If they agreed to participate in the study, the forms were to be returned to the teacher in an envelope. The teacher reviewed each form to ensure that it was signed and to verify which students would be participating in the study, sealed the envelopes, and returned them to me. It was the teacher's responsibility to ensure that data was only collected from students that had agreed to participate in the study. Given the small size of the sample group, having the forms returned in sealed envelopes ensured that the anonymity of the students was maintained.

Data Collection and Instrument Development

There were several data sources that informed the conclusions that I reached. The first dataset was surveys that each participating student completed at the conclusion of a milestone date over the study period. There were three milestone dates, and each participating student completed three surveys. The surveys were completed on paper, and collected by the teacher, who then passed them on to me. Another source of data related to the participating students was their academic achievement over the course of the study period. The teacher provided me with a percentage score for each student-participant at the conclusion of each milestone point. This data was collected over a six-week period between May and June of 2017.

Data was also collected from the teacher. The teacher was engaged with informally three times over the course of the study, primarily to ensure that the teacher was comfortable with using CMfL and that there were no technical issues keeping the students from participating in the study. The teacher was formally interviewed twice over the course of the study. These interviews were recorded and transcribed for the purpose of analysis.

For the purposes of this study, I used completed concept maps to see if any obvious trends were apparent between the first and second maps for the students in the study, although this data was not utilized to derive any conclusions for this study. The students were also meant to use their results from CMfL to measure their understanding of the relationships within a concept set. The teacher had the option to use the students CMfL results to observe trends across student concept maps as well, with the purpose of assessing each student's understanding within the mathematics units.

The ability to measure "usefulness" began with development of determining lists of concepts that maps could be created for. Decisions that were made regarding the methodology and data collection were based on best practices determined from the literature review, as well as input from my supervising professor, the expert-participant, and the teacher. Lists of concepts were developed for Grade 9 mathematics units, namely Analyze Linear Relations, Geometric Relationships, Measurement Relationships, and Optimization. These unit titles and associated concepts were selected from the textbook being utilized for the Grade 9 mathematics course, *Principles of Mathematics 9* (Small, Kirkpatrick, Zimmer, Chilvers, D'Agostino, Duff, Farentino, Macpherson, Tonner, Williamson, & Yeager, 2007).

These lists of concepts (heretofore referred to as a "concept set") were determined by selecting key words or terms from each of the units. For example, one of the terms from the Analyze Linear Relations unit was slope of the line. All three members of the expert group agreed upon the concept sets as being representative of the mathematics unit in question before they were utilized in the study.

Two concept sets were developed each for the Geometric Relationships, Measurement Relationships, and Optimization units. Only one was developed for the Analyze Linear Relations unit. The teacher made the conscious decision to focus on Geometric Relationships, Measurement Relationships, and Optimization, given that the study was running when these units were the focus of study for the Grade 9 students. Additionally, the structure of both the textbook and the teacher's lessons were such that the concepts learned in the Analyze Linear Relations unit would be utilized in the Geometric Relationships; the combined learning from the Analyze Linear Relations and Geometric Relationships units are then necessary to understand the learning that takes place in the Measurement Relationships unit, which finally results in the Optimization unit requiring the combined knowledge gained from the three preceding units.

Once the lists of concepts for each unit were determined, each pair of concepts in a concept set was rated for relatedness by the expert group to produce the referent concept map. The pairwise comparison exercise was provided to the teacher and expert-participant via email, with each pair of concepts presented in one row. The teacher and expert-participant were asked to rate the strength of the relationship between a pair of concepts on a scale of 1 to 5, where 1 meant that the concepts were *completely unrelated*, and 5 meant that they were *highly related*. Once the exercise was completed, the results were submitted back to me. I completed this exercise prior to the teacher and expert-participant, to ensure that the ratings of the other experts did not influence me. The decision to have the input of three experts to create the referent maps was borne of literature suggesting that even experts within a field may hold misconceptions about concepts (Smith, Disessa, & Roschelle, 1994). Further research indicated that although the misconceptions that are held by experts may be different from those held by novices, the problems posed by these misunderstandings are similar, and therefore experts may not provide an accurate visual representation of the knowledge within the field (Perkins & Simmons, 1988).

As a measure to ensure that students remained engaged in the activity of creating the concept map, no more than five concepts were utilized per map. Five was chosen as the appropriate number of concepts for this study as any fewer would not produce a concept map of much value due to the lack of possible pairs, while any more may become monotonous for students, thereby resulting in disengagement which could possibly jeopardize reliability of the results (Goldsmith, Johnson & Acton, 1991). Gronlund and Cameron (2004) recommend that length of testing can increase 10 minutes per grade level. For example, Grade 1 students can be tested for 10 minutes at a time, Grade 2 students for 20 minutes, and so on. Following this logic, students in a Grade 9 class should be able to be tested for 90 minutes at a time. However, given the previously noted monotony the task may engender, as well as CMfL's purpose as a tool for formative feedback (which is more useful with high frequency), it was decided by me and my thesis supervisor that the task take no longer than 15 minutes to complete. The teacher agreed with this decision as well. Since the teacher's course was guided by the textbook, and it was the primary reference tool for the students, the language utilized on the CMfL website for the concepts and feedback was kept consistent with the textbook. To ensure that this was the case, all of the feedback that was delivered through CMfL was reviewed by the teacher.

Once the results were received, they were compiled into one document and compared. Scores that were more than two "rating levels" apart were eliminated. For example, if one expert rated a pair of concepts a 5, the second rated them a 4, and the third expert rated them a 1, the ratings of the third expert were eliminated (Filiz, Trumpower, Ghani, Atas, & Vanapalli, 2015). Once this exercise was completed, the average of the remaining expert ratings was taken to produce one cohesive set of results. This final set of results was utilized to produce the referent concept maps on the CMfL website, with the use of the Pathfinder algorithm.

With the referent maps created, I could see which concepts were related according to the expert group. For each link that existed in each referent map, two types of feedback were created. The first was a textual explanation of the relationship between the two concepts. Usage of textual feedback as a vehicle for formative feedback has been previously proven to be an effective method for communicating conceptual understanding when using concept maps (Trumpower & Sarwar, 2010). An example of the formative textual feedback that was provided in the first set of concepts for Analyze Linear Relationship is an explanation of the relationship between the concepts "slope y-intercept of the line" and "slope of the line":

The slope y-intercept form of a line is expressed as the equation $y = mx + b$. In this form, the variable m represents the slope of the line. That means that when the equation of a line is expressed in y-intercept form, you can immediately determine what the slope of the line is by observing what the value of m is.

The second type of feedback provided was an example problem that illustrated the relationship between the two concepts. The example problem used to illustrate the relationship between “y-intercept of the line” and “slope of the line” was:

Determine the slope and y-intercept from the following graph, and express the equation in slope y-intercept form.

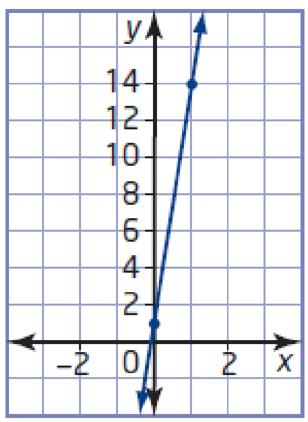

Figure 3 - Example problem as formative feedback

In previous studies that utilized the CMfL website, the secondary feedback provided was usually in the form of a video, website link, or example (Trumpower & Sarwar, 2010, Trumpower, Filiz, & Sarwar, 2014). The teacher in the study wanted to ensure that the student participants were actively engaging with the material, and therefore decided that the secondary feedback should be an example problem that illustrated the relationship between the concepts. From my perspective, providing an example problem was keeping with the theme of the intersection of conceptual knowledge and applied knowledge. The textual feedback could help aid in the acquisition of conceptual knowledge, and the example problem could help with acquisition of applied knowledge. For the participating students, seeing both types of feedback within the context of CMfL could theoretically help with understanding the intersection between conceptual and applied knowledge. Each problem had a full solution, which was made available to the students upon request to the teacher. The teacher collaborated on or reviewed the feedback that was created to ensure that it was consistent with the its presentation in his instruction and the textbook. Towards the end of the period of study, the teacher made the textual feedback and example problems (along with the solutions) available to the students as supplemental study materials in preparation for their final exam. The sequential process for getting CMfL set up for my study is summarized in Figure 4.

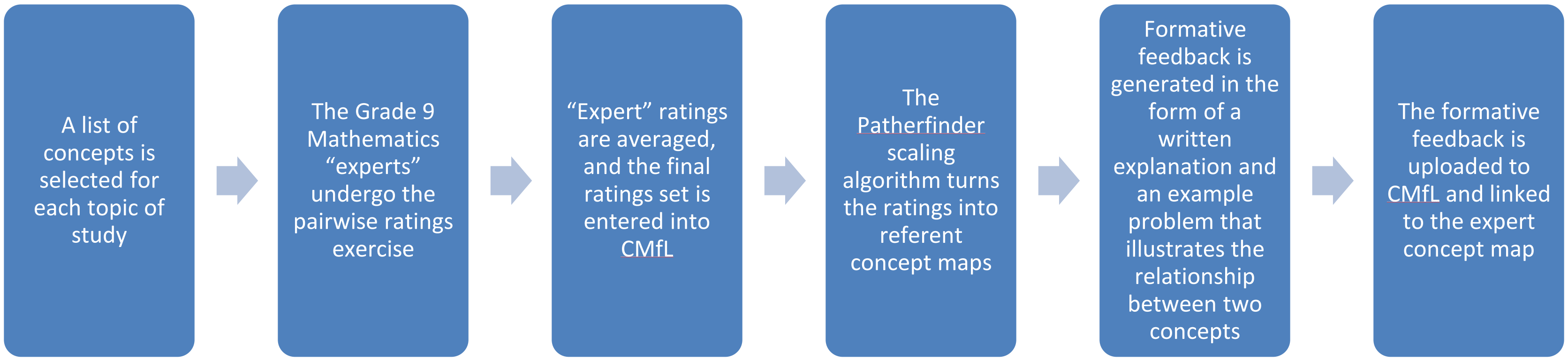

Figure 4 - Sequential process for setting up CMfL for this study

Once the CMfL website was loaded with the referent concept maps, logins and passwords were created for the student-participants, and the website was made available to them. The usernames that were created were generic and were assigned to the students by the teacher. This way, the teacher was able to track progress for each student, but their personal information (such as names or gender) was protected from me as the researcher. Once the students started using the website, the teacher and I met once every two to three weeks over the course of the period of study, based on mutual availability and/or the completion of a milestone exercise. In total, including the final interview, we met five times over the course of the study.

For ease of discussion, I have assigned pseudonyms to each participating student. Table 1 should be used for reference through the course of this thesis:

Table 1
Participating students' pseudonyms

CMfL Designation	**Associated Pseudonym**
Student01	Don
Student02	Roger
Student03	Peggy
Student04	Megan
Student05	Stan
Student06	Betty

The CMfL website was configured so that the students participated in the pairwise ratings exercise twice each for each concept set. Upon completion of the pairwise exercise the first time, the CMfL website automatically compared the concept map generated by the given student’s rating to the referent concept map.

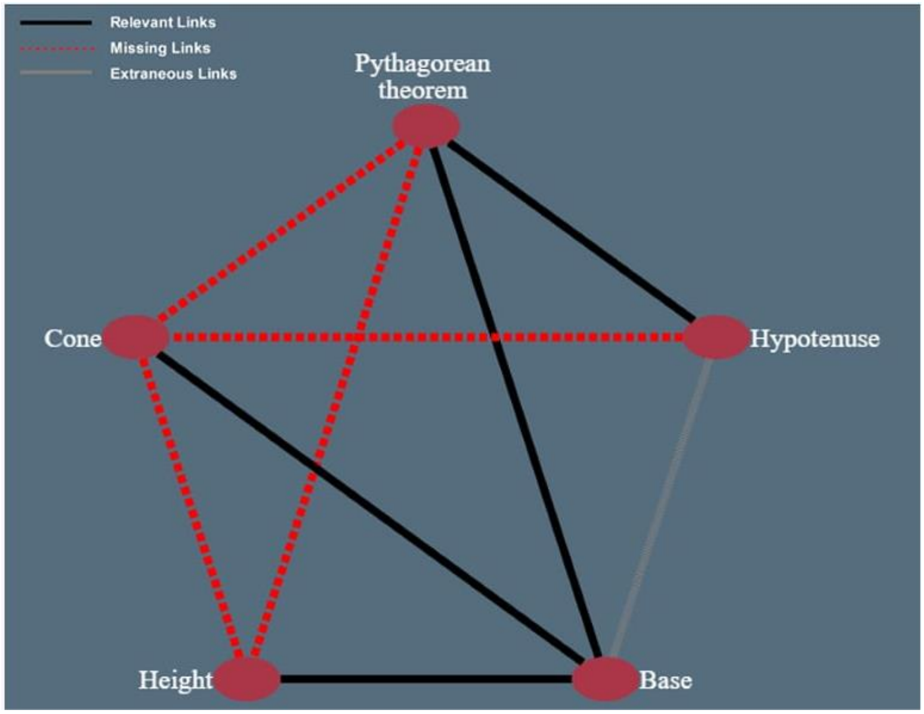

Figure 5 - Example of first attempt for concept map

An example of Burt's first concept map in the Measurement Relationships – Set 1 concept set can be seen in Figure 4. After comparing the student's concept map to the referent map, the CMfL website highlights "relevant links," "missing links," and "extraneous links." Relevant links, shown in solid black lines, appear between concept pairs are that both the student and experts have identified as being related to some degree on the previously described 1-to-5 likert scale. Missing links appear as dotted red lines, and occur when the student has not identified a concept relationship as being related, but the experts have. Messaging on the website prompts student to click on the missing links to obtain feedback. For this study, this is defined as the automated, on-demand formative feedback for the students. If the student clicked on a missing link, they would have the ability to read a textual explanation of why the two concepts are related, and be provided with an example problem to attempt that illustrated the relationship. Finally, extraneous links, shown in solid grey lines, appear when students have identified a concept relationship as being related, but the experts have not. Extraneous links are still considered errors, and are calculated into the final score the student receives after completing one of the concept mapping exercises.

After the first concept map is generated, students were instructed to engage with the concept map by interacting with any of the automatically generated feedback, and by analyzing their relevant, missing, and extraneous links. Once the student is satisfied with their interaction(s), CMfL's next step is to have the student go through the same pairwise ratings exercise again. Once the student completes this step, a second concept map is generated.

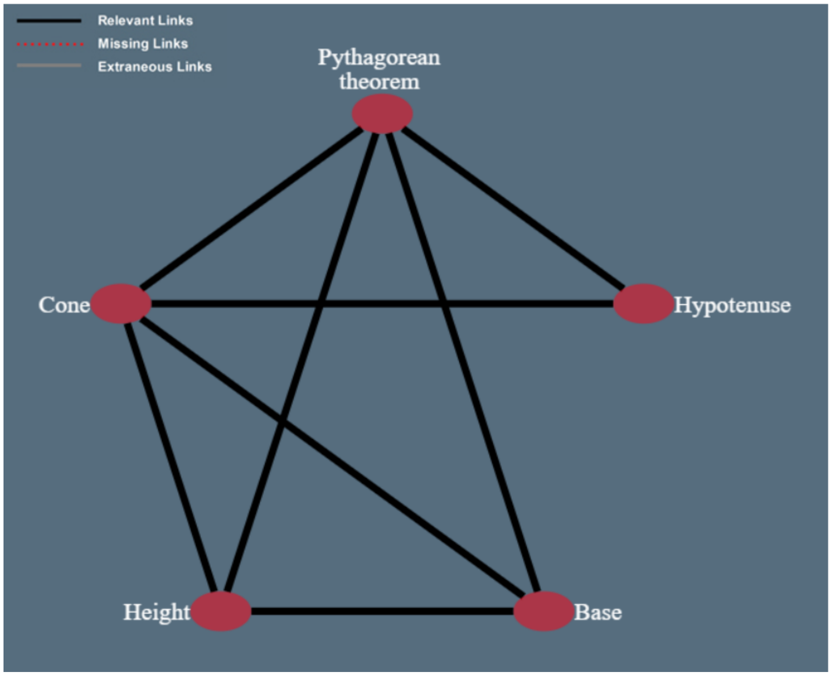

Figure 6 - Post-automatic feedback concept map

An example of Burt's second concept map in the Measurement Relationships – Set 1 concept set can be seen in Figure 5. Once again, relevant, missing, and extraneous links will appear based on the students' ratings and generated concept map in comparison to the expert concept map. At this point, both concept maps are available to the students, so that they can have a visual representation about how their understanding may have changed. Additionally, the website provides a scored analysis to quantify a student's potential improvement.

	Your First Concept Mapping	Your Second Concept Mapping
The number of Relevant Links	4	8
The number of Missing Links	4	0
The number of Extraneous Links	1	0
Your Score	0.44	1

Figure 7 - Example analysis of first concept map vs. second concept

As can be seen in Figure 7, the CMfL website provides a score based on the number of relevant, missing, or extraneous links found in the students' maps. The highest attainable score is 1, or 100%, which is achieved by capturing all relevant links, and not having any missing or extraneous links. This process is repeated for each concept set, resulting in two concept maps (first attempt and post-automatic feedback) for each concept set. Figure 8 is a summary of how the students engaged with CMfL over the course of this study:

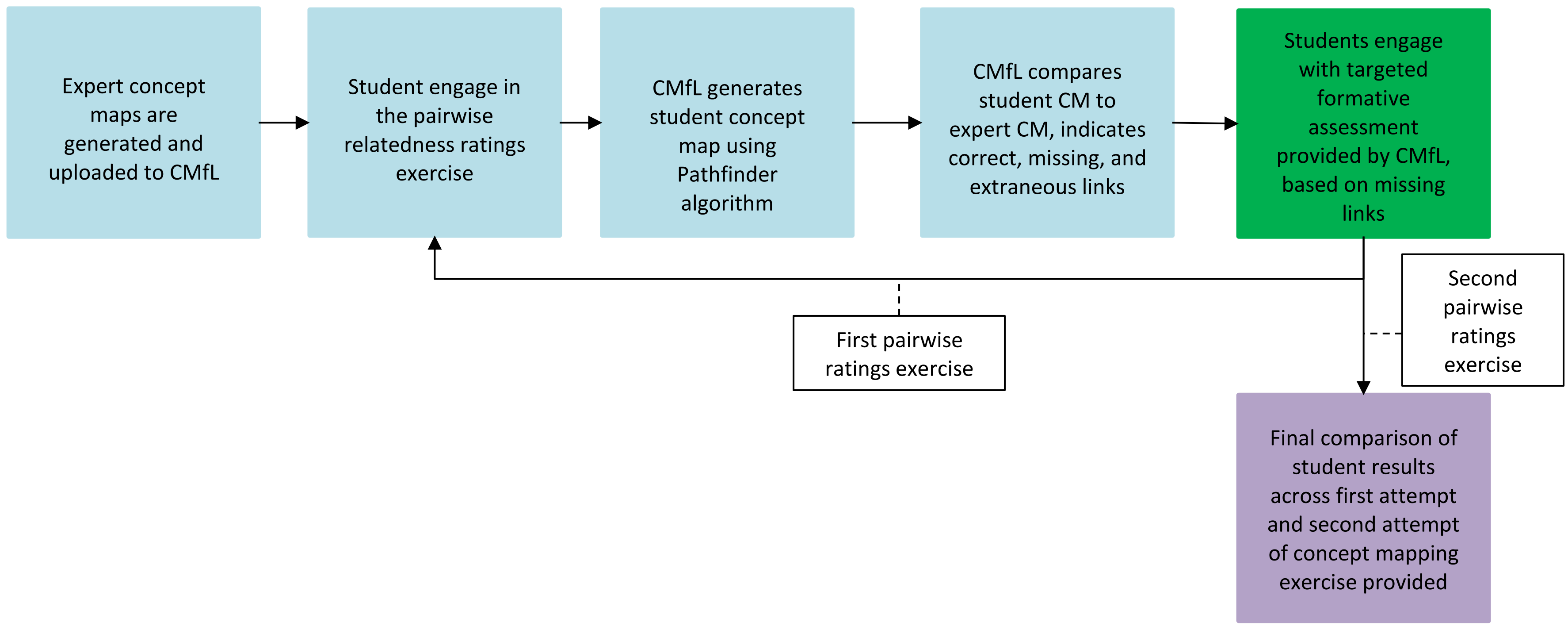

Figure 8 - Summary of the ideal student engagement process with CMfL

Data Collection from Student Surveys and Teacher Interviews

A summarization and timeline of the data collection process for the student surveys and teacher interviews is included in Figure 9:

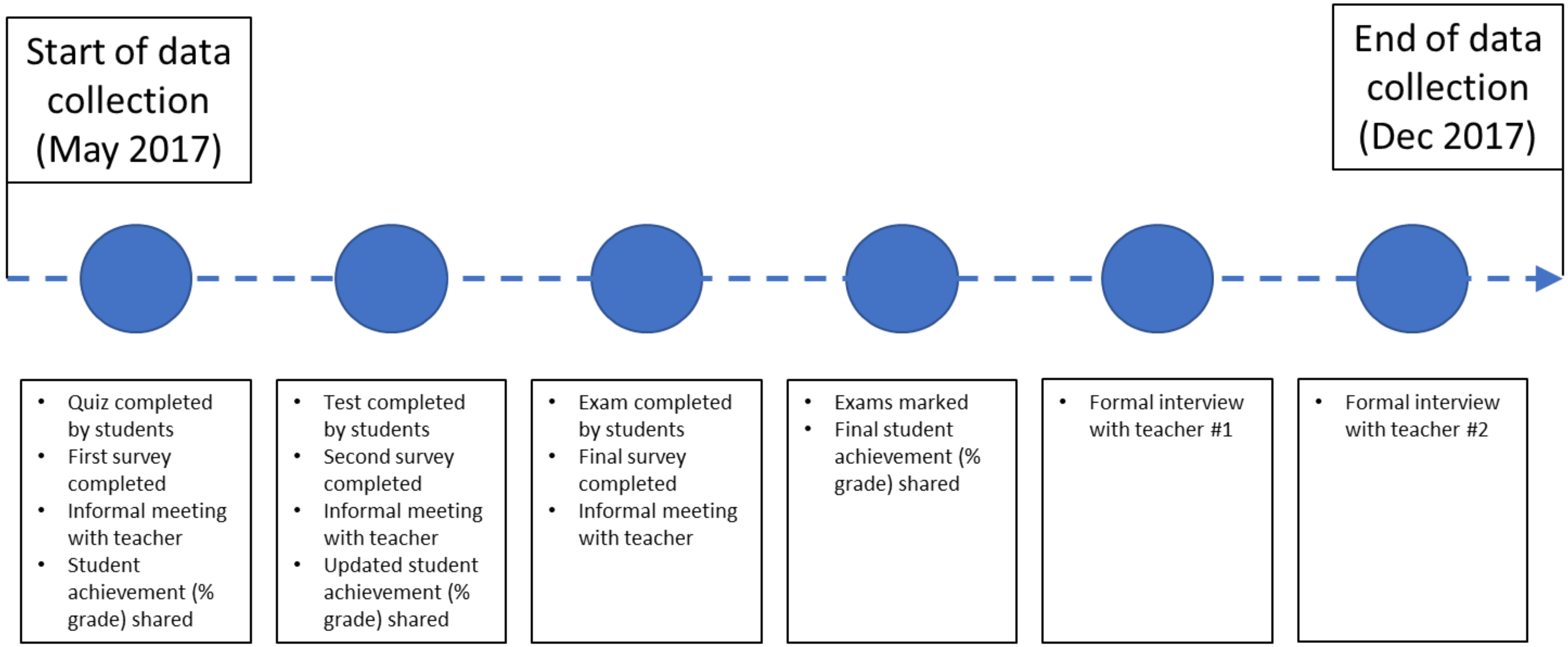

Figure 9 - Timeline and sequence of events for data collection

The students completed surveys at the aforementioned three milestones over the course of the study period. The survey questions were developed by me and reviewed and approved by my thesis supervisor and committee. The purpose of the first two surveys was to gauge the students' opinions on the usefulness and value of CMfL as a learning tool, and to determine if they felt the students had learned something from their use of CMfL. The final survey also examined these aspects but was expanded to allow the students to share what they liked and disliked about the website, as well as any specific improvements they might suggest. The students were identified on the surveys by their usernames on the CMfL website to maintain their anonymity. The teacher collected the surveys in an envelope and sealed them, so that the results were not available to him. In this way, it allowed the teacher to remain unbiased.

The surveys were designed to provide quantitative data regarding students' perceptions of the usefulness of the CMfL website as a tool for their learning. The questions were based on best practices for authoring survey questions and administering surveys, as per *The Practice of Survey Research: Theory and Applications* (Ruel, Wagner, & Gillespie, 2006).

Due to the small sample size of the student population, the data derived from the surveys can be used to observe individual results, as well as to extrapolate potential trends. Common themes across the survey results were analyzed, from which conclusions about the usefulness and effectiveness of the CMfL website were drawn.

The surveys were administered by the teacher, using a paper and pen method. This was done to ensure that the students completed each survey. The sample size of the group allowed for paper surveys to be effective, since the results that were collected could easily be transferred into an electronic format (in this case, a spreadsheet) for analysis of both individual and group trends. As mentioned, students identified themselves on the surveys by their provided aliases (e.g., elementstudent01), which allowed me to compare a student's survey results to their concept maps on CMfL when searching for connections between the data.

The data collected from the teacher consisted of informal and formal interview responses. The teacher and I met three times prior to the final exam, and twice after the final exam. During the meetings that occurred prior to the final exams, discussion was informal. Data was not explicitly collected during these sessions; their purpose was to ensure that the students were on track and engaging with the CMfL website, that the teacher had the resources and support he needed to ensure that the study was proceeding without any major obstacles, and to discuss any trends that the teacher may have been observing regarding student use of CMfL or changes to instructional approach. We also focused on the progress the students were making through the exercise in terms of completing their concept maps. Since the study had only six participants, the teacher was able to assess all concept maps that had been completed by each student at the time of our meetings, and discussed potential interventions that would be tailored for students based on his findings from the concept maps. As the teacher preferred a more applied approach to mathematics learning, the feedback that was provided to students was often in the form of example problems. Completion of these problems was entirely at the discretion of the students, although the teacher was responsible for trying to ensure that students completed all of the CMfL-based exercises. Given the fundamental philosophy of independence in learning that separates the research site from most high schools, this proved to be difficult, and will be discussed in further detail in the *Findings* section of this thesis. These sessions were also used as an opportunity for relationship building between myself and the teacher. I wanted to develop a rapport with the teacher, to ensure that should the opportunity arise to continue or further evolve this study, he would be willing to return in a similar capacity.

The teacher was interviewed twice in a formal capacity. These interviews were recorded, and transcripts of both interviews were created. The questions asked in these interviews were reviewed by the thesis supervisor, with the purpose of determining the following:

1. How the teacher's impressions of how useful CMfL was from the perspectives of both the teacher and the student. In other words, how useful it was as a teaching tool and as a learning tool.
2. How the teacher perceived the effectiveness of CMfL as a tool for providing formative feedback to students without intervention from the teacher.
3. How the CMfL website affected the teacher's instructional methods or teaching style.

The first of the formal interviews that I conducted with the teacher was purposefully set after the final exam, and after final grades had been tabulated. That way, if the teacher had any final comments around the CMfL website with regards to usefulness for students and teachers, and how effective (or ineffective) it was for formative assessment, he would have the opportunity to share these thoughts. This interview focused on the teacher's impressions of the CMfL website, both first impressions and after use by the students. The interview questions were also crafted so that the teacher could voice any strengths and weaknesses he had identified with the website, potential improvements, as well as overall usefulness from the student and teacher perspective. Finally, the interview questions prompted the teacher to assess the usefulness of the website as a tool to assess student strengths and weaknesses, and therefore develop strategies around how to help students with their misconceptions.

Upon analysis of the transcript of the first formal interview with the teacher, it became apparent that there were more data that could further inform some of my conclusions about both the teacher and student experience with the CMfL website. However, to make this data explicit, a follow-up interview would need to occur. A second set of interview questions was drafted that focused on information from the first interview, such as specific examples of student success with CMfL, and any changes to teaching style that may have been affected using CMfL.

The formal interview data was analyzed using coding methodology. Initially, I planned to utilize a set of codes that were derived from the research questions and the key concepts of this study. The first set of codes I tried to utilize were *Desire*, *Formative Feedback*, *Usability*, *Teacher*, *Student*, and *Context*. I felt that these codes reflected the research questions I had investigated and would produce thematic results for analysis. I then began by analyzing the first interview; I focused on key words or phrases that were descriptors in the teacher's responses. For example, the teacher at one point described CMfL as "easy to use," for both teachers and student. I coded this as *Usability* first but felt that the *Student* and *Teacher* codes were also applicable. In another example, the teacher stated that CMfL needed to have a way to indicate that extraneous links had a "negative connotation," which I coded as *Formative Feedback*, *Student*, and *Context*. Continued analysis of the teacher's interview responses revealed to me that the developed codes were too flexible in some ways, and too restrictive in others. Codes such as *Teacher* and *Student* could refer to usefulness, the teacher's observations, or the students' academic achievements from the perspective of the teacher. A code like *Usability* was restrictive as it referred to the teacher's and students' ability to use CMfL, without capturing the specific usefulness of CMfL. The interview questions were also developed prior to the codes, without the codes in mind, which suggested a fundamental misalignment between codes and questions. Thus, this set of codes was completely revised and re-developed. The methodology advocated by Glaser (1978), wherein none of the data is pre-coded until it has been viewed, and an effort has been made to determine how the data functions within the context of the study, was instead considered.

According to Miles and Huberman (1984), this more "grounded" approach allows for the researcher to apply more specific codes to their data, and allows for codes to be more open-minded and context-sensitive. As this study occurred in a very specific type of educational environment, I decided to adopt an emergent set of codes that were customized to the context of the study. Revision of the codes continued as analysis of both formal interviews progressed.

The set of codes utilized were *descriptive codes*, and acted as an analogue for attributing sections of the transcribed text into categories that align to the initial findings from the analysis of students' results. Although the coding process can often result in a set of codes that is more explanatory, further coding analysis was deemed unnecessary given that the codes allowed for the teacher's interview results to act as further evidence to the initial findings that were derived from the student results. The teacher's interview results ended up providing more commentary and explanation for the student results, and in fact provided some further insight into how CMfL could have been more effective. The emergent themes from analysis of the student results were Motivation, Cognition, Metacognition, and Usefulness. In analyzing the teacher interviews, I realized that Motivation and Usefulness applied to participation from the students and teacher, and therefore differentiated between them. The final set of codes utilized are defined in Table 2:

Table 2
Codes and associated definitions

Code	**Definition**
MOT/Tea	The motivation for the teacher to use CMfL
MOT/Stu	The motivation for students to use CMfL
COG	The cognitive learning faculties that CMfL enabled
META	The metacognitive learning faculties that CMfL enabled
USE/Tea	The usefulness of CMfL for teachers
USE/Stu	The usefulness of CMfL for students

Findings

As there were several sources of data, the findings have been divided between data that was collected from the participating students and data that was collected from the teacher. The students' data comes from their survey results, as well as the fluctuations in their academic achievement over the six weeks that they participated in the study. The teacher data came from the formal interviews that were conducted. Integrated findings are also reported; these are an amalgamation of the data from the students and the teacher.

Student Surveys and Academic Achievement

Each question posed during the student surveys, as well as the results of the question per survey, is represented in Figures 8-14. Questions 1 through 5 were posed on each of the three surveys that students participated in. The questions were represented graphically so that any trends regarding students' feelings about use of CMfL would be observable. Question 6 was only asked in surveys 2 and 3, as what the question was measuring a factor that was only prevalent after the second milestone had passed. Finally, question 7 was asked only on survey 3, again because it was measuring a facet of the study that would only be relevant after the third milestone.

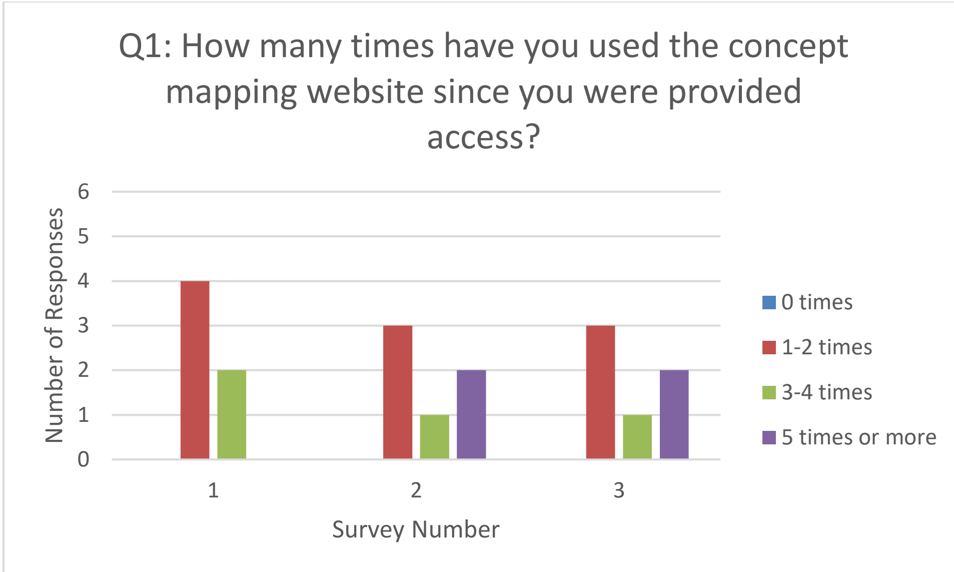

Figure 10 - Results of Question 1 across all three surveys

The first question posed to the students was, “How many times have you used the concept mapping website since you were provided access?” This question was posed so that inferences could be made from two perspectives. Firstly, this question could be an indicator of how useful students felt that CMfL was. If students used CMfL more frequently, then my initial assumption was that they found it useful. Secondly, I wondered if there was a relationship between use of CMfL and student achievement. Based on my review of relevant literature, I posited that students that used CMfL more often may perform better academically.

On the first survey, a majority of the students (n=4) responded that they used CMfL 1-2 times, and the other two students responded that they used CMfL 3-4 times. On the second survey, while half of the students (n=3) still responded that they used CMfL 1-2 times, one student responded that they used CMfL 3-4 times, and two students responded that they used CMfL 5 or more times. Thus, usage increased for some students. The same pattern of reported usage seen on the second survey was maintained on the third survey (see Figure 10).

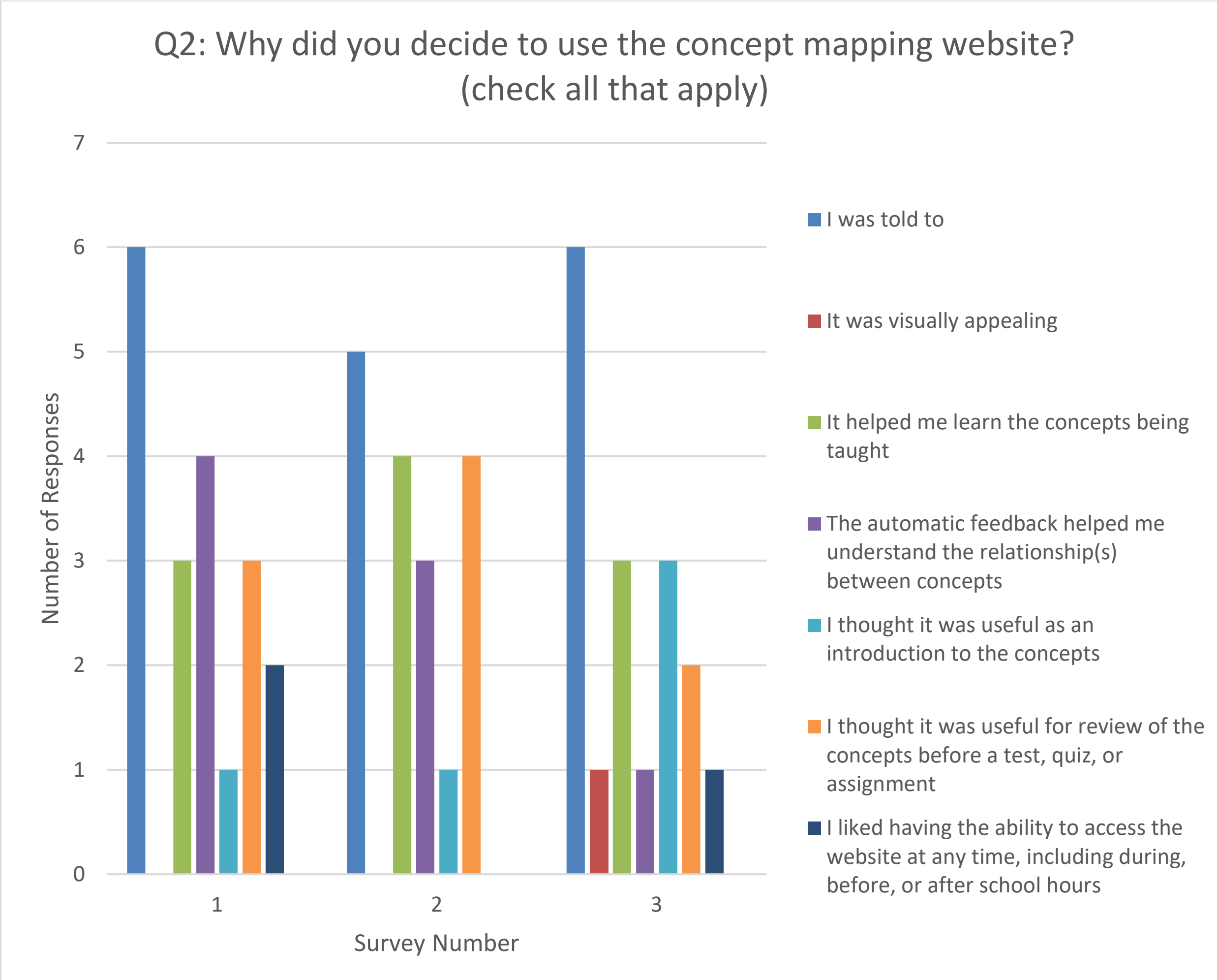

Figure 11 - Results of Question 2 across all three surveys

The second question the students saw on all three surveys they participated in was, "Why did you decide to use the concept mapping website?" The participating students were given a series of options to select from and were instructed to select as many statements as applied to their feelings about the question. The purpose of this question was to determine which aspects of CMfL and the experimental design resonated with the students. In determining why students were using CMfL, I believed that I could infer how to focus use of CMfL to provide the most use to students in Grade 9 for mathematics, and therefore determine which aspects of CMfL to focus on to maximize adoption. I was also interested in seeing if students' impressions of CMfL changed over time. For example, if there were aspects of CMfL that the students did not initially identify as being factors that drove them to use CMfL that they ended up finding useful over time or repeated use.

On the first survey, all the students (n=6) responded that they used CMfL because they were told to. This was the option that received the most responses. Across all three surveys, these results remained relatively consistent; on the second survey, most students agreed with this option (n=5), while by the third survey all of the students agreed with the option again (n=6). The responses “It helped me learn the concepts being taught” and “I thought it was useful for review of the concepts before a test, quiz, or assignment” saw a similar trend across the three surveys. In the first survey, half of the students (n=3) responded to both options. On the second survey, a majority of the students agreed with the response (n=4). On the third survey, the number of students that agreed with the statement decreased for both options. Half of the students (n=3) selected the option “It helped me learn the concepts being taught” and some of the students (n=2) selected “I thought it was useful for review of the concepts before a test, quiz, or assignment.” The option “The automatic feedback helped me understand the relationship(s) between concepts” saw a decline across the three surveys. The majority of students (n=4) agreed with this option on the first survey, half of the students (n=3) agreed with the option by the second survey, and some of the students (n=2) agreed with the option on the third survey. Finally, the option “It was visually appealing” saw relatively consistent responses across all three surveys. On the first two surveys, none of the students selected this option (n=0), while on the third survey, one student selected this option (see Figure 11).

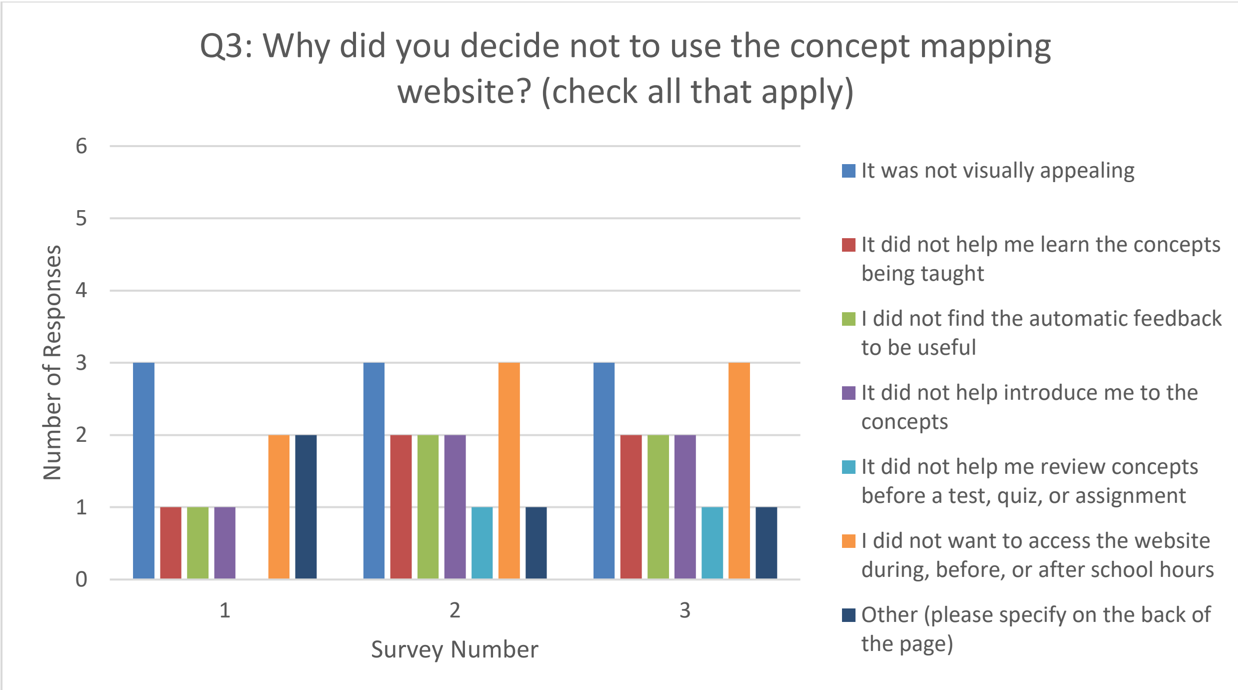

Figure 12 - Results of Question 3 across all three surveys

The third question that the students saw on all three surveys was, “Why did you decide not to use the concept mapping website?” Once again, the participating students were given a series of options to select from and were instructed to select as many statements as applied to their feelings about the question. The purpose of this question was to determine what aspects of CMfL and the experimental design students did not enjoy. I asked this question because the students’ responses had the potential to help determine what facets of the design of CMfL would prevent adoption amongst this audience (Grade 9 mathematics students), which could then theoretically be applied to a wider potential group of users in terms of age and subject matter being studied. The information about what aspects students didn’t like could also help inform improvements that could be made to CMfL.

Across all three surveys, half of the students (n=3) responded that they did not use CMfL because it was not visually appealing. Some of students (n=2) responded that they did not want to access the website during, before, or after school hours on the first survey, although by the second survey and onto the third, half of the students (n=3) selected this response. Some of the students (two on the first survey, one on the following surveys) selected the other options, although the number of students that selected each response increased by one from the first survey to the second. Results for the third survey were the same as those on the second survey (see Figure 12).

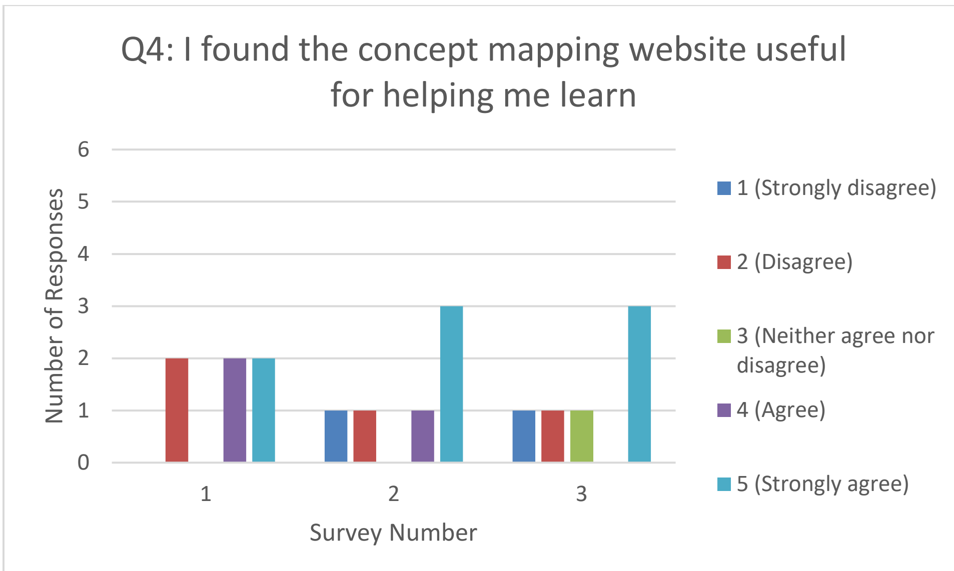

Figure 13 - Results of Question 4 across all three surveys

The fourth question that was posed across all three surveys was rated using a Likert scale from 1 to 5. On this scale, 1 was the lowest level of agreement with the statement (strongly disagree) and 5 was the highest level of agreement (strongly agree). The purpose of this question was to provide insight into one of the research questions of my study, which questioned if CMfL supported learning from the students' perspective. This question, when analyzed within the context of the responses to questions 1 through 3, would provide further insight into why (or why not) students found CMfL worthwhile. Once again, I was also curious about how students' impressions of CMfL would change over time, as they had more time and exposure to CMfL.

Results remained relatively consistent for this question across all three surveys. A majority of the students (n=4) either agreed or strongly agreed with the statement on the first and second surveys; by the third survey, half of the students (n=3) strongly agreed with the statement. Across all three surveys, two of the students either disagreed or strongly disagreed with the statement (see Figure 13).

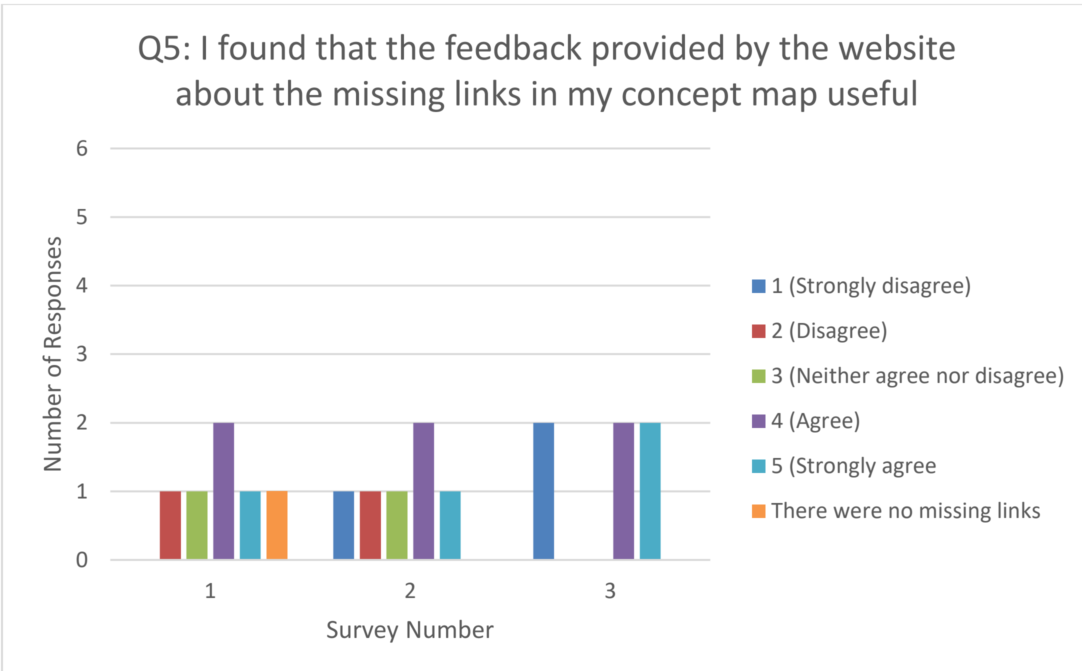

Figure 14 - Results of Question 5 across all three surveys

The fifth and final question that was posed across all three surveys was, once again, in the form of a Likert scale from 1 to 5 (with the same definitions for the ratings). Although the general student impression of "usefulness" of CMfL in the context of supporting student learning was one of the key questions I wanted to answer, the differentiating factor for CMfL was meant to be the targeted formative feedback that it could provide. As such, this question measured the perceived usefulness of that targeted formative feedback. When these results are taken in conjunction with the results of question 2 ("Why did you decide to use the concept mapping website?”), my intention was to determine what aspects of the students’ study practices might have been positively influenced by the targeted formative feedback that was provided. For example, was the formative feedback most useful as an introduction to the concepts, or as a tool for revision leading up to a quiz, test, or exam?

Across all three surveys, some of the students (n=2) agreed with the statement, while the other students reported spread of responses across the first and second survey. By the third survey, some students strongly disagreed with the statement (n=2), and some strongly agreed with the statement (n=2) (see Figure 13).

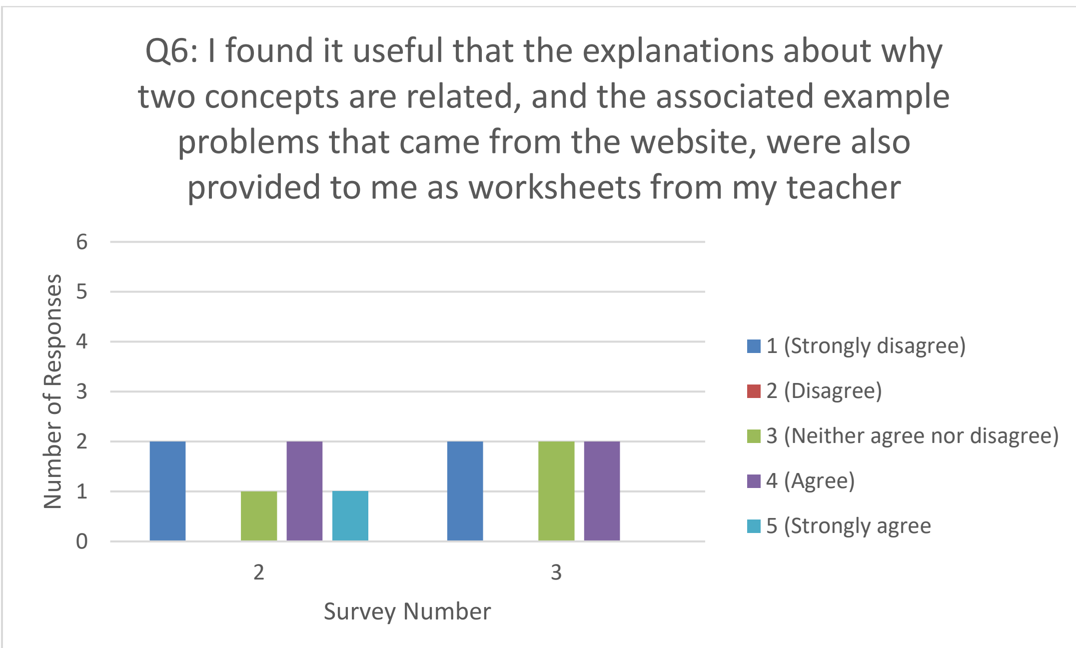

Figure 15 - Results of Question 6 across surveys two and three

Question 6 was again developed to be rated on a Likert scale with same definitions for the ratings. The question stated, “I found it useful that explanations about why two concepts are related, and the associated example problems that came from the website, were also provided to me as worksheets from my teacher.” After the second milestone (a test), the teacher wanted the feedback from CMfL to be made available offline as secondary study material in preparation for the exam the students would be taking at the end of the semester (which was also the end of the student data collection period). The purpose of this question was to determine the usefulness of the formative feedback outside of the context of CMfL. The feedback was designed to be used as a means to target student misunderstandings through CMfL, so use of it outside of the context of CMfL was a factor of the study I was skeptical about. This question was designed to determine the value of the formative feedback when it was removed from its initial purpose.

Across both surveys that this question was posed, some students (n=2) strongly disagreed with the value of the feedback being provided as worksheets, and some (n=2) agreed that having the worksheets was valuable. By the second survey, two of the students responded that they neither agreed nor disagreed with the statement (see Figure 15).

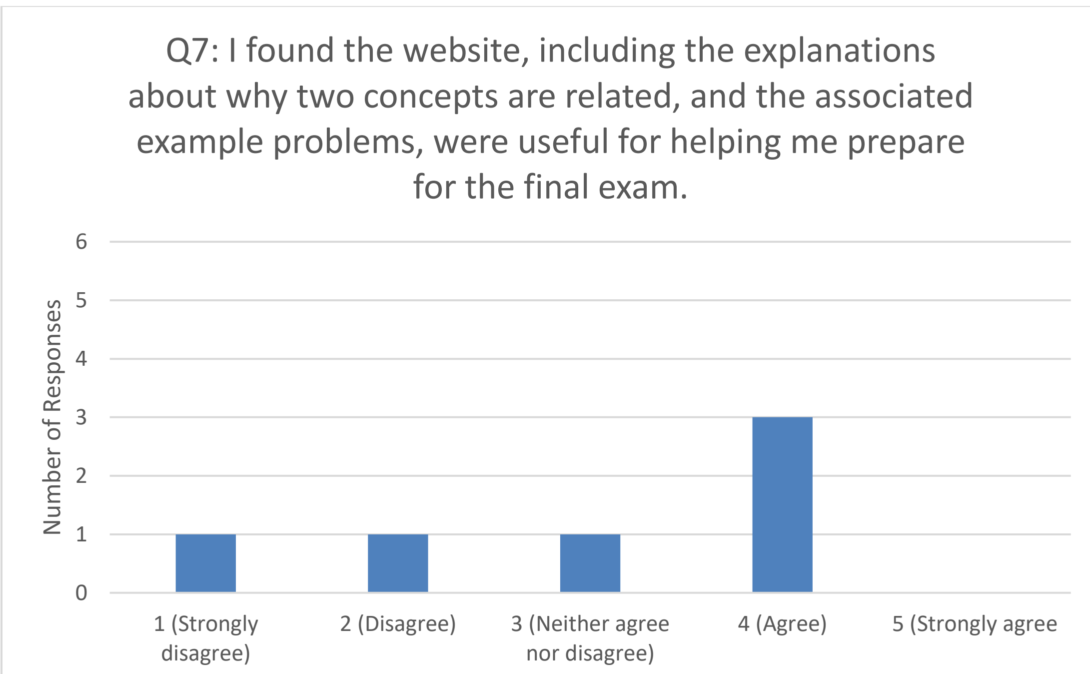

Figure 16 - Results of Question 7

The final question posed to students was, “I found the website, including the explanations about why two concepts are related, and the associated example problems, were useful for helping me prepare for the final exam." This question was only asked to students on the third survey, as it was asked after they had completed the final exam for the Grade 9 mathematics course offered at the research site. This question was developed to determine how useful all aspects of CMfL (the concept maps, the targeted textual explanations, and the associated targeted example problems) were in helping students prepare for the final exam. The data from this question was of particular importance in this study because this was the first time these students would have written a final exam in the Ontario school board. The teacher placed a strong emphasis on preparation for the final exam. With this question, I hoped to determine how CMfL had factored into students' preparation (if at all); in other words, I wanted to know if CMfL had had any influence on the metacognitive learning process of the participating students. For this survey question, half of the students (n=3) agreed that CMfL helped them prepare for the final exam, while the other three responses were dispersed across ratings of 1 (n=1), 2 (n=2), and 3 (n=1) (see Figure 16).

The final survey had three additional questions:

i) What specific aspects of the concept mapping website did you like?

ii) What specific aspects of the concept mapping website did you dislike?

iii) What ideas do you have that could improve the website?

These questions were designed to specifically discern, from the student perspective, what works and does not work on CMfL. These questions allowed for each student to articulate their specific perspectives, which in turn allowed me to consider their responses alongside the trends observed in questions 1 through 7 that led to my initial findings. The data collected from these responses may also be used for future iterations of CMfL, as the suggestions provided may be able to improve CMfL for future users. The responses of the participants to these additional questions can be seen in Table 3:

Table 3

Participant Likes, Dislikes, and Potential Improvements

Participant	**What specific aspects of the concept mapping website did you like?**	**What specific aspects of the concept mapping did you dislike?**	**What ideas do you have that could improve the website?**
Don	- Good idea	- Styling - Layout - Feedback	- Make app
Roger	- Good idea	- Confusing - Wasn't in French - Couldn't find supposed "automatic feedback" - It didn't really help	- More language options - Easier to navigate - Links didn't make sense at times - Make the automatic feedback easier to find. I never saw it - Making it an app for phones/tablets would make it more accessible
Peggy	- The slope connections - The exercises and practice - The map	- Nothing	- Nothing
Megan	- The multiple-choice aspect	- Having to rewrite, but I can see why I would have to	- Make it look nicer
Stan	- I like the web at the end, because it was	- A couple of concepts that I thought should	- Make it look nicer and

	useful for seeing how I did	be related weren't	more interesting
Betty	- I liked that it explained the concepts and then offered questions for practice	- Sometimes it was too much information to review. I know that some concepts are large and require a long explanation but sometimes I found it hard to get the point	- Instead of having just the question maybe the question can be fillable and tell you if you have done it right.

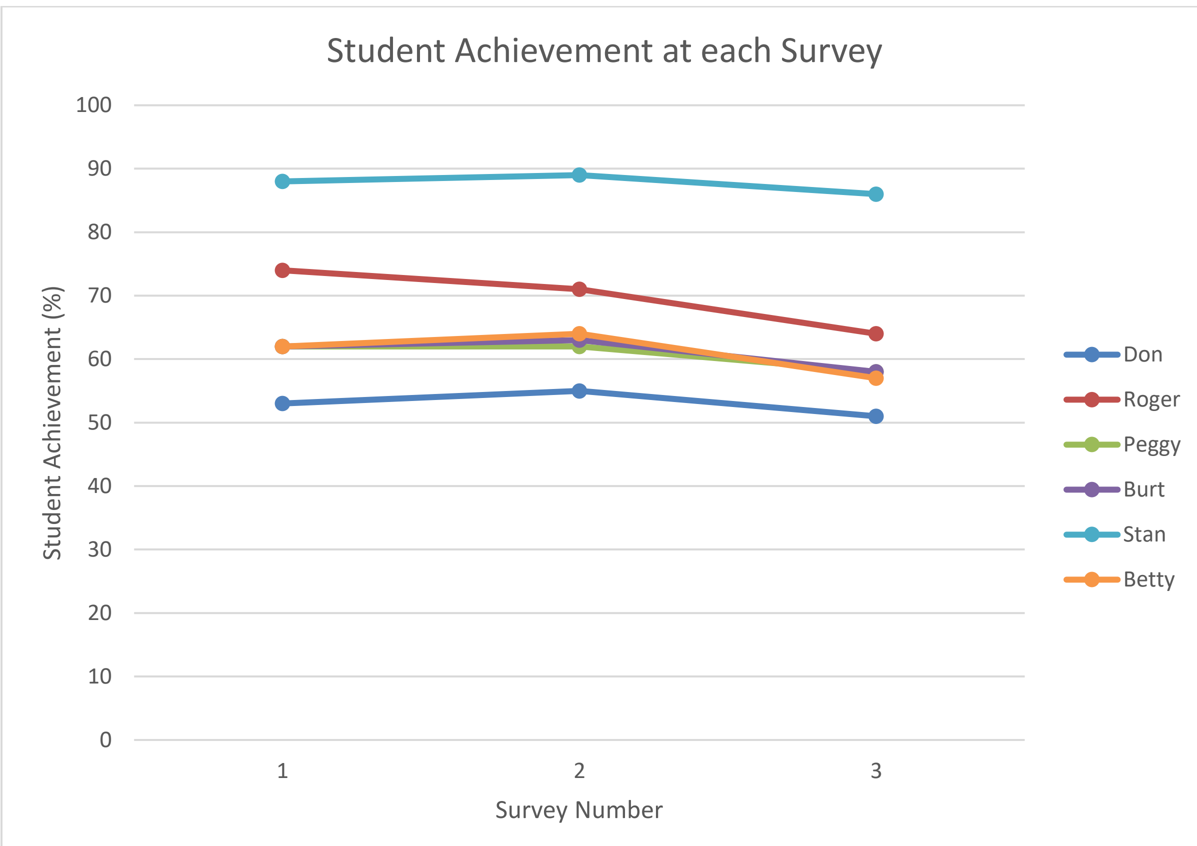

Figure 17 - Graph of student achievement across the student data collection period

Student achievement was recorded at the conclusion of each milestone over the student data collection period. Literature regarding the usage of concept maps for formative assessment suggested that student achievement would improve, so I assumed I would see similar results. I also wanted to see if any inferences could be made when relating student achievement to the results that were obtained through the student surveys.

Don, Peggy, Burt, Stan, and Betty all experienced a slight increase in achievement between milestones 1 and 2, before experiencing a slight decrease after milestone 3 (the final exam). Student 2 experienced a slight decrease between each successive milestone.

Table 4
Student Achievement and CMfL Utilization

Student	**Pseudonym**	**# times used tool**	**Completed all 7 concept maps? (Y/N)**	**Average achievement (across 3 assessments)**	**# of concept maps with improvement following feedback**
1	Don	1-2	N	54.00	2
2	Roger	1-2	Y	69.67	1*
3	Peggy	3-4	N	60.67	1
4	Burt	5+	Y	61.00	5
5	Stan	5+	Y	87.67	5
6	Betty	1-2	N	61.00	1

*Although this student only showed improvement, as measured by the comparison between first and second concept maps within an exercise in CMfL on one concept map, he/she did acquire all relevant links on each of the last 5 concept maps.

Finally, students' achievement and utilization of CMfL, along with generalized results of their CMfL usage, were amalgamated. The generalized results were a summary of how many concept mapping exercises they engaged in where improvement was recorded by CMfL. Students participated in seven concept mapping exercises on the website, meaning the best result here could be 7. This data was integrated into a single view (see Table 4) to determine if there were trends that could be observed between usage of CMfL, student achievement, and improvement across concept mapping exercises as recorded by CMfL.

Teacher Interviews

The first teacher interview was designed around core questions that were crafted to focus on the teacher's impressions of the usefulness of CMfL as a learning tool for students, its usefulness for teachers, and to collect the teacher's feedback around improvements that could be made to CMfL to make it more effective for students. The interview was designed with the expectation that it would be somewhat conversational or semi-structured; I expected to ask follow-up questions and to probe the teacher for more details based on the responses that were provided. An abridged version of the questions posed, along with follow-up questions, are listed here:

1. What is your first impression of the website [*referring to CMfL*] just by looking at it?
    a. Did you find that desire was an issue with the students here?
2. From a usability perspective, how usable is the website is the website?
    a. What do you think of the extraneous links from that usability perspective?
    b. Do you have any suggestions for how we can emphasize the negative connotation, or negativity, of the extraneous links?
3. What do you think can be done to make [CMfL] more immediately appealing to students, to increase that desire to use it?
    a. Do you think the interface would translate pretty well [to a mobile medium]?
4. What do you think can be done to the website so make it more immediately appealing to teachers, so that they would want to use it in their classrooms?
5. What do you like about the website? Anything specifically?
6. Whether from the student's or teacher's perspective, what do you think can be improved?

7. Did you find that students that produced concept maps that were closer to the expert (or referent) concept maps also displayed a stronger understanding of the subject matter?
8. What did you find students' impressions of the website were? What did you observe through their use, through their interactions with [CMfL], through their discussions with each other during class time?
    a. Do you have any thoughts or ideas about how we could get this student population to reflect on their results?
9. Given the truncated data collection period, if we had more time, would the results have been more positive?
10. Did you think the concept mapping website was useful?
11. Did you think it was useful from the teacher's perspective, to help with your assessments or evaluations?
12. From the students' perspective, if we were to present CMfL in an ideal state, would you consider it to be useful?
    a. Given the limitations we had, did you still think CMfL was useful to some students?
13. If you were given the opportunity to use [CMfL] again, would you?
14. What is the ideal age group to target for CMfL
    a. Why?

Although I initially felt that the first survey collected the data I needed from the teacher, my analysis indicated that a second survey was needed. The second survey was designed so that I could collect more specific information regarding student use of CMfL, as well as how the teacher's usage of CMfL may (or may not) have affected the instructional strategies utilized.

Once again, the interview was designed to be somewhat conversational and to accommodate follow-up questions as necessary. An abridged version of the questions, along with follow-up questions, were as follows:

1. Did you find that [CMfL] helped students make connections between concepts, and if so, can you provide any examples?
    a. Did you find that the feedback that the concept mapping website provided was helpful in helping that student achieve that understanding?
2. Can you provide any specific examples of how [CMfL] may have affected your teaching?
    a. Due to the small sample size, would you suggest that [CMfL] didn't affect your teaching, but it did help with one-on-one instruction?
3. Can you provide any specific examples of how the tool informed a one-on-one interaction you had with a student?
4. Do you find that the use of concept maps, or similar tools like mind maps, have been adopted by the students as a learning strategy? If so, are they using them in math now, or it any other subjects?
    a. Can you provide any specific examples of the other subjects where concept maps are being used?
    b. You mentioned some of your colleagues are using [concept maps] as well, what are some of the subjects they are being used in?

Discussion

During the study, all students engaged with the CMfL website at least 1-2 times. However, usage of the website did not increase past that point for some students. By the midpoint of the study, after survey 2, maximum adoption of the website had already occurred for all participating students. Three students never advanced past using the website more than one or two times. Student motivation emerged as a code during analysis, and the response to questions 1, 2 and 3 of the survey suggested that a specific theme around what did or did not motivate students to use CMfL would become clearer. For the students who engaged with CMfL more frequently, my initial assumption is that they derived some value through use of CMfL. Extending the line of inquiry introduced by student motivation, the second questions posed across all three surveys was, "Why did you decide to use the concept mapping website? (check all that apply)." Given the nature of this question, there are a number of potential responses. As can be seen from the results of the first potential response, "I was told to," the responses are reasonably consistent. This response is truthful; if students agreed to be a part of the study, part of the requirement was to use the CMfL website. Not much can be inferred directly from these results, although I believe that this is an indicator of a lack of intrinsic motivation towards use of CMfL. Additionally, I believe this to mean that although they found the website useful, aspects of the design of either the website or study did not appeal to them over the duration of the data collection period. Further analysis of the survey responses will provide more evidence to validate this assertion.

The next potential response was, "It was visually appealing." The students did not agree with this statement. On the first two surveys, none of the students in the sample agreed with it. In the last survey, one student selected it. A lack of motivation to engage with CMfL due to its lack of esthetic appeal emerged as a prevalent theme over the course of the analysis. This theme continued throughout my analysis.

"It helped me learn the concepts being taught" was the next optional response. Responses were relatively consistent across the three surveys. Three students agreed with this statement on surveys one and three, and four agreed with it on the second survey. This would become a noticeable trend over the course of the data collection period: half (or more) of the students surveyed would agree to positive statements regarding the usefulness of the CMfL website as a tool for learning, with a consistent number, or even a slight uptick occurring on the second survey. By the time of the third survey, however, that number would drop. For this question, the indication from the response is that three of the six participants found that the CMfL website was useful for assisting in their understanding of the concepts being communicated in the course.

I looked at the next two responses, "The automatic feedback helped me understand the relationships between the concepts," and "I thought it was useful as an introduction to the concepts," simultaneously. The trend regarding the "automatic feedback" response was very interesting. Four respondents agreed with the statement on the first survey, three on the second survey, and only one on the final survey. Analyzing this question in isolation leads to the conclusion that the CMfL website is increasingly ineffective as a tool for providing automated feedback over time. At the very least, the CMfL website may be ineffective in its current configuration, wherein textual feedback was provided, along with an example problem that illustrated the relationship between the concepts. However, the next question about using CMfL as "an introduction to the concepts" also provides some interesting insights. Across the first two surveys, only one participant agreed with this statement. By the third survey, three agreed. So, over time, the CMfL website provided a valuable introduction to the concepts being taught, but may not have been as valuable as a tool for providing feedback over time. The feedback that was provided by the website was initially found to be useful, and stayed useful to at least 50% of the sample group through the second survey, at which point they would (presumably) have had more time to engage with all of the concept mapping exercises on the CMfL website. However, the feedback was not updated over the course of the study. By the time they reached the end of the data collection period, there was nothing new to see, or no further explicit insight provided by the website. At this point, any further understanding that the concept maps and feedback that CMfL provided would rely on interpretation from the students, and how they utilized those interpretations to engage with the teacher. In other words, any further knowledge acquisition from CMfL based on the current configuration would rely on students' cognition and, more importantly, metacognition. The students would need to understand how use of CMfL had helped them, and how they could derive more from the offering. The sample group's inverse trend in response with respect to the usefulness of the CMfL website as an introductory tool becomes explainable. CMfL did not evolve over the course of the study; the static nature of the configuration over the course of the study meant that, logically, maximum value would be derived initially. Once the relatedness ratings exercises were complete, the student could only review the generated concept map. This meant that any further usefulness from the website would rely on the student conducting concentrated, independent review of their own concept maps and the expert concept maps, and then engaging with their colleagues or the teacher in conversation around their interpretations (metacognitive processes). As this is a non-traditional learning method and was not specifically required for the purposes of the study, any expectation of this occurring may have been unrealistic. Therefore, the data indicating that this configuration of the CMfL website is most valuable as an introduction to concepts feels valid within this context.

The next optional response for question 2 was, “I thought it was useful for review of the concepts before a test, quiz, or assignment.” On the first survey, 3 participants agreed with this statement. On the second survey, that number had increased to 4, but by the last survey, it had dropped to 2. When taken in conjunction with students’ responses regarding the value of CMfL as an introduction to concepts, these responses indicate that over time, the CMfL became less valuable as a tool for revision and preparation before a summative assessment. Once again, this makes sense in the context of the study. All the concept mapping activities were made available to the participants immediately. These results seem to indicate that by the second survey, the students had completed most of the exercises and were deriving more value from repeated use of the CMfL website. However, by the end of the course, since no new materials were added to CMfL, it became less useful as a tool for revision. In context with the other responses to this question, the results present a consistent narrative. For example, when comparing the responses to this answer along with those for, “The automatic feedback helped me understand the relationship(s) between concepts,” and “I thought it was useful as an introduction to the concepts,” it can be seen that this configuration of CMfL is helpful as an introduction to concepts, but may not be as useful over time. As student understanding of a subject increases, which can occur as a function of time and exposure to the material, the feedback provided by the CMfL website becomes less relevant.

One of the key aspects of the study was the use of CMfL as an independent study tool, which was explored with the optional response, “I liked having the ability to access the website at any time, including during, before, or after school hours.” The responses received to this question were unexpected. On the first survey, two participants agreed with the statement. On the second survey, none did. By the last survey, one student agreed. This suggests that having the ability to access the CMfL website, and by extension, the feedback and questions provided, was never a priority for most participating students. Although the students had the ability to access this resource at their own discretion or desire, responses to this question led me to believe that the website was most likely predominantly utilized in class hours. This aligns with some of the feedback received from the teacher. During the course of the study, when we realized that progress on completion of the CMfL tasks had stalled, the teacher arranged to have some review time in class dedicated to completion of said tasks. The students' individual results will be discussed later in this thesis. Results from that analysis, along with the results from the teacher's interviews, reveal that the participants in this study were generally weak when it came to working independently outside of the school setting. My initial conclusion based on these findings, and the analysis of the results of question 2, is that the CMfL website would be more effective as an introduction to concept relationships, to be conducted and discussed with the teacher during class time to maximize the impact of engaging with the website. The final potential response was "Other," with the students being asked to specify what these other factors that drove them to use the CMfL website were. None of the participants selected this option.

To determine if there were specific aspects of the website, either in design or in configuration for this study, that were deterring the participants from using the website, participants were asked, "Why did you decide not to use the concept mapping website?" Once again, students had multiple potential responses they could choose. Further to this point, the potential responses to this question were also designed to determine what can be changed or improved to increase the usefulness of the website. The lack of visual appeal of the CMfL website was the predominant theme that emerged from student responses. Of the six participants, three selected, “It was not visually appealing” as a reason for why they did not use the website, or at least why they did not use it to its full capacity. Going back to question 1, which asked, “How many times have you used the concept mapping website since you were provided access?” revealed that by the time of the third survey, three participants had only used CMfL 1-2 times. Further investigation into each participants’ individual responses reveals that Don, Roger, and Stan were the participants that selected this response consistently. Although lack of visual appeal remained an issue for Stan, this participant was able to look past it and derive some value from use of the website based on his/her other responses. However, for Don and Roger, this remained a deterrent. With 50% of the participants consistently finding issue with the aesthetic appeal of the website, one of the key takeaways is that the CMfL website needs to be redesigned to appeal to students in this demographic to be valuable. If unappealing visual design prevents students from using the website, as it seems to have in this instance, there is limited hope of widespread adoption or derivation of value from the feedback being presented. The website design provides students with their first impressions of the CMfL. According to Xu (2013), if students’ find that the presentation of the website is ugly or unprofessional, they may not consider the results of the exercises produced by the website to be noteworthy (despite the significant amount of research and development that may have gone into the product).

The next three responses to question 3 (“It did not help me learn the concepts being taught,” “I did not find the automatic feedback to be useful,” and “It did not help introduce me to the concepts”) had the same consistent feedback. All three responses had one student agree with them in survey 1, and two students agree with them across surveys 2 and 3. Further investigation into which students made these responses once again reveals that Don and Roger made these consistent statements. Analysis of this feedback in concert with the visually unappealing design of CMfL, along with the fact that both students only accessed the website 1 to 2 times over the course of the study, reveals a larger narrative. At this point, although the sample size of the study is small, these students are generally in the minority. Since the students only accessed CMfL once or twice over the course of the entire study, their assertions that the website did not help them learn the concepts being taught, that they did not find the automatic feedback useful, and the website was of no help even as an introduction to the concepts, is questionable. Since both students engaged with CMfL so infrequently, I am inferring that the visual design of the website was unappealing enough that they did not find any of the results from the website to be worthy of note. Additionally, Roger did not complete the total number exercises that were made available through the website. This means this student did not actually experience all of the material that the website had to offer for feedback, and that there was potential for this student's opinion to have changed had they engaged more frequently with CMfL. My assumption at this point is that, since at least four of the student population did not feel this way about the website, the feelings of these two students are the result of a lack of engagement with CMfL. This speaks more to the usability of the website, or its ability to appeal to students, as opposed to the actual content. These results lead into a theme around metacognition; students that engaged with CMfL more have responded more positively to its value of a study tool. This suggests that the more frequently CMfL was used in this study, the more the participating students felt that they were acquiring knowledge and therefore finding CMfL useful.

The next response to question 3 ("It did not help me review concepts before a test, quiz, or assignment") reveals student impressions of CMfL as a tool for revision. None of the students agreed with this statement during the first survey, which occurred when they had access to CMfL but only one milestone event (quiz) had passed. After the second milestone, which was a test, one respondent agreed with the statement. After the last milestone, the final exam, one student agreed with the statement. Analysis into which student(s) selected this response reveals that only Roger felt this way. Referring to student achievement, Roger was the only student to see a consistent downturn in grades across the duration of the study. Of the other five participants, four saw a minor uptick in achievement after the second milestone, and one remained steady. Further, Roger accessed the website only 1-2 times, and did not complete the activities. Although this analysis applies to a single student's response, the reoccurring theme around more frequent use of CMfL leading to feelings of increased usefulness of CMfL once again appears.

Focusing on the responses to the statement, "I did not want to access the website during, before, or after school hours" reinforces the emergent theme regarding the usability and visual appeal of the website. Responses to previous survey questions have led to inferences that the presentation of CMfL acted as a deterrent for many of the participants. Analysis of which students identified issues with the presentation of CMfL and responded with "not [wanting]" to access the website reveals an overlap. "It was not visually appealing" was also identified as a reason that students chose not to use CMfL, along with "not [wanting]" to for two of the participants across all three surveys.

Finally, when given the option to specify a different reason for not using CMfL, Peggy indicated across all three surveys that "[they] didn't have time." In the first survey, Betty remarked that use of CMfL "… did not cross my mind often." Betty's only response for not using CMfL on surveys 2 and 3 was that they did not want to. Contextualizing these responses for this study is difficult, as these responses do not belay any specific trends. They are specific to each student. In the final survey, when provided with the opportunity to identify areas in which

CMfL could be improved, Peggy provided no feedback. If this student had provided an example or some reasoning for why CMfL was too cumbersome to fit into their schedule, specific mitigations could have been suggested for future iterations of CMfL. Betty did provide some suggestions. Betty identified that she felt overwhelmed by the amount of information that was presented in CMfL. Betty also provided the suggestion that a fill-in-the-blank question would be better than an actual mathematics problem as one of the types of feedback.

Analysis of questions 1, 2 and 3 together revealed themes around motivation, metacognition, and cognition. When considered in concert with the utilization and completion rates reported in Table 3, some inferences can be drawn. As previously stated, motivation to complete the exercises available in CMfL appeared to have been low based on the completion rates. When considering the responses to question 2 which focused on reasons why students chose to use CMfL, the most frequently cited response was that they were told to. Linking this to questions 3 which focused on why students did not use CMfL, the most consistently cited reason was that it was not visually appealing. From a metacognitive perspective, the student responses to questions 2 and 3 suggest that the participating students recognized, to some degree, how CMfL informed their learning practice. Regarding question 2, the responses to "It helped me learn the concepts being taught" and "I thought it was useful as an introduction to the concepts" reveal that CMfL in this context was a stronger tool for learning new concepts. At least three students across all three surveys agreed that CMfL helped them learn the concepts being taught. Regarding agreement that CMfL was useful as an introduction to the concepts, agreement with this response trended up by the final survey. Results for the other responses were mixed. This suggests that as students received more exposure to CMfL, they found CMfL valuable for certain aspects of their learning process. Specifically, CMfL was valuable as an introduction to concepts and did help students learn, but it does not seem to have made a strong impact as a study tool, and the value of the formative feedback decreased over time.

Questions 4 through 7 were presented as a Likert scale, from 1 (strongly disagree) to 5 (strongly agree). Question 4 stated, "I found the concept mapping website useful for helping me learn." Across all three surveys, at least three participants selected either "Agree" or "Strongly Agree." In fact, until the final survey, four of the six participants selected one of these two responses. This means that for most of the duration of the study, the majority of participants felt that CMfL was a useful resource for their learning. Analysis of the specific participants responses revealed that Don and Roger selected either "Strongly disagree" or "Disagree" across all three surveys. This is consistent with the feelings that those two participants expressed across all other questions. Worth noting is that on the final survey, only three of the participants remained positive about CMfL for helping them learn. Burt selected "3" on the scale for the last survey. This change of mind can likely be attributed to student achievement after the last milestone, the final exam. Every participating student, regardless of how they engaged with CMfL, saw their achievement score decrease after the final exam. Burt experienced a 5% decrease, and the final survey was administered immediately after the exam. Although students had not received their final grades yet, it is possible that this student was aware of how their performance on the exam would affect their grade.

Question 5 states, "I found the feedback provided by the website about the missing links in my concept map useful" for the first two surveys. The teacher wanted to provide the problems and full solutions for the example problems that acted as the secondary feedback available through CMfL. After analyzing the results of the second survey, the I felt that this question needed to clearly differentiate between the usefulness of the feedback, versus the usefulness of the solutions. As such, the question was altered for the final survey to say, "I found the feedback (the explanations about why two concepts are related, and the associated example problems) provided by the website about the missing links in my concept map useful." Initially, three participants responded in the positive ("Agree" or "Strongly Agree"), one "Neither agreed nor disagreed," one disagreed, and one stated that they had no missing links after engaging with CMfL. By the second survey, one of the participants had shifted to "strongly disagree." By the last survey, two participants "Strongly Disagreed" while the other four responses were split between "Agree" and "Strongly Agree." As with the previous questions, Don and Roger responded negatively. That said, most participants did find that the feedback that was provided was useful. Student achievement reflects this, as all four of the participants that agreed on the usefulness of the feedback (Peggy, Burt, Stan, and Betty) saw either an increase in achievement at the second milestone, or at least had their achievement remain steady. Roger saw a steady decline in achievement. In combination with Roger's infrequency of engagement with CMfL, along with his and Don's other responses to survey questions, this response is expected. Don's responses are more interesting, as he did see an increase in achievement after the second milestone, but either disagreed or strongly disagreed with this statement across all three surveys. During our touchpoints over the duration of the study, the teacher identified this student as not having done any observable work in the mathematics course, outside of some time with CMfL that was encouraged by the teacher himself. Don's achievement at the recorded intervals was 53%, 55%, and then 51%. The teacher credited CMfL with providing enough information acquisition for Don to have passed the course, as his efforts had been minimal in the course otherwise.

Question 6, which was added to the second survey and carried over to the last survey, states "I found it useful that the explanations about why two concepts are related, and the associated example problems that came from the website, were also provided to me as worksheets from my teacher." The teacher wanted to make the problems and associated solutions available in case students did not encounter the feedback through CMfL. Making this feedback available outside of CMfL meant that the contextual purpose of the feedback, which was to provide an explanation of a relationship, was missing. An interesting implication of removing the feedback from its designed context of being issued as required through CMfL was that the feedback was made available to students in the more "traditional" manner of worksheets. Having the feedback available to students as worksheets would likely be a format that the students had seen at some point over their careers as mathematics students. I was concerned that providing the feedback in a familiar format would further deter adoption of CMfL, but the students' responses do not seem to indicate that. Don and Roger strongly disagreed across both surveys, as expected. Three participants responded in the positive at first, with one neither agreeing or disagreeing, but by the last survey the split was even. Two students (Don and Roger) strongly disagreed, two neither agreed nor disagreed, and two agreed. This is the first question without a single participant strongly agreeing with to the usefulness of an aspect of the experience.

Finally, question 7 stated, "I found the website, including the explanations about why two concepts are related, and the associated example problems, were useful for helping me prepare for the final exam." This question was only posed on the final survey, as that survey occurred immediately after the final exam. Three participants agreed with the statement, while one neither agreed nor disagreed, one disagreed, and one strongly disagreed. This follows the pattern that I have observed in questions 1 through 6, wherein three or four of the participants find CMfL and its associated resources useful, while two do not agree.

One of the research questions posed for this study was to determine the usefulness of CMfL regarding supporting student learning in and independent study environment. Questions 4 through 7 were all focused on which aspects of CMfL, if any, students found useful. The pattern across these questions is that three of the participating students found most aspects of what CMfL provided useful, while the other three participating students either did not, or did not have strong feelings one way or the other. Questions 4 and 5 ("I found the concept mapping website useful for helping me learn" and "I found the feedback provided by the website about the missing links in my concept useful") both saw agreement from the students. This reinforces previous inferences from the student results, indicating that CMfL was useful for helping students learn, and that the feedback provided by the missing links was useful. Both of these types of "usefulness" trended more positively by the end of the data collection period, indicating that as students had more exposure to (or more time with) CMfL, they were discerning which aspects of the website were beneficial to their learning process. Conversely, for questions 6 and 7 ("I found it useful that the explanations about why two concepts are related, and the associated example problems that came from the website, were also provided to me as worksheets from my teacher" and "I found the website, including the explanations about why two concepts are related, and the associated example problems, were useful for helping me prepare for the final exam" respectively), the results are not as convincing to me. The availability of feedback in the form of worksheets did not seem to resonate with the students, as only two of the students agreed with the statement. While three of the students indicated that they agreed that CMfL helped them prepare for the final exam, achievement across all participating students declined after the final exam. This suggests that the participating students have some metacognitive awareness of how use of CMfL can inform their learning processes. When referring to frequency of usage, and student achievement, once again the most prevalent theme is that more frequent use of CMfL appears to align with great value derived from CMfL and stronger student achievement relative to peers.

The final survey had three additional open-form questions:

i. What specific aspects of the concept mapping website did you like?

ii. What specific aspects of the concept mapping website did you dislike?

iii. What ideas do you have that could improve the website?

In reviewing these comments associated to these questions, it is clear that different students appreciated different aspects of what CMfL had to offer. Participants provided valuable feedback in regards to what they liked and did not like. The consistent theme of issues with the visuals of CMfL came up again, further cementing the finding that aesthetic appeal is a factor in participant engagement. Roger’s comments regarding what he did not like are particularly telling. Although he had previously identified the lack of visual appeal as a factor for why he did not use the website, when the opportunity to provide specific criticisms in his own words was provided, he took it and added more context for these feelings. The most resonant of the feedback, in my opinion, was Roger’s comment that CMfL was not offered in French. The research site is an English school, and the Grade 9 mathematics course that this study was conducted in was an English course. As such, differentiation in language was not a consideration for me or the teacher. The reason this piece of feedback stood out initially is because it could help explain some of the other comments made by Roger. Roger’s other feelings of confusion, and his inability to locate the feedback, indicates that the language barrier may have caused issues for him from the outset of the study. As previously stated, this participant had only accessed CMfL 1-2 times according to his surveys. These survey responses indicate that Roger's first experiences with the website may have been off-putting enough, and the instructions for using CMfL may have been confusing enough, that he did not see value in committing to the exercises on the website. The Montessori philosophies around independence that the research site is based on, along with the design of the study, meant that intervention from the teacher relied on the Roger voicing any issues he was experiencing or concerns that he had. If Roger did not fully comprehend the purpose and instructions for use of CMfL and did not engage with the teacher for clarification, the website would not have been useful to him. These factors coalesce and may help explain Roger's final criticism, that he did not find the website helpful.

Peggy's specific reference to "the slope connections" as being an aspect she liked is interesting. This suggests that CMfL may have been a resource (in addition to the textbook and instruction from the teacher) that helped her increase their understanding of a specific topic in the Grade 9 mathematics course. This specific finding validates my assertion that CMfL can be used as a resource for automated feedback that would be useful for students. Peggy further stated that both the "exercises and practice" and "map[s]" were aspects of CMfL that they liked. The concept maps, along with the secondary feedback provided by the exercises and practice, are two of the three core learning tools that CMfL provides. The textual feedback, which is the first type of formative feedback provided by CMfL, was absent in Peggy's comments. Since the textual feedback is a short explanation of why two concepts are considered to be related based on the referent concept map, it is purely "knowledge-based" feedback. Peggy's appreciation of the application-based questions that were offered as the secondary feedback provides insight into the types of feedback that provided her with better opportunities for learning. This finding is also interesting because having application-based exercises as secondary feedback was a decision made in conjunction with the teacher. This indicates that Peggy appreciated having feedback in a familiar form presented through CMfL, as this would be the type of feedback that the teacher would have provided through his "regular" teaching methods.

Burt's feelings about CMfL are quite simple, as he indicated appreciation for the Likert-scale based relativity ratings ("multiple-choice aspect"); he understood the reasoning for having to repeat the pairwise ratings exercise, but did not appreciate actually repeating the exercise. This finding suggests that the time it takes to complete a concept mapping exercise may need to be decreased to maintain the attention of some students. Five concepts were chosen per concept mapping exercise in an effort to streamline the pairwise ratings exercise while still having enough concepts to produce a map that would have some value. Streamlining the process any further would require a revision of how CMfL fundamentally functions, so addressing what this student did not like would be difficult. It is worth noting that Burt still accessed CMfL "5 or more times" based on his survey responses, so despite the time deterrent, he may have still found value in CMfL.

Stan identified the "web" (concept map) as being an aspect that he liked about CMfL, and noted that the [concept map] itself allowed him to see how he was progressing. The fact that the only issue identified with CMfL for Stan was that concepts that he felt were related did not show as such reveals that this student critically considered the results of his concept maps. One of the unplanned benefits of use of CMfL for formative feedback was the debate that some students engaged in with the teacher upon seeing their results. Questioning why some links existed on the referent maps, and why some did not, indicated that students were exploring the deeper relationships between concepts. For Stan, use of CMfL seems to have assisted with the structural organization of their knowledge. This is supported by his achievement, as this student had the best recorded grades across the duration of the study.

Betty identified both forms of formative feedback (textual explanation and associated example problem) as being aspects of CMfL that she liked. Her preference for the traditional forms of feedback (as opposed to the concept map itself) indicates that it was helpful to provide the students with a familiar form of feedbacl. In fact, given that only two of the students explicitly stated that the concept maps were aspects of CMfL that they enjoyed, I surmise that CMfL is a resource that students would need to gain a level of familiarity with before understanding how to visually review the maps as a form of feedback. This aligns with some of the feedback received from the teacher during his interviews; he felt that adoption and appreciation of CMfL would increase if it was a tool that was introduced at the start of the course and utilized throughout. Betty did note that she occasionally found the amount of feedback that CMfL was providing was overwhelming. The explanations and example problems that were provided through CMfL were carefully cultivated to ensure consistent language and definitions with other materials that were available to the students (such as the textbook and class notes), but this participant's feelings indicate that CMfL would provide more value as a tool to explore relationships between basic, foundational concepts. It is possible that some of the conceptual relationships that CMfL attempted to provide formative feedback on may have been too complex, since this study occurred closer to the end of the course. This means that the majority of the course had already been completed, and the concepts being taught at the point of the study often required an understanding of concepts that were taught prior to the introduction of CMfL as a learning tool. These findings again align with the teacher's assertion that CMfL would see more success if was introduced at the beginning of a course.

In reviewing the opportunities for improvement to the CMfL tool, certain points emerge. As expected from my analysis, the appearance of CMfL was something that could be improved. Two of the participants introduced the option of presenting CMfL as a mobile application; if this change could be implemented, it could result in positive change with respect to the adoption of CMfL amongst participants in this age group. Not only would development of a mobile version of CMfL provide an opportunity to improve the aesthetics of the website, it would also likely provide students of the age of the participants in this study a medium that they identify with better than a desktop-based website. The teacher supported this assertion as well, as his observations of the participants reveal that they would use their phones or tablets more frequently than laptops or desktops. A survey of a representative sample of American teenagers aged 12-17 supports the assumption that many teenagers are "mobile-first" internet users (Madden, Lenhart, Duggan, Cortesi, & Gasser, 2013). If these results hold true for Canadians in the same age range, and assuming that in the intervening years the use of mobile technology such as cell phones has become even more prevalent, this idea to shift CMfL to a mobile platform becomes more appealing.

Translating CMfL to a mobile application may also help mitigate some of the usability issues that Roger listed as areas for improvement. During his interviews, the teacher commented that a mobile application would lend itself well to the pairwise ratings exercise. The teacher likened the pairwise ratings exercise to quiz games or polls that are available on a mobile platform, and suggested that similar activities are available through popular social media applications such as Facebook. His suggestions indicate that transferring CMfL to a mobile application would make the process self-explanatory for students, since they are already familiar with similar activities through that form of media. Although not verifiable through the evidence collected during this study, my feeling is that the language issues experienced by Roger would not have been as significant had CMfL been mobile accessible. Use of mobile applications are so prevalent, and the cues designed to guide mobile application users are so visually descriptive and intuitive, that CMfL may have been easier to navigate just by virtue of the user's prior experience with mobile technology.

As previously noted, Betty felt that the amount of feedback being provided by CMfL was overwhelming. As an improvement, she suggested that the secondary feedback could be a fill-in-the-blank question, as opposed to a practice problem. The teacher helped design the formative feedback such that the practice problem (secondary feedback) was directly related to the textual explanation of relationship between the concepts (primary feedback). In order to provide students with both knowledge- and application-style questions, which are two of the four categories of assessment according to *Growing Success* (Ontario Ministry of Education, 2010), a document that acts as a guide for all secondary education institutions in Ontario. With this design, the teacher was able to provide formative assessment for two Ministry-mandated assessment categories. However, Betty's suggestion may lead to a structure that would yield more definitive results for knowledge-based feedback in future iterations of the study. The idea of a fill-in-the-blank question also appeals to me because if the secondary feedback is to be a question (as it is now), it should be in the same format as primary feedback provided. Particularly with the age group of this study, pivoting between the assessment categories of knowledge and application, and asking them to understand the connection between these categories without teacher support, may have been asking too much of the students. In other words, expecting the students to create linkages between understanding of the mathematics concepts and then applying these concepts might have been too ambitious. The results of the concept mapping exercises are further evidence of the lack of support for using the CMfL tool may have been an issue. Generally, the first one or two exercises completed by students do not show much improvement between their first and second attempts at the pairwise ratings exercises. This indicates a need to acclimatize to CMfL as a learning environment. This finding can likely be extended to the types of feedback being provided, as well. If the primary feedback to is be within the knowledge category, then the secondary, question-type feedback should also occupy this realm. Further to Betty's suggestion that the question be fill-in-the-blank, future iterations of this study could repurpose the information that was used as primary feedback as the question that is used as secondary feedback. This would mirror the repetitive nature of the pairwise ratings exercise, wherein the assumption is that after engaging with the feedback, a user's second concept map will be an improvement.

The impact that CMfL had on student achievement is difficult to discern in isolation. The small sample number, coupled with the truncated period of data collection, means that fluctuations in student achievement scores should not be considered statistically significant.

Observing the results of all of the students' achievement across the three milestones in the study (see Figure 16), the most noticeable trend is that student results increased after the second milestone, and decreased after the final milestone (the final exam). The most probable reason for this dip at the end of the course is the final exam. The students in the sample group were in Grade 9. According to the Ontario curriculum, this is the first time that these students would have written a final exam as part of a culminating evaluation. This suggests that the effort that the students put into preparing for the exam may not have been adequate. Research by Warren (2010) suggests that bridging the gap between Grade 12 Advanced Placement English classes by preparing high school students to be evaluated as college students resulted in better student achievement in the first year at a post-secondary institution, although it did not result in tangible improvement on AP English evaluations, which are graded based on a stringent template. I believe these results may hold true for any major academic transition, including moving from Grade 8 to Grade 9 in Ontario.

Moving away from the students' specific milestone results for the survey questions, and into their average achievement over the course of the study along with their utilization of CMfL led me to some further assertions. Firstly, not all of the participating students completed the exercises available to them through CMfL. In fact, only three of the six participants completed all seven exercises available. This finding suggests that students were not effectively motivated to engage with CMfL, which corroborates with the student survey results.

Exploring the relationship between student achievement and improved concept maps, as recorded on CMfL, reveals that of the three students that completed all the concept mapping exercises, two saw improved results in their concepts maps after engaging with the automated feedback in five of the seven exercises. Delving deeper into these students' (Burt's and Stan's) results shows that in both cases, the first concept mapping exercises did not see comparative improvement, but that five of the remaining exercises did see improvement. This could indicate that the students' ability to integrate CMfL into their learning processes improved after first use of CMfL That said, it is also possible that the difference in the subject matter between the mathematics units could be responsible for this improvement. If assuming those results do mean that Burt and Stan successfully integrated CMfL into the way they learned, I am also assuming that subsequent exercises were likely better understood by these two students. These evidence-based assumptions led to a number of results that can be categorized as improvements. Roger also completed all exercises but saw improvement only once. Looking into these results, Roger's first concept mapping exercise shows improvement, while all six other exercises were stagnant. Observing the concept maps generated in exercises two through seven, it can be seen that all relevant and extraneous links are present, and that there are no missing links. Roger may have realized the relative nature of the pairwise ratings exercise. By rating all pairs of concepts the same in a concept set (for example, rating all pairs of concepts at 3 in an exercise), this student was able to see all correct and extraneous links, and therefore would not see any missing links. A lack of missing links means that the student would not have the opportunity to engage with the automatic feedback, effectively defeating the purpose of CMfL from the perspective of using formative feedback to aid learning.

Analysis of student achievement further solidifies the findings that frequency of use of CMfL may be associated with higher student achievement. I have already mentioned that Burt and Stan seem to have been able to utilize CMfL as a learning tool over time, which was reflected in the number of improved concept maps they produced while interacting with the feedback and completing the exercises. Observing their achievement also reveals that relative to their peers, they achieved at or above the median of the students' results.

Based on student achievement, engagement with CMfL, and the student survey responses, my findings indicate:

1. Increase in frequency of engagement with CMfL may support student learning
2. CMfL is useful as an introduction to the mathematical concepts being taught, but may not be ideal as a tool for revision of concepts
3. Students' motivation to use CMfL is low, but improving specific aspects of the usability and visual appeal of the system may improve adoption

The last set of data came from the formal interviews that were conducted with the teacher. Analyzing the teacher's interview responses using the previously established set of emergent codes, some key themes emerged. Many of the teacher's interview responses were coded as referring to the usefulness of CMfL for teachers, hence the emergence of this theme. Analysis of the teacher's statements reveals how CMfL was useful in the context of this study, as well as how valuable the teacher felt that CMfL could be in larger studies and in other subjects. Focusing on the study-specific comments recorded, there are a few responses I discuss in more detail in this section. Firstly, the teacher mentioned his appreciation for how CMfL could be used independently by students. He specifically stated that "[he] like[d] that students can [use CMfL] independently… They can sort of, police their own studying and learning that way." The teacher identifying this feature makes sense, as the research site's relationship to Montessori educational philosophies means that learning tools that provide students with the freedom to engage with them when and where they want to are valued. At the beginning of the study, it was posited that CMfL would fit into the research site's philosophies, so this statement by the teacher acts as confirmation that CMfL can be of value in this setting. Further to the student-driven nature of CMfL, the teacher appreciated that CMfL did not require significant set-up. The teacher stated in the interview that he felt that CMfL "require[d] very little additional effort on my part," which meant that the teacher found it very easy to implement into his teaching practice in the context of the interview. However, this finding should come with the caveat that, were a teacher new to a subject try to implement use of CMfL while still developing classroom material, and without the outside assistance of a researcher like myself, he may find that setting up CMfL would be a more time-consuming process. I specify that this caveat applies to teachers that would be new to a subject because my assumption is that these teachers would need to develop much of the material they utilize in class. If this was the case, and the material then needed to be adapted to fit the format of CMfL, the process might feel onerous. For my study, the teacher had already developed the teaching material utilized, so working together to adapt it for CMfL may have been a small extension of existing work. The teacher also spoke the usefulness of CMfL as a tool for assessment of student learning. Across both interviews and different questions, the teacher noted that there was great value in using CMfL as way to tangibly show the progress of student understanding in a novel way, without the use of a traditional test/quiz. The teacher had previously worked as a mathematics teacher in England, and reflected on that experience, stating that "sometimes, in fact often, you need to provide evidence of progress as a teacher. And this would be an effective way of doing that, because you could give the students these maps to complete before having taught them something, and then after, and you'd have concrete evidence showing that they've improved hopefully." The teacher also referred to "ah ha" moments, where students would struggle with understanding concepts, but would experience a breakthrough through the use of CMfL, The teacher provided the specific example of one of the student-participant's grappling with Pythagorean theorem, and how the relationship between the sides of a right-angle triangle were related. The teacher noted that, with assistance from the targeted feedback provided by CMfL, this student-participant was able to achieve understanding. The teacher also articulated how valuable CMfL was as a tool that allowed for a teacher to see assessment "for" and assessment "as" learning, rather than assessment "of" learning. The teacher specifically stated that CMfL was valuable as a "different way that we can assess, particularly in math, because we get pigeonholed into assessment 'of' learning, with quizzes and tests and whatnot, any sort of different method that reaches into the assessment 'for' learning or 'as' learning is very much appreciated. They're few and far between sometimes." A reoccurring response was that CMfL was very valuable in the subject of mathematics, as it was much more common and easy to find traditional tools (e.g., quizzes, tests, assignments).

In terms of how CMfL informed the teacher's instruction, from the teacher's perspective CMfL was most useful in helping facilitate one-on-one interaction with the student-participants. The teacher felt that it made it very easy to address "fires" when it came to student learning, as he could see which concepts students were repeatedly struggling with and intervene as he saw fit. However, the teacher also volunteered that CMfL did not affect his classroom teaching methodology. The teacher indicated that the "small sample size" made him feel that class-wide trends were not easily observable. This will be discussed further in reference to the theme of improvements that can be made to CMfL. The teacher also spoke to the transferability of CMfL. The teacher felt that CMfL could be used in any school subject, and provided examples of how use of CMfL had resulted in paper-based concept maps were being utilized by teachers and students at the research site in courses such as English, Science, Media Studies, and Career Studies.

Another prevalent theme in the teacher's interview responses was the usefulness of CMfL for students (from the teacher's perspective). The teacher mentioned more than once that CMfL was valuable for helping students make connections between mathematics concepts. In other words, CMfL was useful for helping students understand the relationships between mathematics concepts, and therefore facilitated the theoretical understanding of the mathematics concepts being taught. These findings correspond to the student survey responses. Across the set of three surveys, at least three of the six participants consistently stated that the CMfL website was useful for helping them understand the concepts being taught. With the teacher's feedback as supporting data, my initial conclusion is that CMfL is useful for assisting students in understanding mathematics concepts. The teacher further found that the feedback provided by CMfL was useful for aiding in student understanding. Once again, this corresponds to the student survey responses. This correspondence in findings between the teachers and the participating students suggests that CMfL was a valuable and useful tool for students and teachers. Further strengthening this argument, the teacher felt that CMfL would be useful for students of "any age or ability" due to the "lightness" and "efficiency" of CMfL for use by students. However, the teacher did also state that the older student, the more valuable CMfL would be. The teacher found that he informally heard positive things about CMfL from certain students around how useful it was, but that these were the students who appeared to be engaging with CMfL more frequently and "honestly" (as the teacher put it). This frequent engagement with CMfL aligns with some of the initial findings from analysis of the student data, which suggested that those who engaged more frequently with the tool responded more positively in survey questions, and generally performed better with respect to student achievement according to the teacher's records. The teacher mentioned the lack of visual appeal as an impediment to student usefulness, which is again something that completely aligns with the student feedback. The lack of aesthetic appeal was frequently cited by students as being a deterrent to using the website.

Another emergent theme was around cognition with respect to CMfL, referring to strategies that support information acquisition. During the coding process, cognition emerged as a code that applied to many of the statements the teacher made. Concept mapping itself is an elaborative cognitive strategy, making the emergence of this code unsurprising. Whether teacher-created (Jacobs-Lawson & Hershey, 2002) or student-centred (Buldu & Buldu, 2010), what makes the use of concept maps effective is that they require the learner to critically consider the organization of the knowledge, the relationships between concepts, and to assimilate this new knowledge into their existing understanding of the subject being studied. One of the most powerful statements that the teacher made regarding that was coded as cognitive related to student use of CMfL was his belief that CMfL would result in some learning occurring by engaging with it at any level. The teacher stated that CMfL "would be useful, rolled out to a classroom of any ability really." The teacher went on to say that "[going] through the motions will tell you information [required] to learn a particular unit," but also qualified these statements by saying that better learning would occur for students that wanted to engage with CMfL. In other words, the teacher came to the conclusion that CMfL would result in some learning regardless of student engagement, an important finding. CMfL inherently forces students to consider the relationships between mathematics concepts they are being taught, and therefore results in knowledge acquisition to some degree. This aligns with both literature findings and the evidence-based assertions I have made.

The teacher also stated more than once that use of CMfL drove debate about which concepts should and should not be linked; the teacher recalled students suggesting that certain relationships that were not linked on referent concepts maps should have been, and that students would justify their positions, which is evidence of critical thinking skills being developed amongst the participating students. The teacher also offered specific examples of how CMfL helped a certain student understand the right-angle triangle relationships in the Pythagorean theorem. The teacher stated that the combination of the visual links between concepts on the concept map, as well as the feedback provided by the website, helped one particular student's understanding significantly. These findings support the assertion that CMfL can be used for self-regulated learning. It also supports the theories presented around the use of targeted formative feedback that I have presented. The teacher also offered some feedback on how CMfL could become even more valuable from a cognitive perspective. In its current iteration, CMfL highlights missing links in red, shows extraneous links in grey, and correct links in black. The teacher offered the suggestion that learning would be improved by adopting the “traffic light” colour scheme to the website. If green represented correct links, yellow showed missing links that required attention, and red showed incorrect links (as it does now), the impact for students would be much stronger. The teacher indicated that from his observations, participating students did not consider extraneous links mistakes; the participating students were solely focused on having all the correct links on their maps.

Successful use of CMfL means that aspects of metacognition are at play, another theme represented in the teacher’s responses. As visual representations of knowledge organization, concept maps can be used as feedback to clearly highlight one’s specific areas of conceptual understanding or lack thereof (Trumpower, Sharara, & Goldsmith, 2010), and students can easily monitor their developing understanding across successive concept mapping activities, thereby facilitating metacognitive awareness. It is immediately apparent by the number of statements the teacher made that from his perspective, CMfL was a stronger tool from a cognitive perspective than a metacognitive perspective. That said, there are many factors that relate to metacognition that need to be met for CMfL to be considered a useful tool in that arena, and those factors can be derived from the teacher’s statements. On the positive side, the teacher mentioned multiple times that students were using concept maps as a learning and study tool, in mathematics and in other subjects. This was not a phenomenon that was noticed prior to introduction of CMfL. Additionally, due to the increase in student use of concept maps, other teachers were adapting their practice to include concept maps as a teaching aid. As previously mentioned, the teacher noted that concept maps were being used in other subjects being taught at the research site. The teacher provided the example of a course called Media Arts, where the teacher was using concept maps at the beginning of study units to provide an overview of what students would be learning and how subjects within the course were related. For both students and teachers to increase utilization of concept maps indicates a recognition of the value of concept maps as a learning tool, especially since both parties were integrating use of concept maps into their practices more regularly. However, the teacher was not able to provide any examples of concept maps being used for assessment, or to provide feedback, as they do with CMfL. This indicates that concept maps, as a tool, only ingratiated themselves so far into the students' and teachers' learning and teaching practices. The teacher also specifically noted that he did not feel that the participating students were gaining as much insight or understanding from CMfL as they could be. He stated that although there were specific examples of students engaging in debate about which concepts were connected or not, or that specific learning (Pythagorean theorem) was occuring, these were exceptions rather than rules. The students that completed CMfL exercises did so in a relatively rote manner. The teacher felt that age may have played a factor in this finding. He felt that older students would have a better idea of the value of engaging with the CMfL process, and therefore would be able to adjust their learning practices better. Regarding older students, the teacher stated that "as you get older, you want more and more ways to ensure that you're picking up the material, to ensure that your knowledge is on the right track, particularly in the latter years of high school and in the early years of university, when you need that confidence, you need to know that you're doing things correctly." This is one of the aspects of metacognition that may have prevented CMfL from being as useful as possible to this group.

Motivation for both students and the teacher was a factor that would have contributed to deriving more use from CMfL, had one or both parties felt compelled to engage with the tool.

The teacher explained in the formal interview that he offered class time to students to complete the CMfL exercises, and despite this, three of the six participants did not. This initial finding aligns with the results provided by the students in the surveys that they participated in. Many students in the sample did not engage with CMfL very often, with the aesthetic appeal and usability of the system most frequently and consistently cited as deterrents. I also feel that there was an opportunity for the teacher to use the students concept maps to alter his teaching methods. As mentioned, the teacher did indicate that he felt that the small sample size meant that the CMfL results were better for informing one-on-one interactions with students, but the general student achievement leads me to believe that the teacher could have modified his practices based on the data that was available. The educational philosophies of the research site pertaining to student independence also meant that the teacher expected students to come to him to discuss the CMfL exercises. Student-directed conversations with the teacher did occur, but these students were described as "high achievers" by the teacher and were therefore probably (at least relatively) more motivated to use CMfL. This indicates that some of the participating students may have needed extra feedback based on their CMfL results and achievement, but may not have received it.

The teacher also noted some improvements that could make CMfL more useful. Firstly, the teacher felt that using CMfL from the beginning of a subject would render it more valuable to both students and teachers. This study launched near the end of the school year, so the teacher felt that we may not have been able to engage students as fully as we could have. The teacher also noted that a reporting function would make CMfL much more useful for teachers. Even with the small number of students participating in the study, the teacher felt that there was no easy way to observe trends in class-wide student learning. This is part of the reason that CMfL was only used to inform one-on-one interactions with students and did not affect his classroom instruction. From the cognitive perspective, the teacher suggested that a "traffic light" model that was previously described. The teacher felt that the negative connotation that should be associated to extraneous links (in addition to the negative connotation associated to incorrect links) was not being communicated by CMfL, and offered this suggestion as a solution. The teacher also mentioned that adoption of CMfL may increase if the website was available in a mobile format so that students could interact with it on a smartphone or tablet, which was also suggested by some of the participating students. Finally, the teacher mentioned that from the perspective of the usefulness of CMfL for students, the format would benefit greatly from being "gamified." The teacher mentioned that modeling the pairwise ratings exercise similarly to the way quizzes are presented on popular websites such as Facebook or Buzzfeed would greatly encourage students to use CMfL more often.

Tying into some of the comments the teacher made with respect to how CMfL was useful for teachers and students, the teacher felt that CMfL would be most useful for students if it was introduced at the beginning of the school year. The teacher explained that from the perspective of students, having CMfL utilized right at the beginning of a course would indicate to them that it was to be used as a regular part of their schooling, as opposed to an extra (or extraneous) tool that was optional. In this way, he believed that students would have engaged more frequently, and with greater vigour. Speaking from his own perspective as a teacher, he also stated that it is simply easier to introduce new assessment methods like CMfL at the beginning of the year to interest students. Further to the link between usefulness for teachers and usefulness for students, the teacher mentioned that students and teachers were utilizing concept maps in other subjects. He indicated that CMfL may have precipitated the use of concept maps as a teaching and learning tool. At the very least, this was true for the teacher-participant, as he is also responsible for the Science course being taught. If concept maps are being viewed favourably by both teachers and students at the research site, this validates the core usefulness of CMfL as an education tool in this environment.

I believe that the results obtained in this study verify the assertions that I had regarding use of CMfL in a Montessori environment, but that the degree of verification varies. With respect to supporting student learning, I think that the results show that CMfL is a tool that can provide this supportive capacity. However, there are many facets to student learning that CMfL needs to be revised to address to be as effective a tool as I had thought and hoped it would be. Firstly, students need to want to use CMfL. In its current state, these results indicate that they do not. Although it has been mentioned many times to this point, the lack of visual appeal and rudimentary user interface were impediments to student adoption, according to the student surveys and the teacher's observations. At least for the age group that this study was focused on, improvements in presentation of CMfL are required to allow for students to truly engage with CMfL and use it to its full potential. The students at the research site are in a unique environment, where they have the opportunity to study and learn in ways that they feel suit them best. This means whatever tools and methodologies they want to use to independently study are encouraged. Since the teacher acts as more of a guide through the material, as opposed to an instructor, enforcing a study practice that is meant to be independent can be difficult. This is coupled with the school's philosophy around independent study, meaning that a teacher that adheres to the philosophy strictly would probably not want to force use of a specific tool. When embarking on this study, I assumed that students that are often introduced to alternative and innovative ways of learning would be excited to engage with CMfL. However, I think that the lack of visual appeal contributed to a feeling of mundanity, for lack of a better term. I believe the feeling around CMfL was similar to what I'll refer to as the "roller coaster" effect (keeping in mind I do not claim to have invented this terminology and definition). If a person is on a roller coaster for a very long time, the thrill of the ride is diminished; one can only be exhilarated by a hundred-foot drop so often within a limited span of time. With CMfL being introduced as yet another study methodology at the end of an academic year, my suspicion is that it may have been one hundred-foot drop too many for the participating students.

There are also many intangible factors that I believe have contributed to the results as presented. Firstly, I had assumed that use of CMfL as a study tool would increase student achievement, defined as the grades students received on evaluations, that contributed to their overall achievement (or final grade) in the course. Based solely on the quantitative results of the students' achievement, CMfL cannot be defined as having a statistically significant impact on student achievement. As the teacher mentioned in his interview, the timing of when the study took place was problematic. The teacher was referring to this issue in terms of student adoption, but I believe that the problem runs deeper than that. The study period was located late in the academic year, and included the exam period. It totalled about six weeks of the school year. This means that the majority of student evaluations had already taken place, and therefore the majority of "weight" for academic scores that would make up a student's final grade was accounted for. As such, a given student's final grade could only shift so much based on their academic achievement during the study period. a student would need to significantly outperform their average achievement, either positively or negatively, for a truly noticeable change in final grade. To attribute any change in achievement to CMfL, again either positively or negatively, contextual information around the students' completion rates, in comparison to their individual achievement results were required. This data does indicate that students that completed more CMfL exercises performed slightly better than their peers, but results of this nature would have been easier to observe if either the study had occurred over a longer period, or if student achievement had been baselined at the beginning of the study. The disadvantage to baselining student results in this specific study however, would be that the truncated data collection period means that students would have only had a few evaluations (a quiz, a test, and the final exam) over the course of the study. This may have skewed results in the opposite direction, meaning that major changes in achievement scores could have been observed, but attributing these changes solely to CMfL would have been difficult.

As mentioned, the data collection period included the results of the final exam. This is significant because, for the student participants of this study, this was the first time that any of them had written a formal exam. I believe that this helps to explain the net-drop that occurred in overall student achievement at the end of the data collection period, and also explains why the student survey responses were more mixed in the final survey. Based on some of the informal conversations that the teacher and I had leading into the final exam, he expressed some concern around how the students were preparing for the final exam. I believe that this aligns with the results obtained. It seems that the students in the class may not have understood the breadth of material that the exam would cover, and therefore were not prepared to be evaluated on the academic year’s worth of mathematics material. The final survey was administered immediately after the exam. I believe that this contributed to the results of that survey. My suspicion is that many of the students realized upon completing the exam that they did not perform as well as they may have hoped or expected to. In particular, the results of the survey question around use of CMfL as a tool for revision were much more mixed than they were on the previous survey. I suspect that these results may have been a reaction to writing the exam. With that said, the mixed or negative feedback regarding CMfL should not be disregarded for contextual or interpretive survey feedback like this. It should be taken in earnest, as CMfL can be effective, but can also be improved.

Some of the improvements are directly related to teacher use of CMfL. Although the teacher did provide some very enthusiastic feedback about CMfL, and clearly stated that he would use CMfL again, there are some improvements that were suggested that would strengthen CMfL immensely. The teacher's suggestion of creating a reporting tool that would provide a printout of which links students were missing would make CMfL much more usable from an assessment perspective. If CMfL can provide this data in a concise way, as opposed to now where the teacher would need to go through each student's results for each exercise, it would provide clear feedback to the teacher on areas of weakness regarding student understanding. This was further underlined by the fact that the teacher provided this thought in this particular scenario, when he was managing only six students. If using CMfL to inform the teacher's classroom instruction with a group that small is still too cumbersome, it would be difficult to expect teachers with more students use CMfL in that way as well. It is my feeling that analysis of student concept maps can inform the teacher's classroom teaching practices, and aid in recognizing subject matter that students need further instruction on. However, it's clear that CMfL as currently designed cannot meet this need, based on the teacher's use of CMfL. Using CMfL to only inform one-on-one student interaction, as opposed to using it to address one-on-one and classroom interaction, is inefficient use of a teacher's time with CMfL. The made many comments indicating that CMfL was very useful, but in a classroom with a larger class, I suspect that the findings would have been more negative.

Limitations

Limitations to this study included the small sample size of the student population, the timing of when the study occurred, lack of student engagement with CMfL, CMfL's lack of visual appeal, and the teacher's limited utilization of CMfL. Regarding the sample size issue, as currently designed, the group of participating students numbered six. As such, the study has very low power for any statistical analyses from survey results. This was one of the reasons that the study was designed to collect qualitative data (teacher interviews) as well as quantitative data (student achievement, student surveys). If the methodology of this study can be reused in a larger classroom, data of greater statistical power may be obtained.

Another limitation of the study is that it began late in the academic year, for both the students and the teacher. The timing of the study may have affected student engagement. Having participation in CMfL be an addendum to students' current study practices resulted in lower than anticipated completion rates of the CMfL exercises. This means that the data obtained from CMfL was incomplete, and any analysis from said data had to be verified through the survey results and teacher responses. In future, richer data would be obtained if CMfL was ready for students to use at the beginning of a course.

The issue of student engagement is also related to CMfL's lack of visual appeal, which data collected from both the students and teacher revealed was a deterrent to adoption. Both students and the teacher cited this as an obstacle for use. Furthermore, both student responses and the teacher's feedback indicated that CMfL would have been much more popular had it been available as a mobile application. According to the teacher's experiences and observations, students were much more comfortable using mobile devices such as smartphones. If CMfL can be redeveloped to appear more like quizzes on websites like Facebook or Buzzfeed, the teacher hypothesized that student use would increase dramatically.

Although a condition of participation in the study was for the participating students to complete all CMfL exercises, this did not happen. Based on the survey results, many cited the lack of visual appeal as a reason that they did not want to use CMfL. Some also noted that they did not find CMfL useful. Some specific comments note that the amount of information being provided by CMfL was overwhelming. In considering all these factors, there are many modifications to the design and methods that might be useful for similar studies in the future. Firstly, if it is not possible to launch CMfL in-line with the beginning of a course, it would be best to reduce the number of exercises students are required to complete. The teacher wanted to use CMfL as an opportunity to provide an additional avenue for revision for students. This meant that CMfL covered materials from the course that had occurred weeks, or even months, before CMfL was made available to students. Although the provision of this material seemed like a good idea, it may have deterred some students from completing all of their assigned CMfL exercises due to the sheer quantity. Another factor to consider was the independence with respect to how students approached their learning. As mentioned, the Montessori learning philosophies applied at the research site allow for students to have some freedom with respect to how they work and study. CMfL was a foreign process that was introduced later in the academic year, meaning that many students had already established their work patterns. Since the students also did not have any required method of approaching their work, making CMfL completion mandatory was not something they were used to. If this methodology is adopted for a future study, it remains important to try to introduce CMfL at the beginning of the course. Otherwise, it would be best to reduce the amount of work students are expected to complete in CMfL.

Many steps could also be taken to improve the teacher’s utilization of the results from CMfL. Firstly, the CMfL’s inability to provide a summary of student results from a concept mapping exercise was flagged by the teacher as a feature he felt was missing. The inability to quickly see the performance of every participant in class meant that the teacher did not use the results of CMfL to inform classroom teaching. If he had been able to see, for example, that many students in a group struggled with understanding how the hypotenuse was related to the Pythagorean theorem, he would have been able to re-address the subject within a classroom instruction scenario or alter his teaching method in the future. Having to go through each student’s results individually meant that the teacher did not quickly see patterns in student understanding, and therefore did not use CMfL to address potential student needs. This was despite the small number of participants. Many teachers will not have the opportunity to work with such a small group of students over the duration of a course, meaning that CMfL would need to be revised to have a reporting function for teachers to derive value from CMfL.

Despite these limitations, major findings of the study derived from the student results from CMfL, the student surveys, and the teacher interviews are:

- CMfL is useful for providing on-demand, formative feedback, but would have been more useful if students used it more frequently or considered their results from the system more carefully.
- CMfL was a useful tool for providing the teacher with data that informed his individual interaction with students.
- CMfL may have had a greater positive impact on both students and the teacher had they been motivated to use it.

- CMfL is a strong tool for the cognitive learning, which aids in its ability to act as a tool for self-regulated learning.
- CMfL is a moderately useful tool for metacognitive learning. While it can be a useful tool for self-regulated learning, it may be preferred by students that are older than those in this sample, as they are, in the experience of the teacher, already more intrinsically motivated.

Implications for the Field

CMfL is a tool that can be utilized to help students find the intersection between conceptual knowledge and the critical consideration of that conceptual knowledge. On a small scale, the study helped illustrate CMfL's potential value for developing conceptual understanding, and how formative feedback can aid student learning. The students that used CMfL more often, and completed more exercises, generally saw some improvement in their achievement. There are many ways that this study can be modified and extended that would result in impactful results. Firstly, driving adoption relies on improving the visual appeal of CMfL, and making it mobile friendly. Reconfiguration of the visuals of CMfL would be my first step before introducing the tool into a classroom again. Amongst the visual aspects that would need be reconfigured, I would want to change the colours of correct, missing and incorrect links on student concept maps so that it is immediately apparent to students that both incorrect and missing links require reflection.

The next priority would be to add the previously described reporting function for teachers, which would allow for teachers to use CMfL in a much more effective and efficient manner, as it would make it much easier to determine problem areas for an entire class. As currently configured, CMfL can still easily provide insights into an individual student's understanding. Extra effort is required on the part of the teacher to find patterns of misunderstanding across classes, since the teacher would need to look at each individual student's maps to observe trends.

While the implications outlined up to this point speak to extending CMfL itself to improve its effectiveness, they do lead into the implications of how CMfL can affect classroom instruction. Within this study, the teacher attested to how effective CMfL was for informing his one-on-one interaction with students. With a smaller class like the one in this study, this ability to quickly assess each sutdent's understanding, which can then be used to inform an interaction between the student and teacher, can be invaluable. If students engage with CMfL, it can provide a teacher with regular, quick feedback to determine problem areas that students may be experiencing. By reviewing the student-generated concept maps, a teacher can easily approach a student and have a discussion tailored towards the perceived misunderstandings that the student has based on their concept maps. This level of personalized instruction can be greatly beneficial for students and can help a teacher understand the issues that a particular student may be experiencing. It is also possible that a teacher may realize a deficiency in the way he was instructing when it comes to a certain topic, and make adjustments. For a student with sufficient motivation, CMfL can also shift the dynamic of responsibility with respect to learning. For instance, the teacher pointed out how, according to the Ontario mathematics curriculum, measures of assessment for, as, and of learning are required. From the perspective of the teacher, assessment for learning and assessment of learning is harder to do for mathematics classes. Traditional mathematics assessments and/or evaluations are usually quizzes or tests, both of which are examples of assessment of learning. CMfL can be used as assessment for learning, in that the tool automatically identifies strengths and weaknesses on the generated concept map, and points to next steps by providing both descriptive feedback and an example problem for students to work through for missing links (as per the configuration utilized in this study). Additionally, as designed for this study, CMfL results did not count towards academic achievement. CMfL was purely meant as an activity to provide a learning opportunity for students. As a tool for assessment as learning, CMfL involves monitoring of progress and reflection on results by students. Since the activity was student-driven, it also ensured that ownership and responsibility for learning and enhancing learning and understanding belong to the student, which links back to the metacognition theme that applied throughout the study (O'Connor, 2002). CMfL is a tool that can be used to further emphasize that student learning depends on the student being active and engaged in the learning process. Although the teacher remains an important part of coordinating the classroom and environment and providing instruction, independent learning is a skill that students must continue to improve as they get older and move into different tiers of educational study, or even within their personal and professional lives. While CMfL may not be the solution to making students stronger independent learners, it can be used as an aid to begin the process of having students drive their own learning, and consider their strengths and weaknesses in a space where they can make mistakes without academic consequences, from the privacy of their own computer screens. In other words, shifting the responsibility of knowledge development or acquisition to students and away from teachers could be a major implication that implementation of CMfL could help drive. From a practical perspective, it would be beneficial to have feedback available not just for missing links, but also for extraneous links. This would be a substantial amount of work; when designing the referent concept map, considerations would have to be made for every potential extraneous link, and feedback would have to be situated differently. Currently, feedback in missing links explains why the two concepts should be related. Feedback for extraneous links would need to explain why two concepts are *not* related. This distinction would have to be very clear, to prevent student confusion. With that in mind, the fact that extraneous links are technically also incorrect needs to be emphasized based on the findings of this study.

Conclusions

The results of this study support the assertion that a concept mapping website that provides on-demand formative feedback can be an integral tool in an environment where independent learning is a core pillar of the educational philosophy. This finding can be extrapolated out into later high school, post-secondary, and even real-life working scenarios. The ability to learn independently is imperative to future success in any context, be it academic or otherwise. The findings of this study suggest that concept mapping can sit alongside more commonly used strategies leveraged by the teacher in this study, such as reading, note-taking, and educational videos to ensure long-term knowledge transfer occurs, with some caveats. First amongst these caveats, students need to be motivated to use tools like CMfL. Secondly, for teachers to derive maximum value, a reporting function that can produce a printout of results must be added. CMfL, or a similar tool, can be beneficial to both students and teachers, but it must be easier for both parties to use before its maximum utility can be achieved, and therefore maximum benefits can be realized.

With these implications in mind, there are many future research opportunities to consider. More fulsome results using the methodology outlined in this study would be achieved in two ways. Firstly, implementing CMfL as it is currently configured in a classroom with older students would probably produce more complete data, at least from completion of the CMfL exercises. The teacher pointed out that, in his experience, tools like this have a greater impact on older students that have greater motivation to perform well in their classes. Whether this is because of extrinsic motivation (such as obtaining admission to a desired university or college program) or intrinsic motivation is hard to specify, but the teacher’s experience in this regard should not be ignored. To get complete results from a group of the same age as the participating students in this study, the visual appeal of and usability of CMfL needs to be overhauled. This was frequently cited as a barrier to student use. Ideally, CMfL would be rebuilt as a website that adapts to mobile devices. Use of mobile devices was cited by both students and the teacher as a way to drive student adoption.

Future studies would also benefit from a larger student population. With only six participants, the data derived from this study is very specific to this scenario, with theoretical implications. The conclusions of this study are of low statistical power. If a larger class participated, it is possible that statistically significant quantitative results would be obtained. With that in mind though, if the expectation remains for the teacher to use CMfL as a tool for both one-on-one interaction and classroom instruction, a reporting feature would need to be added. If the teacher is unable to quickly determine trends in student weaknesses, it is unlikely based on the results obtained in this study that CMfL would be considered very useful by him. It may still be useful for students from a metacognitive lens, but based on the questions posed in this study, CMfL would need to be improved for teachers as well.

Appendix: Letters of Assent and Consent

Letter of Assent for Students

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Letter of Assent

Project Title: Montessori Grade 9 Students and Their Use of an Online Concept Mapping Website: A Case Study Exploration of Their Relationship

Principal Investigator: Arun Vanapalli

Supervisor: David Trumpower

What is a research study?

A research study is a way to find out new information about something. You do not need to participate in a research study if you don't want to participate.

Why are you being asked to be part of this research study?

You are being asked to take part in this research study because we are trying to learn more about how feedback that's provided automatically by a computer program may help you learn. We are asking you to be in the study because as a student at The Element, you have independent time to work on subjects and can access the computer program during this time.

If you join the study, what will you have to do?

- You will be given a username and password for a website, called the "online concept mapping website"
- You will be asked to log in to the website and complete an activity that will result in a concept map about the subject you are studying
- By completing the activity and generating the concept map, you will also gain access to feedback that may help you learn more about the subject you are studying
- At the end of a regularly scheduled test, quiz, or assignment, you will be asked to complete a short survey about how you feel about the online concept mapping website
- Every time a new chapter or unit begins, a new concept mapping activity will be made available to you through the online concept mapping website; you will be asked to complete this activity, and then after the regularly scheduled test, quiz, or assignment from that chapter or unit, you will complete the same short survey
- You can use the concept mapping website as many times as you want
- You will be in the study for four to six (4 to 6) months

Are there any risks to being a part of this study? There are no risks to joining this study.

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Will the study help you? This study may be able to help you focus on areas of a subject that you may not understand as well as you want to. It will also help highlight areas of a subject that you are doing well in. Since the online concept mapping website can be accessed at any time, you can use it to get feedback, examples, or explanations about subjects without having to wait to speak to a teacher. The online concept mapping website can also be used as a study tool.

Will the study help others?

This study might be able to help your teacher identify areas within a subject you need help with, or help him/her design and deliver better lessons that focus on aspects of a subject that students in your class may need extra help with.

Do your parents know about this study?

Your parents will be informed about your participation in this study as well. You can talk this over with them before you decide.

Who will see the information collected?

The information collected will only be the concept maps you've generated through your use of the online concept mapping websites, and your survey responses. The concept maps you've generated will only be seen by your teacher, and the survey results will only be seen by the Principal Investigator and Thesis Supervisor listed at the top of the study. All the survey information will be securely locked away in a file cabinet in the office of the Thesis Supervisor, on the University of Ottawa campus. No personal information (for example, names or birthdays) will be collected at all.

Do you have to be in the study?

You do not have to be in the study. There is no penalty for choosing to not be a part of the study. In other words, choosing not to participate will have no effect on your grades whatsoever. If you don't want to be in this study, you just have to tell us. You can change your mind and stop being part of it at any time. All you have to do is tell your teacher, or ask your parents to tell the teacher or the Principal Investigator. If you choose not to participate in the study, you will still have the option to use the concept mapping website if you would like to. Your concept maps will not be collected, and you will not participate in surveys.

What if you have any questions?

You can ask any questions that you may have about the study, at any time. To ask questions, please ask your teacher or your parents to contact the Principal Investigator by email at [redacted]. You can also take more time to think about being in the study, and talk some more with your parents about being in the study.

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Other information about the study.

If you decide to be in the study, then please write and sign your name below.

You will be given a copy of this paper to keep.

Once completed, please include this form along with the signed consent form from your parents in a **sealed** envelope, and return to a teacher at The Element High School by (insert date here).

Would you like to take part in this study?

_____ Yes, I will be in this research study. _____ No, I don't want to do this.

______________________	______________________	__________
Student's name	Signature of the student	Date
Arun Vanapalli	______________________	__________
Person who received assent (Principal Investigator)	Signature	Date

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Letter of Consent for Parents of Participating Students

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Letter of Consent

INVITATION TO PARTICIPATE

Title of the study: Montessori Grade 9 Students and Their Use of an Online Concept Mapping Website: A Case Study Exploration of Their Relationship

Principal Investigator
Arun Vanapalli, M.A. Candidate, Faculty of Education, University of Ottawa

Thesis Supervisor
David Trumpower, Professor, Faculty of Education, University of Ottawa

Dear parent/guardian,
Your child is invited to participate in the M.A. thesis research project conducted by Arun Vanapalli, under the supervision of David Trumpower. Thank you for considering this request.

Purpose of the Study: The purpose of the study is to examine how effective the use of computer-based feedback can be for improving learning for Grade 9 mathematics students

Participation: Your child's participation will consist of the following:

- Your child will be given a username and password for a website, called the "online concept mapping website"
- Your child will be asked to log in to the website and complete an activity that will result in a concept map about the subject they are studying
- At the end of a major activity (for example, a test, quiz, or assignment), your child will be asked to complete a short survey about how they feel about the online concept mapping website
- Every time a new chapter or unit begins, a new concept mapping activity will be made available to your child through the online concept mapping website; he/she will be asked to complete this activity, and then after the test, quiz, or assignment from that chapter or unit, he/she will complete the same short survey

Participation will be entirely online. Your child can complete the study anytime, anywhere. Your child will only need to have access to a computer with an internet connection.

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Risks: There are no risks associated with your or your child's decision to participate in this research.

Benefits: This study may be able to help your child focus on areas of a subject that he/she may not understand as well as they want to. It will also help highlight areas of a subject that your child is doing well in. Since the online concept mapping website can be accessed at any time, your child can use it to get feedback, examples, or explanations about subjects without having to wait to speak to a teacher. The online concept mapping website can also be used as a study tool.

Additionally, this study might be able to help your child's teacher identify areas within a subject he/she may need help with, or help the teacher design and deliver better lessons that focus on aspects of a subject that students need help with.

Confidentiality and anonymity: Your child's participation will be anonymous and his/her data will be stored with a special code. There is no way to determine your child's identity in the study as he/she will not be asked for any personal individual identifiers such as name, address, or prior schools of attendance. Your child's teacher will access the concept mapping website to review your child's concept map for teaching purposes.

Conservation of data: The data gathered from participants will be stored in the Principal Investigator's computer and only the Principal Investigator and Thesis Supervisor will have access to all of the data. Your child's teacher will have access to the concept maps only. In order to ensure confidentiality of electronic data, completed data will be printed. The electronic data will be removed from the Internet. Printed data will be used to analyze and evaluate data. All paper data (printed data from the online concept mapping website and surveys) will be stored in a locked file cabinet in the supervisor's office, where it will reside for five years after the complete data collection at the University of Ottawa.

Voluntary Participation: Your child is under no obligation to participate and if he/she chooses to participate, he/she may withdraw from the study at any time and/or refuse to answer any given question. If he/she chooses to withdraw, all information your child provided will be destroyed and not used in the report or subsequent publications. Refusal to participate will have no negative impact on your child's academic achievement (grades). If your child chooses not to participate in the study, he/she will still have the option to use the concept mapping website if they would like to. Their concept maps will not be collected, and they will not participate in surveys.

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There are two copies of the consent form, one of which is yours to keep.

If you have any questions or require more information about the research project, you may contact the principal investigator, Arun Vanapalli, at [redacted] or his supervisor, David Trumpower at [redacted] or via phone at [redacted]. David Trumpower's office is located at [redacted]

If you have any questions regarding the ethical conduct of this study, you may contact the Protocol Officer for Ethics in Research, University of Ottawa, Tabaret Hall, 550 Cumberland Street, Room 154, Ottawa, ON K1N 6N5
Tel.: (613) 562-5387
Email: ethics@uottawa.ca
By signing this document, you have agreed to allow your child to participate in the study.

Please print this letter of consent for your records. Once completed, please include this form along with the signed assent form in a **sealed** envelope, and return to a teacher at The Element High School by (insert date here).

Parent/Guardian's name	Signature	Date

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Letter of Consent for Teacher

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Letter of Consent (Teacher Participant)

INVITATION TO PARTICIPATE

Title of the study: Montessori Grade 9 Students and Their Use of an Online Concept Mapping Website: A Case Study Exploration of Their Relationship

Principal Investigator
Arun Vanapalli, M.A. Candidate, Faculty of Education, University of Ottawa

Thesis Supervisor
David Trumpower, Professor, Faculty of Education, University of Ottawa

Dear participant,
You are invited to participate in the M.A. thesis research project conducted by Arun Vanapalli, under the supervision of David Trumpower. Thank you for considering this request.

Purpose of the Study: The purpose of the study is to examine how effective the use of computer-based feedback can be for improving learning for Grade 9 mathematics students

Participation: Your participation will consist of the following:

- You will be asked to distribute usernames and passwords to access the "online concept mapping website"
- You will approve formative feedback (in the forms of example problems, instructional videos or demos, and/or textual definitions) to be used on the online concept mapping website
- You will rate pairs of concepts related to the subject you are teaching so that an expert concept map can be prepared
- You will review student concept maps to see if student strengths/weaknesses can be determined by comparing student concept maps to the expert concept map
- You will observe student use of the online concept mapping website and listen to student conversations about the website, and record observations
- You will participate in interview sessions with the Principal Investigator after every test, quiz, or assignment that results in the completion of a chapter or unit of study
- You will have the opportunity to review all interview material should you choose to

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Participation will occur online for assessment of students' concept maps, and in person for the interviews.

Risks: There are no risks associated with your decision to participate in this research.

Benefits: This study may be able to help you identify areas within a subject your students may need help with, or help you design and deliver better lessons that focus on aspects of a subject that students need help with. This study may also help your students deepen their understanding of a subject independently, as the online concept mapping website will be set up to provide feedback as soon as they need it.

Confidentiality and anonymity: Your participation will be as anonymous as possible and your data will be stored with a special code. Only the Principal Investigator and Thesis Supervisor will be aware of your identity, but given the specificity of the class and school being utilized for this study, there is a possibility that you will be identifiable, particularly to your own colleagues and administration. Interview conversations will be recorded using the audio recording functionality of the Principal Investigator's cell phone, which will be password protected. Once the interview audio recordings have been transcribed into a word processor, the audio files will be securely deleted and the written interviews will be stored in the Principal Investigator's computer. In the final submission, your interview responses may be quoted, but you will not be identified. You will be referred to only a "the teacher."

Conservation of data: The data gathered from you will be stored in the Principal Investigator's computer and only the Principal Investigator and Thesis Supervisor will have access to data. In order to ensure confidentiality of electronic data, completed data will be printed. The electronic data will be password-protected on the computer of the Principal Investigator. Any audio recordings made on the cell phone of the Principal Investigator during the interview period will be transferred to the computer of the Principal Investigator and will be password-protected. Printed data will be used to analyze and evaluate data. All paper data (printed data from the interviews) will be stored in a locked file cabinet in the Thesis Supervisor's office, where it will reside for five years after the complete data collection at the University of Ottawa.

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Voluntary Participation: You are under no obligation to participate and if you choose to participate, you may withdraw from the study at any time and/or refuse to answer any given question. If you choose to withdraw, all information you provided will be destroyed and not used in the report or subsequent publications.

There are two copies of the consent form, one of which is yours to keep.

If you have any questions or require more information about the research project, you may contact the principal investigator, Arun Vanapalli, at [redacted] or his supervisor, David Trumpower at [redacted] or via phone at [redacted] David Trumpower's office is located at [redacted]

If you have any questions regarding the ethical conduct of this study, you may contact the Protocol Officer for Ethics in Research, University of Ottawa, Tabaret Hall, 550 Cumberland Street, Room 154, Ottawa, ON K1N 6N5
Tel.: (613) 562-5387
Email: ethics@uottawa.ca

By signing this document, you have agreed to participate in the study.

Please print this letter of consent for your records. Once completed, please return this form the Principal Investigator.

______________________	______________	___________
Your name	Signature	Date

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Letter of Consent for Expert-Participant

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Letter of Consent (Expert Participant)

INVITATION TO PARTICIPATE

Title of the study: Montessori Grade 9 Students and Their Use of an Online Concept Mapping Website: A Case Study Exploration of Their Relationship

Principal Investigator
Arun Vanapalli, M.A. Candidate, Faculty of Education, University of Ottawa

Thesis Supervisor
David Trumpower, Professor, Faculty of Education, University of Ottawa

Dear participant,
You are invited to participate in the M.A. thesis research project conducted by Arun Vanapalli, under the supervision of David Trumpower. Thank you for considering this request.

Purpose of the Study: The purpose of the study is to examine how effective the use of computer-based feedback can be for improving learning for Grade 9 mathematics students

Participation: Your participation will consist of the following:

- You will be given pairs of concepts related to the subject being taught to grade 9 mathematics students, and be asked to rate each concept pair on a scale from 1 to 5 based on how related you believe they are
- You will send the results of your rating of pairs exercise to the Principal Investigator
- You will be asked to do this up to 10 times over the course of the study

Participation will occur entirely online.

Risks: There are no risks associated with your decision to participate in this research.

Benefits: There are no benefits associated with your decision to participate in this research.

Confidentiality and anonymity: Your participation will be anonymous and your data will be stored with a special code. There is no way for others to

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determine your identity in the study as you will not be asked for any personal individual identifiers such as name, address, or prior schools of attendance. Only the Principal Investigator and Thesis Supervisor will be aware of your identity.

Conservation of data: The data gathered from you will be stored in the Principal Investigator's computer and only the Principal Investigator and Thesis Supervisor will have access to data. In order to ensure confidentiality of electronic data, completed data will be printed. The electronic data will be removed from the computer or cell phone of the Principal Investigator. Printed data will be used to analyze and evaluate data. All paper data (printed results from your rating of concept pairs) will be stored in a locked file cabinet in the Thesis Supervisor's office, where it will reside for five years after the complete data collection at the University of Ottawa.

Voluntary Participation: You are under no obligation to participate and if you choose to participate, you may withdraw from the study at any time and/or refuse to answer any given question. If you choose to withdraw, all information you provided will be destroyed and not used in the report or subsequent publications.

There are two copies of the consent form, one of which is yours to keep.

If you have any questions or require more information about the research project, you may contact the principal investigator, Arun Vanapalli, at [redacted] or his supervisor, David Trumpower at [redacted] or via phone at [redacted] David Trumpower's office is located at [redacted]

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By signing this document, you have agreed to participate in the study.

Please print this letter of consent for your records. Once completed, please return this form to the Principal Investigator.

____________________	____________________	____________
Your name	Signature	Date

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Letter of Information

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Project Title: Montessori Grade 9 Students and Their Use of an Online Concept Mapping Website: A Case Study Exploration of Their Relationship

Principal Investigator:
Arun Vanapalli, M.A. Candidate, Faculty of Education, University of Ottawa

Letter of Information

Invitation to Participate

You are being invited to participate in the M.A. thesis research project conducted by Arun Vanapalli, under the supervision of David Trumpower. You are being asked to take part in this research study because we are trying to learn more about how feedback that's provided automatically by a computer program may help you learn. We are asking you to be in the study because as a student at The Element, you have independent time to work on subjects and can access the computer program during this time.

Thank you for considering this request.

Purpose of the Letter

The purpose of this letter is to provide you with information required for you to make an informed decision regarding participation in this research.

Purpose of this Study

The purpose of the study is to examine how effective the use of computer-based feedback can be for improving learning for Grade 9 mathematics students

Inclusion Criteria

You are being recruited to participate in this study because you are a student participating in the grade 9 mathematics course at the The Element High School.

Exclusion Criteria

Students not participating in the grade 9 mathematics course at The Element High School will be excluded from this study.

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Study Procedures

If you agree to participate, you be asked to do the following:

- You will be given a username and password for a website, called the "online concept mapping website"
- You will be asked to log in to the website and complete an activity that will result in a concept map about the subject you are studying
- By completing the activity and generating the concept map, you will also gain access to feedback that may help you learn more about the subject you are studying
- At the end of a regularly scheduled test, quiz, or assignment, you will be asked to complete a short survey about how you feel about the online concept mapping website
- Every time a new chapter or unit begins, a new concept mapping activity will be made available to you through the online concept mapping website; you will be asked to complete this activity, and then after the regularly scheduled test, quiz, or assignment from that chapter or unit, you will complete the same short survey
- You can use the concept mapping website as many times as you want
- You will be in the study for four to six (4 to 6) months

Possible Risks and Harms

There are no risks to joining this study.

Possible Benefits

The possible benefits to this study may be able to help you focus on areas of a subject that you may not understand as well as you want to. It will also help highlight areas of a subject that you are doing well in. Since the online concept mapping website can be accessed at any time, you can use it to get feedback, examples, or explanations about subjects without having to wait to speak to a teacher. The online concept mapping website can also be used as a study tool.

Compensation

You will not be compensated for your participation in this research.

Voluntary Participation

Participation in this study is voluntary. You do not have to be in the study. There is no penalty for choosing to not be a part of the study. In other words, choosing not to participate will have no effect on your grades whatsoever. If you don't want to be in this study, you just have to tell us. You can change your mind and stop being part of it at any time. All you have to do is tell your teacher, or ask your parents to tell the teacher or the Principal Investigator. If you choose not to participate in the

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study, you will still have the option to use the concept mapping website if you would like to. Your concept maps will not be collected, and you will not participate in surveys.

Confidentiality

Your participation will be anonymous and your data will be stored with a special code. There is no way to determine your identity in the study as you will not be asked for any personal individual identifiers such as name, address, or prior schools of attendance.

Contacts for Further Information

If you have any questions or require more information about the research project, you may contact the principal investigator, Arun Vanapalli, at [redacted] or his supervisor, David Trumpower at [redacted] or via phone at 613-568-5800 ext. 4117. David Trumpower's office is located at [redacted]

If you have any questions regarding the ethical conduct of this study, you may contact the Protocol Officer for Ethics in Research, University of Ottawa, Tabaret Hall, 550 Cumberland Street, Room 154, Ottawa, ON K1N 6N5
Tel.: (613) 562-5387
Email: ethics@uottawa.ca

Publication

If the results of the study are published, your name will not be used. If you would like to receive a copy of any potential study results, please contact Arun Vanapalli, at [redacted] or his supervisor, David Trumpower at [redacted] or via phone at [redacted]

Consent/Assent

Please see the Consent and/or Assent form(s) also provided to you.

This letter is yours to keep for future reference.

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