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Collaborative mind mapping to support online discussion in teacher education

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Abstract

Mind maps that combine text, images, color and layout elements, have been widely used in classroom teaching to improve retention, knowledge organization and conceptual understanding. Furthermore, studies have shown the advantages of using mind maps to facilitate collaborative learning. However, there are gaps in the literature regarding the use and study of collaborative mind mapping in online learning settings. This integrated-article dissertation explores the implementation of online collaborative mind mapping activities in a mathematics teacher education program at a Canadian university. The studies were developed with participants enrolled in three different courses where at least two of the online activities used collaborative mind mapping for knowledge construction. Rather than prove the efficacy of a visual tool, as other studies have, this research provides an understanding of how the learning and knowledge construction process occurs when student interact with one another using a mind mapping tool. The set of articles contained in this dissertation answers to the questions: (1) What are the roles that collaborative mind mapping plays in the participants' education as mathematics teachers? (2) What are the differences between student interaction in threaded forums and mind maps? (3) How does online collaborative mind mapping enhance the aspects of engagement, representation, and expression in teacher education? (4) How can grounded theory methods be developed with sources of online multimodal data such as online mind mapping? (5) How do students interact and construct knowledge when they engage in online collaborative mind mapping? The research view is qualitative and uses a variety of descriptive case study, content analysis, and constructivist grounded theory methods. This dissertation provides insights into online collaborative knowledge construction when using collaborative mind mapping and adds to the existing literature on online learning, especially concerning the use of visual, collaborative tools. It contains guidelines and suggestions to implement this type of learning experiences in other courses and/or other education levels.

Keywords

Mind maps, online collaboration, visual tools, online learning, knowledge construction.

Lay Summary

Mind maps are powerful visual tools that are widely used in classroom teaching to improve retention, understanding, and knowledge organization. New technologies allow for mind maps to become collaborative online tools that can also facilitate discussions. However, the process of how students collaborate using this technology has not been deeply studied before, and teachers desiring or requiring to use online mind maps in their classrooms don't have research-based recommendations that can improve the learning experience. This dissertation is composed of five articles that explore the uses of online collaborative mind mapping in an undergraduate education program. The research describes how online discussions in mind maps are different from those in forums, and what are the interaction patterns and behaviours that students develop when engaging in mind mapping activities. It provides important recommendations for higher education instructors that wish to use mind maps as a powerful visual tool in their courses.

Co-Authorship Statement

Chapters two, three, four, and six of this dissertation have been published or are currently in press as co-authored papers. As the co-author of these papers, I acknowledge Rosa Cendros Araujo as the lead author, whose tasks included conceptualizing, writing, and revising these articles. I am acknowledged as co-author primarily because of my role as Principal Investigator in the projects that supported Rosa's research assistantship. While initial drafts of the papers were delivered to me for review and comment, my contributions in this regard were minor to their development. For these reasons, I fully support the inclusion of the articles as components in Rosa's doctoral dissertation.

Dr. George Gadanidis.

[redacted]

Signature

Date: 2 May 2019

Dedication

To my beloved father, who left this world while I was writing this dissertation, and to my youngest daughter, who arrived before I finished it.

To my mother, husband, and oldest daughter, who held me together through all of it.

Acknowledgments

First and foremost, I would like to express my very great appreciation to George Gadanidis, my research supervisor, for his guidance and useful critiques of this work. He motivated and supported my journey since my application to the Ph.D. program, as well as in publications and funding applications. In his role as principal investigator in the projects that supported my research assistantships, he provided me with access to the data for this study, along with valuable support on how to store, organize, and analyze it. His thoughtful advice, timely encouragement, and confidence in my skills kept me progressing in my dissertation ahead of schedule.

I also wish to acknowledge the advice given by Immaculate Namukasa as a member of my research committee. She has been a great help in pointing out theories to orient my research, and her thoughtful suggestions improved the quality of manuscripts that fed this dissertation, such as my comprehensive examination paper and research proposal.

This dissertation has also benefited from feedback of various reviewers and editors, as well as conference sessions chairs and discussants. I am particularly grateful for the feedback given by Drew Polly, Leping Liu, David Gibson, Susie Gronseth, and Elizabeth Dalton, editors of the volumes in which I participated. Their valuable comments improved my work for publication and subsequent inclusion in this dissertation.

My special thanks are extended to Lisa Floyd and Josephine Gordon, the instructors who kindly gave me access to their online courses and enthusiastically implemented the online mind mapping activities with their students.

In terms of funding, this research benefited from the generous support of the Ontario Government in the form of two Ontario Graduate Scholarships, the Social Sciences and Humanities Research Council through a Partnership Development Grant that supported my research assistantship, and the Western Centre for Teaching and Learning through a Fellowship Grant that also supported my research assistantship.

Finally, I would like to express gratitude to my family for their loving support and source of motivation throughout my Ph.D. studies.

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Preface

All of the work presented henceforth was conducted in the Faculty of Education at Western University, using data from the project Mathematics for Teachers, with ethics approval from Western University #108363. I have received permission from Dr. George Gadanidis to use this data (Appendix A), and I bounded my procedures to the original letter of information and consent form of the study (Appendix B). Quoting from the Ethics Protocol approved by Western's Research Ethics Board: "The study will investigate the use/effect of the resources and related teaching methods on the development of teacher mathematical and pedagogical knowledge, and attitudes/beliefs towards mathematics and its teaching." My study fits within this research mandate: (1) The mind maps I investigated were considered "teaching methods" integrated into the online platform of the course; and, (2) my research questions address the role of mind maps in knowledge creation (how students interact differently and how the knowledge they develop is different when mind maps are used).

A version of Chapter 2 has been published as: *Cendros Araujo, R. & Gadanidis, G. (2017). Online Discussion Tools in Teacher Education: Threaded Forums and Collaborative Mind Maps in a Mathematics Education Program. In D. Polly (Ed) Handbook of Research on Innovative Practices in Teacher Preparation and Graduate-Level Teacher Education. Hershey, PA: IGI Global*. Refer to Appendix C for the publisher's letter of permission to use this book chapter in my dissertation.

A version of Chapter 3 has been published as: *Cendros Araujo, R. & Gadanidis, G. (2017). Online tools for small-group discussion: a comparison between threaded forums and collaborative mind-maps. In L. Liu & D. Gibson, Research Highlights in Technology and Teacher Education 2017 (pp. 81-89). Chesapeake, VA: Association for the Advancement of Computing in Education (AACE)*. The AACE Copyright Policy states that authors hold "the right, after publication by AACE, to reuse any portion of the work, without fee, in future works of the author's own provided that the AACE citation and notice of AACE copyright are included" (https://www.aace.org/copyright/).

A version of Chapter 4 has been accepted for publication and is currently in press as: *Cendros Araujo, R., & Gadanidis, G. (In Press). Engagement, Representation, and*

Expression in Online Mind Mapping Activities. In S. Gronseth, & E. Dalton (Eds). Universal Access Through Inclusive Instructional Design: International Perspectives on UDL. New York, NY: Routledge. Refer to Appendix D for the publisher's letter of permission to use this book chapter in my dissertation.

A version of Chapter 5 appears in: *Cendros Araujo, R (2019). Grounded Theory with Online Multimodal Data: The Case Study of Online Collaborative Mind Maps. AERA 2019 Proceedings*. According to AERA Proceedings Copyright Policy (http://www.aera.net/Publications/Publications-Permissions), I hold copyrights of this work, and no permission is needed to republish.

Chapter 6 is a pre-print (prior to peer review) of an article to appear in ZDM Mathematics Education. The final, peer reviewed, and authenticated version will be available as: *Cendros Araujo, R., & Gadanidis, G. (2020). Online collaborative mind mapping in a mathematics education program: A study on student interaction and knowledge construction. ZDM Mathematics Education, 52(5)*. According to Springer's self-archiving policy (https://www.springer.com/gp/open-access/authors-rights/self-archiving-policy/2124), I may use this article while including the above acknowledgement.

I was the lead author in all these manuscripts, responsible for all major areas of concept formation, data analysis, as well as manuscript composition. George Gadanidis was the supervisory author and contributed with manuscript edits.

Chapter 1

1 Introductory Chapter

This chapter provides a thorough introduction to the problem regarding online collaborative mind maps, and the subsequent research purpose, goals, and questions that were formulated to address the problem. The contributions of this research to the field of education are also explained. Finally, the chapter closes with an organized overview of the five papers that compose the dissertation.

1.1 Problem Description

Today's classrooms and learning materials are filled with images. After many years of research about pedagogy, learning psychology, and neuroscience, it would be unthinkable to teach complex concepts without the facilitative aid of a diagram, an illustration, or a photo. Vision and the metaphor of seeing are so immersed in the way we learn and understand that we use expressions such as "taking perspective", "seeing the big picture", and being "visionary" in our everyday language. In this context, mapping – as in mind mapping and concept mapping – is understood as an alternative form of thinking that follows this metaphor of seeing (Hyerle, 2009).

In the 21st century, visual representations for education have had an upturn with the rise of multimodality and multiliteracies within the field of curriculum. In Eisner's (2002) words, curriculum needs to consider that "humans employ different knowledge systems to acquire, store, and retrieve understanding, and they use different performance systems to express what they know about the world" (p. 148). Kress & Bezemer (2015) explain that "we must attend to all signs in all modes which are present in and constitute 'learning environments' – whether as designers of these or as those who engage with such environments" (p. 156).

More recently, multimodality has been presented as a natural component of technological trends in education. Jewitt (2006) explains that with the inclusion of technology, writing –and the general use of language- becomes only one part of the learning process, as a number of different ways to express meaning shape the "multimodal character of new technologies" (p. 53). For this reason, much of the recent work related to visual representations for learning is also related to educational technology (e.g. Hanewald & Ifenthaler, 2014; Kwon & Cifuentes, 2007; Ng & Hanewald, 2010).

According to Bezemer and Kress (2016), the emergence of new technologies that offer distinct semiotic and social possibilities is making a profound result "in the weakening – in the demise, even – of structures that had previously been relatively stable […] There are now fewer instances where 'canonical' forms, modes and media are known, or will be used or will serve best." (p. 137). They continue to assert that because alternative modes to speech and writing – such as colour, layout, and music- are more readily available than they used to be, it makes their inclusion, not only possible but essential. In their words, "in the contemporary complex of social demands with more means more easily available, it seems unavoidable, or imperative even, to make use of this larger set of resources" (Bezemer & Kress, 2016, p. 137)

Furthermore, collaboration has been added to this conjunction between visual representations and technology with the advent of communication tools for education. In curriculum, trends related to 21st Century Competencies often present technology, collaboration, and visualization as mutually related components. For example, the Ontario Government (2016) in their document Towards Defining 21st Century Competencies for Ontario defines clear connections between digital tools and resources, key transformational learning practices, and competency development. The document mentions graphing tools and concept mapping tools as technologies that can foster, amongst other competencies, coordination, communication, metacognition, analysis, problem-solving, and reasoning.

However, in online environments, when small group activities are included, online forums are still a predominant tool used for interaction (Anderson, 2018; Harasim, 2017). Still, research studies have consistently shown that students rarely engage in critical discourse or higher stages of communicative processes through online threaded forums (Anderson, 2018; Fahy, 2005; Garrison et al., 1999; Lucas et al., 2014). Rourke and

Kanuka (2007), after reviewing two decades of research literature on discussion forums, concluded that “the percentage of messages in which students engage in critical discourse, mutual critique, or argumentation, in whatever way it might be operationalized, ranges from 5 to 22%” (p. 106).

Furthermore, the diminishing or lack of student-student interaction is only one constraint of threaded discussion forums. Gao, Zhang, and Franklin (2013) explain that even though students can insert images and links to external resources, the predominant mode of expression in threaded forums is text. This is an important limitation because “humans employ different knowledge systems to acquire, store, and retrieve understanding, and they use different performance systems to express what they know about the world” (Eisner 2002, p. 148). Regarding this constraint, Jewitt (2006) explains that with the inclusion of technology, writing –and the general use of language- becomes only one part of the learning process, as several different ways to express meaning shape the “multimodal character of new technologies” (p. 53).

To address both the issues of lack of meaningful interaction and text as the single mode of expression, researchers suggest the inclusion of external representations that allow students to engage in discussion and visual knowledge construction (Gao et al., 2013; Kirsh, 2010). External representations are defined as “structures in the environment that allow the learner to interact with some content domain”. The representation – the figure, picture, diagram, graph, statue or model – is external because “these are outside the head and should be distinguished from internal mental representations. Learning with external representations thus involves inspecting, manipulating, modifying, or assembling components of external representations that stand for the objects, relations, and phenomena to be learned” (de Vries, 2012, p. 2016).

In this context, mind mapping is a technique to “represent understanding of a subject matter in multimodal forms” (Hanewald and Ifenthaler, 2014, p. 4). Because sometimes mind maps are named concept-maps, it is important to clarify that mind maps feature a non-linear arrangement that starts with a key notion which radiates into branches. In contrast, concept maps are hierarchical and structured, indicating the exact relationship between concepts or ideas (Ng and Hanewald, 2010). Henceforth, mind maps provide free flow of ideas in a more intuitive way, which encourages brainstorming and allows a quick view of the main concept.

Regarding the educational uses of mind maps, Hanewald and Ifenthaler (2014) mention that they can be used as a note-taking strategy or as a planning tool, while explaining that mind maps' functions are "to organize and present information [and] as an 'advance organizer', that is a global overview of the material" (p. 13). The educational uses mentioned in this paragraph involve one single learner. However, mind maps are also used as a strategy for collaborative learning. Kwon and Cifuentes (2007) showed that building a map in small groups requires students to communicate and negotiate, which leads to greater individual understanding.

A lot of research has explored the benefits of using visual technologies for collaborative learning in terms of knowledge construction (Komis et al., 2002; Madrazo and Vidal, 2002; Suthers and Hundhausen, 2003). These benefits can be summarized in supporting problem-solving and meaning-making, negotiation, and serving as a space for shared memory awareness. A recent meta-analysis collaborative learning technologies (Chen et al., 2018) showed that visual representation tools were one of the most effective for online collaboration, because "they not only function as cognitive tools but also elicit group discourse […] As shared artifacts, they greatly promote consensus building and knowledge convergence, which may lead to successful completion of group tasks" (p. 830)

Regarding students' attitudes during collaborative visual representations, research has shown that visual representations increase motivation and interest towards learning (Ahmed & Abdelraheem, 2016; Balım, 2013; Lin et al., 2016; Wilson et al., 2016), they afford a more creative and fertile learning environment that accommodates different learning styles (Wilson et al., 2016), and improve relationships among students (Wang et al., 2017).

To sum up the benefits of visual representations of learning, they can be an alternative to text-based interaction and feature a model of non-linear communication that increases student motivation, conceptual understanding, and interconnection. But despite these advantages, previous research has focused on very particular applications, such as individual students’ concept maps and how they support posterior collaboration, synchronous peer interaction during concept mapping or collaborative concept mapping within the framework of project-based learning.

Mind maps, which offer a more flexible and creative layout, have rarely been explored in previous research. Also, most of the studies have focused on conceptual understanding and learning outcomes derived from visual representations, but little research has focused on the nature of student interaction. So, a gap in the literature exists because student-student asynchronous interaction during collaborative mind mapping has not yet been studied. At present, there is no theory that describes the abundance of multimodal information contained in online collaborative mind mapping, nor that interprets the elements of meaning which have significance for learning construction. Researchers studying the pedagogical applications of mind maps are confronted with the task of developing these models. Educators must be provided with a tool to find the elements that best reveal the learning process during online mind mapping to better support individual and group knowledge construction.

As Harasim (2017) claims, the challenge to integrate online learning strategies in the curriculum “is not necessarily resistance to change by educators, but the lack of a theory or strategy to assist teachers and guide the pedagogical transformations required” (p. 111). A theory that provides insights of how the learning and knowledge construction process occurs when students interact with one another in a mind mapping tool would allow teachers to integrate visual tools with collaboration activities, and to do so in a more effective way.

1.2 Research Purpose

The purpose of this study was to discover and describe teacher candidates’ interaction and knowledge construction during online collaborative mind mapping. Rather than prove the efficacy of a visual tool, as other studies have, the compendium of papers presented in this dissertation provides an understanding of how the learning and knowledge construction process occurs when student interact with one another in a mind mapping tool.

1.3 Research Questions

Within the context described above, this research focused on responding to the following questions:

1. What are the roles that online activities -threaded forums and mind maps- played in the participants' education as mathematics teachers?

2. How do teacher candidates interact when they engage in online discussions through threaded forums and mind maps?

3. What are the differences between teacher candidates' interaction in threaded forums and mind maps?

4. What are the affordances in terms of engagement, representation, and expression of online mind mapping activities?

5. What are the challenges and advantages of using constructivist grounded theory methods to analyze online collaborative mind mapping data?

6. How do mathematics teacher candidates interact with one another when they engage in online collaborative mind mapping?

7. How do they construct knowledge in online collaborative mind mapping?

1.4 Contributions to the Field of Education

The Ontario Government (2016) in their document *Towards Defining 21st Century Competencies for Ontario* defines clear connections between digital tools and resources, key transformational learning practices, and competency development. The document mentions graphing tools and concept mapping tools as technologies that can foster, amongst other competencies, coordination, communication, metacognition, analysis, problem-solving, and reasoning. This research will be of value to expand existing literature, especially concerning the use of visual tools for learning, and to inform practice and generate suggestions for teachers and developers to implement this type of learning experiences in other courses and/or other education levels, as well as set the stage for further research.

Also, this study has relevance within the framework of multimodal literacy studies, which emphasizes going beyond "traditional conceptions of literacy that maintain language at their center" (Jewitt, 2006, p. 8). In this scenario, mind maps provide a new range of multimodal possibilities for online learning, such as layout, colour, image and video that enrich student's interaction and experience, and which can be applicable to multimodal collaboration, discussion, and assessment, opposed to traditional methods in online learning. The theory developed in this study describes the abundance of multimodal information contained in online collaborative mind mapping and interprets the elements of meaning which have significance for learning construction.

In addition to these theoretical and practical implications, there are methodological contributions that this research could make. First, on the intersection of qualitative and online research, which is still an incipient and promising field (Salmons, 2016). This research will illustrate how digital data that includes multimedia content can be collected, stored, and analyzed using qualitative methods. And second, this research will be an example of how grounded theory can be developed using secondary data in educational research.

1.5 Background and Positioning of the Researcher

I have an extensive background in higher education as an instructor, curriculum developer, instructional designer, and administrator, providing leadership and management in the areas of e-learning curriculum integration, design of online courses and learning environments aimed at improving learning and academic experience of students and professionals.

Most of this experience was developed in Venezuela, where I completed undergraduate studies as Bachelor of Education, specializing in Educational Sciences and Technology.

The characteristic that separated my undergraduate studies from other bachelor's degrees in education is that, instead of specializing in a subject matter and then going for a teaching program, I undertook 5 years of studies in pedagogy, curriculum, instructional design, and educational technology, among other education disciplines. This baseline in my education shaped the way in which I engaged in educational research, with a broad understanding of educational problems and an approach to design solutions that made instruction more efficient. A second undergraduate degree in Engineering also contributed to this mindset of striving for efficiency.

As I moved forward in my academic and professional career, I realized that not all problems in classrooms (specifically online classrooms) can be solved with a prescription of new strategies and technologies alone. Collaboration in online learning was one of such problematic areas that I found both as an online course developer and as an instructor. This has been the focus of my research during graduate studies. I pursued a Master of Science in Educational Information Technology, where I looked at how instructors in higher education fostered constructive interaction in online learning using quantitative research.

My background and experience in positivistic research posed challenges in conducting qualitative research throughout my Ph.D. studies, but at the same time it gave a perspective on technologies and multimodal artifacts being not just sets of resources subject to human action, but agents in educational processes, and co-creators in knowledge building. Currently, I frame my ideas within new materialism perspectives (Barad, 2007; Hekman, 2010; Garber, 2019). This interaction between humans and technology also relates to the theory of Distributed Cognition (Kirsh, 2006), Latour's (2005) Actor-Network Theory, Gibson's (1986) Theory of Affordances, Levy's (1997) model of Collective Intelligence, and Borba and Villarreal's (2005) Humans-with-Media concept. The general understanding of these authors is that both humans and non-humans have agency and that the presence of technology affords new ways of processing and constructing knowledge that would not be possible otherwise.

1.6 Review of literature and models of knowledge creation and online collaboration

Back in 1962, when computers still occupied the size of a room, Douglas Engelbart, a prolific computer inventor and engineer, introduced the idea of using computers to store, access, and share information with the purpose of *augmenting human intellect* (Engelbart, 1962). He created a framework to understand what he called *collective IQ,* where collaboration between humans, and between humans and artifacts was an important part of developing, integrating and applying knowledge.

However, ten years would pass until the invention of an online technology that allowed online group communication. In 1972, Murray Turoff created the EIES computer conferencing system. In 1978, he coauthored *Network Nation*, a book that became the seminal work in online collaboration and learning. However, during the 1980s, the field of online learning was primarily based on the use of computer conferencing, and in some cases, email, which did not support sophisticated learning strategies (Harasim, 2017). It was not until the 1990s that online platforms evolved enough to support teachers' and students' constructive interactions, such as discussions, debates, and other knowledge-building activities.

The following section explores the area of online collaborative learning pedagogies, including the major role that asynchronous discussions have played in shaping the state of the field, and presents an outline of the most prominent models of interaction and knowledge construction in online environments.

1.6.1 Asynchronous discussions for online collaboration

Research about asynchronous discussions in online learning has shown evidence of its advantages. First, online discussions are beneficial to foster in-depth consideration of others' viewpoints when compared to face-to-face classrooms (Berry, 2005). Students are more thoughtful about what they write in online posts than about what they say in classrooms sessions (Rollag, 2010). Also, online discussions can increase the participation of students who don't usually speak in the classroom (Neidorf, 2012). This can benefit reflective learners, who prefer to revise the material carefully before expressing their ideas (Felder & Silverman, 1988), and it can increase the confidence of ESL international students when communicating with their peers (Al-Shalchi, 2009). Finally, the interaction through asynchronous discussions has the potential to build a community of learning (Brower, 2003).

In terms of knowledge construction, a lot of research has highlighted the importance of online discussions in facilitating learning as a result of student interaction (e.g. Garrison et al., 1999; Henri, 1992; Means et al., 2014), and many have proposed models that evidence learning and knowledge construction processes. In Harasim's (2007) words: "text-based, archival, group discussion […] offers a powerful new opportunity for reviewing and studying the quality of student participation (in online discussions/discourse) over time, to assess whether learning and conceptual change are occurring. And if so, under what conditions" (p. 287). According to Lucas, Gunawardena, and Moreira (2014) "asynchronous messages result in artifacts of learning that demonstrate students' behaviour during learning processes and their analysis may help us to understand and optimize learning and the environments in which it occurs" (p. 574). The following section explores the most influential of asynchronous discussion models of analysis.

1.6.2 Analyzing interaction and knowledge construction in online environments

Online discussions have the potential to support constructivist learning. However, according to Harasim (2017), "while the internet does introduce the potential for interaction and active networking, it is essential to demonstrate how that interaction leads to learning" (p. 107). So, many researchers have developed models to analyze online interactions to find evidence of learning happening, that is, of knowledge construction (see Donnelly & Gardner, 2011 for a comprehensive review of models). Additionally, the fields of social network analysis and learning analytics, have rendered significant contributions to study interaction and knowledge construction. Below, I describe the most cited models and contributions.

1.6.2.1 Computer-Mediated Conferencing (CMC) Analytical Model

Henri (1992) was the first author to develop an analysis model for the qualitative study of asynchronous communications. She proposed five key areas: (1) Participation, deconstructed into: rate, timing and duration of messages; (2) Interactivity, explored for explicit and implicit interaction; (3) Social Events, understood as dialogue unrelated to problem content; (4) Cognitive Effects included clarifications, making inferences, judgment and strategies; and (5) Metacognitive Events, deconstructed into knowledge (person, task, strategy) and skill (evaluation, planning, regulation, self-awareness).

This model is framed under the cognitivist understanding of learning, which emphasizes the process of learning rather than its product, and stresses the process of metacognition. The model suggests that educators can analyze asynchronous messages in three different levels, according to their pedagogical intention: (1) what is said on the subject or content under discussion in terms of exactitude, logic, coherence, and/or relevance; (2) how it is said in terms of participation, social presence and interactivity; and (3) what thinking processes and strategies are employed, whether they are cognitive or metacognitive.

1.6.2.2 Interaction Analysis Model (IAM)

In 1997, Gunawardena, Lowe, and Anderson (1997) created the Interaction Analysis Model (IAM) to assess knowledge construction in an online collaborative learning environment. This model is based on social constructivism and defines interaction as the glue of knowledge construction. The IAM suggests five phases, each containing a set of learning processes: (1) sharing and comparing of information, (2) discovery and exploration of dissonance or inconsistency, (3) negotiation of meaning/co-construction of knowledge, (4) testing and modification, and (5) agreement statement(s)/applications of newly constructed meaning.

This model is one of the most frequently used in the literature about online knowledge construction (see Lucas et al., 2014), and it is “one of the most coherent and empirically validated instruments in the research field” (p. 574). This is in part because the authors have developed a set of detailed indicators for observing the type of cognitive activity present in a message as a unit of analysis.

1.6.2.3 The community of Inquiry (CoI)

The Community of Inquiry (CoI) is an influential model to analyze interaction in online text-based environments that has been developed at the University of Calgary for almost two decades. Since its publication, the article *Critical inquiry in a text-based environment: Computer conferencing in higher education* (Garrison et al., 1999) has generated significant interest amid online learning researchers, and the CoI as a framework has been used in many publications (See https://coi.athabascau.ca/publications/). Today, CoI has been established as a theory that describes how students and teachers communicate and construct knowledge in an online learning environment (Garrison, 2017).

A Community of Inquiry (CoI) is "composed of participants who assume the roles of both teacher and learner while engaging in discourse with the specific purposes of facilitating inquiry, constructing meaning, and validating understanding that in turn metacognitively develop the ability and predisposition for further learning"." (Garrison, 2017, p. 23). In this framework, there are three key elements or presences considered in an online experience: the cognitive, the social, and the teaching presence.

The cognitive presence is "the extent to which learners are able to construct and confirm meaning through sustained reflection and discourse" (Garrison et al., 1999, p. 11), and it is only achievable through communicative relationships. For this reason, the social presence is a fundamental element in the model, which is defined as "the ability of participants to identify with a group, communicate purposefully in a trusting environment, and develop personal and affective relationships progressively by a way of projecting their individual personalities" (Garrison 2017, p. 25). The third element in the CoI framework is the teaching presence, defined as "the design, facilitation and direction of cognitive and social processes for the purpose of realizing personally meaningful and educationally worthwhile learning outcomes" (Anderson, Rourke, Garrison, & Archer, 2001, p. 5).

1.6.2.4 Collaborativism or Online Collaborative Learning (OCL) theory

Collaborativism as a learning theory was proposed by Harasim (2002) in reference to "educational applications that emphasize collaborative discourse and knowledge work mediated by the internet" (Harasim, 2017, p. 117) This model defines learning as *Intellectual Convergence*, the higher stage of a collective cognitive process. Collaborativist learning theory describes three stages or phases that students need to go through to achieve learning: Idea Generating, Idea Organizing, and Intellectual Convergence (Harasim, 2002).

The first phase, Idea Generating, refers to brainstorming and generating diverging information on a particular content or problem. In the second phase, Idea Organizing, participants confront the originally generated ideas, question them, combine them and organize them to select the strongest alternatives or positions. Finally, the third phase, Intellectual Convergence, reflects a shared understanding, a product, or a solution collectively generated.

Collaborativism also defines specific roles for teachers and students. In this model, the role of the teacher is "to engage the learners in the specific language or vocabulary and activities associated with building the discipline" (Harasim, 2017, p. 123), this implies introducing the content to be discussed, and providing course readings, comments, and questions as frame of reference during discussions. The role of the student is "to engage in the three processes of collaborative discourse and to learn and apply the analytical terms of the discipline to solve a knowledge problem" (p. 125).

1.6.2.5 Contributions of Learning Analytics

The field of learning analytics has the purpose to collect and analyze learning data in order to inform and improve processes or outcomes (Siemens et al., 2011). There are two classes of learning analytics depending on the level and kind of decision making targeted (Ferguson, 2012). First, at a macro or institutional level, learning analytics can inform stakeholders and policymakers about behaviours of large amounts of students, faculty, and administrators, to make large-scale decisions. On the other hand, the class of learning analytics that can inform teachers, students, and developers on their practice, is done at a micro level. This is the area where learning analytics has provided significant contributions to understanding how students interact and construct knowledge in virtual environments.

In terms of interaction, learning analytics studies have rendered important findings regarding speaking and listening behaviours during online discussions (Wise, Zhao, & Hausknecht, 2014). For example, the criteria that can be extracted with learning analytics approaches includes temporal distribution of participation (i.e. range of participation, number of sessions, percent of sessions with posts, average session length), speaking quantity (i.e. number of posts made and average post length), listening breadth (i.e. percent of posts read), and listening reflexivity (i.e. number of reviews of own posts and number of reviews of other's posts).

In practical terms, educators have used the information extracted by learning analytics to create learning interventions, that is, to present this information back to the students with the intention of influencing their interaction. For example, Marbouti and Wise (2016) developed Starburst, a software designed to present discussion threads as a tree structure, allowing students to see the discussion structure and the location of their comments within it, as well as colour codes for the parts of the discussion they have been attending to (Figure 1). The purpose was to aid students in selecting which threads to read and respond to, and to facilitate the connection between posts.

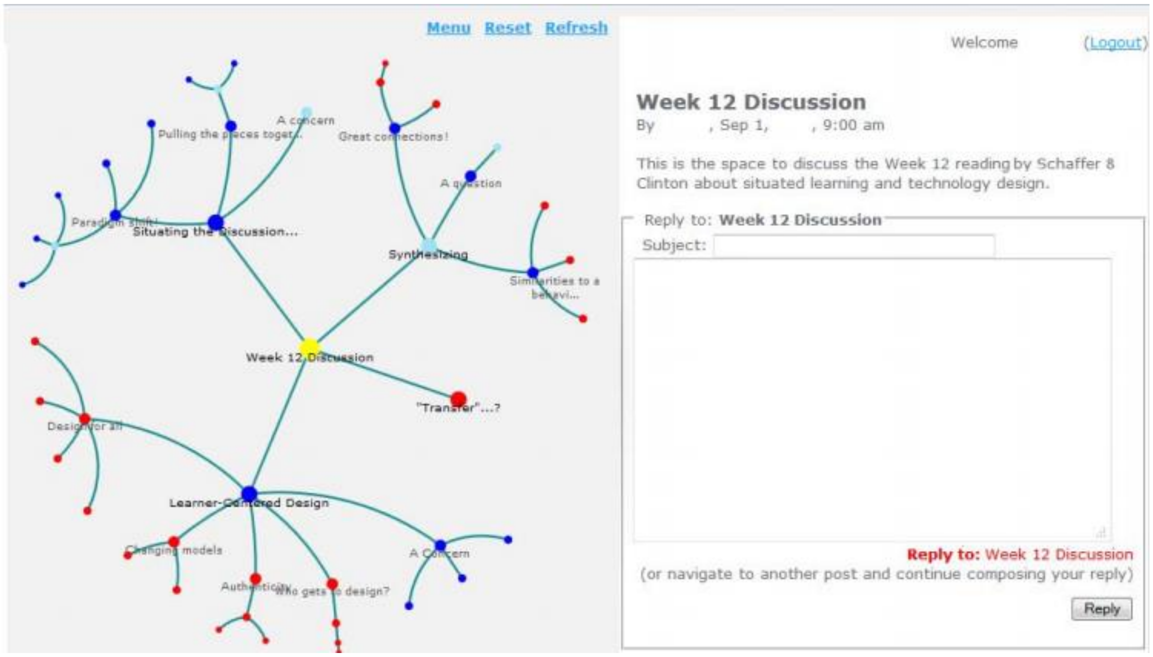

Figure 1. The Starburst discussion tool, student view. Image from Wise et al. (2014)

1.6.2.6 Contributions of Social Network Analysis

Social networks analysis (SNA), “or structural analysis, aims at studying relationships between individuals, instead of individual attributes or properties” (Romero & Ventura, 2010, p. 609). According to Stepanyan, Mather, and Dalrymple (2014), “the use of SNA in educational research can become a fundamental resource for understanding student interaction and participation, subsequently leading to improvement of teaching techniques and tools” (p. 679).

As early as 1990, Levin, Kim, and Riel (1990) described a method to graphically display the relationships between sets of messages submitted to an online conference. Later, Blake and Rapanotti (2001) also used a visual representation of the computer conference in the form of a directed graph or interaction map.

More recent developments (which relate to data mining and learning analytics) have advocated to analyzing the structure and content of discussions in online communities. For example, Prata et al. (2009) proposed social network analysis to distinguish between a variety of speech acts, such as informing belief, disagreeing with concepts, offering collaborative acts, and insulting. Also, visualizing and clustering on discussion forum graphs have been applied as social network analysis to measure different variables of small groups in collaborative educational interactions, such as interactivity and group cohesion (Saqr, Fors, Tedre, & Nouri, 2018), culture and role (Stepanyan et al., 2014), or centrality (Zuo, Mu, & Han, 2012). Figure 2 shows an example of a SNA visualization.

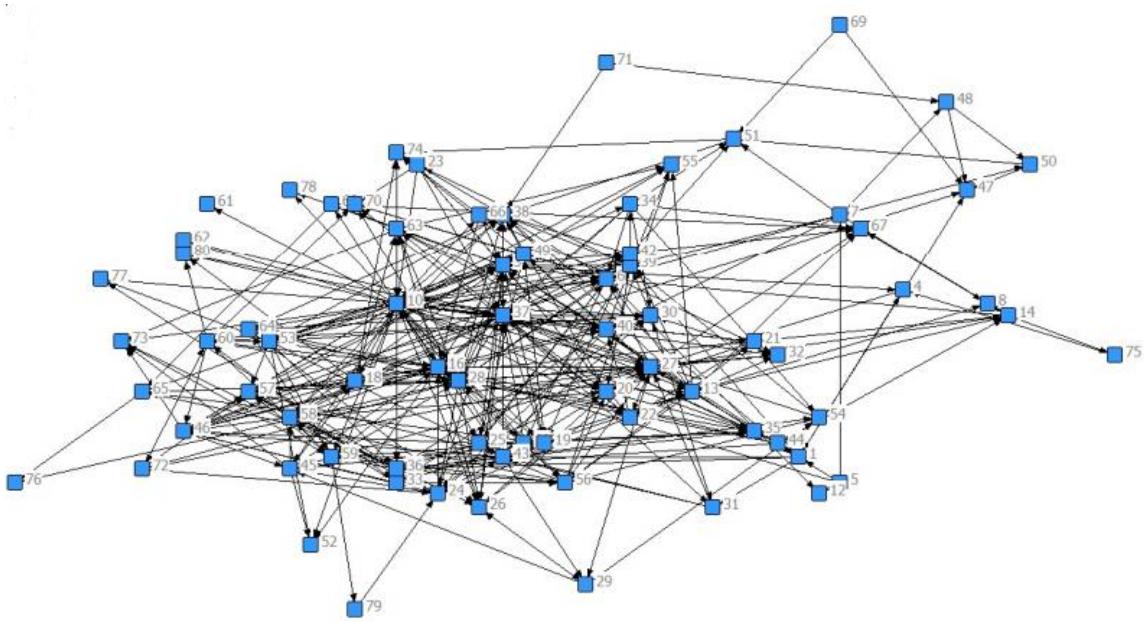

Figure 2. Example of an SNA of 80 students' online learning interactions. By Zuo et al. (2012)

1.7 Organization Overview of Remaining Chapters

This integrated-article dissertation is composed of five chapters, each one developing a topic related to online collaborative mind mapping in the context of teacher education. What these papers have in common is that they were developed using the case study of three courses in the mathematics teacher education program at Western University. Since each course used different mind mapping tools and instructors used two different kinds of prompts, there was plenty of room to look at different affordances, perspectives, and outcomes of the mind mapping activity.

Chapter 2 presents a study using a comparative approach of the interaction developed in threaded forums and online mind maps. The framework used to compare interaction was the Community of Inquiry model (Garrison, 2017) and I respond to the questions: How do students interact when they engage in online discussions through threaded forums and mind maps? And what are the differences between student interaction in threaded forums and mind maps?

Chapter 3 also uses a comparative approach to view the affordances of threaded forums and mind maps in relation to teacher education. In this descriptive case study, I looked into the online components of a blended course with the intention to respond the question: What are the roles that each online activity played in the participants' education as teachers? In this context, a role is understood as a function or effect, intended or not, that a particular tool had in teacher candidates' learning experience.

Moving beyond tool comparisons, Chapter 4 provides a look into mind mapping experiences through the lens of Universal Design for Learning (UDL). Based on the premise that mind maps can provide a new range of multimodal possibilities, such as layout, colour, image and video, that can foster inclusive learning, Chapter 3 uses UDL guidelines (CAST, 2018) as a framework to describe and analyze results of the online mind mapping activities.

Chapters 5 and 6 are closely related, as they are part of the same study seeking to answer how do mathematics teacher candidates interact and construct knowledge when they engage in online collaborative mind mapping. Chapter 5 focuses on the method of constructivist grounded theory (Charmaz, 2014) using online and multimodal data, outlining challenges presented while using this method and developing the data analysis. Chapter 6, as the largest and most comprehensive paper of this dissertation, moves on to present the grounded theory of knowledge building through mind mapping.

Finally, Chapter 7 presents the general discussion and conclusions that relate the separate five papers to each other and to the field of online collaborative learning.

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Chapter 2

2 Online Tools for Small-Group Discussion: A Comparison between Threaded Forums and Collaborative Mind Maps

In a constructivist framework of learning, knowledge is constructed through social interaction with others (Dewey, 1916; Vygotsky, 1978). The same principle applies if the scope is narrowed to online learning, where collaboration and interaction are important factors for success. In a meta-analysis of e-learning research (Means, Bakia, & Murphy, 2014), the elements of peer-feedback, a sense of social presence, and a collaborative pedagogy in the online environment were identified as variables that increased learning outcomes.

In online environments, small-group activities, when they are included, are generally conducted through threaded forums as the medium for students to share and build knowledge collaboratively. However, research studies have shown that students have difficulty engaging in critical discourse or higher stages of communicative processes through online threaded forums (see Fahy, 2005; Gao, Zhang, & Franklin, 2013; Garrison, Anderson, & Archer, 1999; Rourke & Kanuka, 2007).

As an alternative to threaded forums in online learning, mind mapping is presented as a technique to “represent understanding of a subject matter in multimodal forms” (Hanewald & Ifenthaler, 2014, p. 4). Because sometimes mind maps are named concept-maps, it is important to clarify that mind maps feature a non-linear arrangement that starts with a key notion which radiates into branches. In contrast, concept maps are hierarchical and structured, indicating the exact relationship between concepts or ideas (Ng & Hanewald, 2010). Henceforth, mind maps provide free flow of ideas in a more intuitive way, which encourages brainstorming and allows a quick view of the main concept. Regarding educational uses, mind maps can be used as a note-taking strategy or as a planning tool, while explaining that mind maps’ functions are “to organize and present information [and] as an ‘advance organizer’, that is a global overview of the material” (Hanewald & Ifenthaler, 2014, p. 13). Furthermore, the inclusion of technology in education has allowed new affordances for mind map creation. For example, in a comparison of manually created concept maps to electronic versions, digital mind maps allow the flexibility of hypertext, which enables infinite changes and the insertion of media (Ng & Hanewald, 2010).

The educational uses mentioned above involve one single learner. However, mind maps are also used as a strategy for collaborative learning. Building a map in small groups requires students to communicate and negotiate, which leads to greater individual understanding (Kwon & Cifuentes, 2007). In a more recent study, the biggest difficulty faced by students developing concept maps was to work collaboratively due to the need for negotiation and consensus on every single topic (Marriott & Torres, 2014). Still, this challenge was seen as a benefit because students also build on their persuasive and argumentative skills.

Despite the advantages of collaboratively building online external representations, previous research have focused in very particular applications, such as individual students' mind maps and how they support posterior collaboration (see Suthers & Hundhausen, 2003; Van Amelsvoort, Andriessen, & Kanselaar, 2007), synchronous peer interaction during concept mapping (Komis, Avouris, & Fidas, 2002; Madrazo & Vidal, 2002; Marriott & Torres, 2014) or collaborative concept mapping within the framework of project-based learning (Wu & Hou, 2014). Also, there is a framework to study collaborative practice in knowledge cartography (Selvin, 2014), a term that includes mind maps, concept maps, and other forms of visual representations of knowledge. And although this framework is broad, it is based on an experiential individual approach without a specific focus on interaction. So, we are now exploring the use of collaborative mind mapping as a substitute for threaded forums for small-group discussion in blended courses of the K-6 mathematics education program at a Canadian university. In this context, we are interested in responding to the questions: How do students interact when they engage in online discussions through threaded forums and mind maps? And what are the differences between student interaction in threaded forums and mind maps?

2.1 Framework

We understand the learning environment of the case study as a Community of Inquiry (Garrison, 2017). A Community of Inquiry (CoI) is "composed of participants who assume the roles of both teacher and learner while engaging in discourse with the specific purposes of facilitating inquiry, constructing meaning, and validating understanding that in turn metacognitively develop the ability and predisposition for further learning"." (p. 23). In this framework, there are three key elements or presences considered in an online experience: the cognitive, the social, and the teaching presence. The cognitive presence is "the extent to which learners are able to construct and confirm meaning through sustained reflection and discourse" (Garrison et al., 1999, p. 11), and it is only achievable through communicative relationships. For this reason, the social presence is a fundamental element in the model, which is defined as "the ability of participants to identify with a group, communicate purposefully in a trusting environment, and develop personal and affective relationships progressively by a way of projecting their individual personalities" (Garrison, 2017, p. 25). The third element in the CoI framework is the teaching presence, defined as "the design, facilitation and direction of cognitive and social processes for the purpose of realizing personally meaningful and educationally worthwhile learning outcomes" (Anderson, Rourke, Garrison, & Archer, 2001, p. 5). However, as the settings of the online activities in our case study required very little to none teacher intervention, our analysis will consider only the cognitive and social presence of the CoI model. Table 1 shows all categories and indicators of the COI Framework, excluding the teaching presence, which was not evaluated in this study.

Table 1. Indicators and Definitions of the COI Framework (Garrison, 2017).

Presence	Categories	Indicators
Social Presence	Interpersonal Communication	• Affective expression • Self-disclosure • Use of humor
	Open Communication	• Continuing a thread • Quoting or referring explicitly other's messages • Asking questions • Complimenting • Expressing appreciation or agreement.
	Cohesive Communication	• Addressing or referring to other participants by name

		• Addressing or referring to the group using inclusive pronouns (we, us, our) • Using communication that serves a purely social function.
Cognitive Presence	Triggering Event	• Recognize Problem • Sense of Puzzlement
	Exploration	• Brainstorming ideas • Offering supportive or contradictory ideas and concepts • Soliciting narratives of relevant perspectives or experiences • Eliciting comments or responses as to the value of the information or ideas.
	Integration	• Convergence or integration of information • Synthesizing • Providing a rationale, justification or solution
	Resolution	• Applying • Testing or defending a solution

2.2 The Case Study

In our research, we use a case study approach, with the purpose of collecting in-depth stories of teaching and learning. We studied a 'bounded system' (that is, the thoughts and actions of participants of a particular education setting) so as to understand it in the way it functions under natural conditions (Yin, 2014). The case was limited to the five sections of the K-6 education program at the Faculty of Education in a Canadian University. The five sections were treated as a single case, as Teacher Candidates (TCs) participated in the same online environment with the same tasks to complete.

Participants were 143 TCs registered in two courses. The first one was a mandatory mathematics methods course, which had a total duration of 17 weeks, using a face-to-face delivery mode, where TCs engaged hands-on with mathematics activities and coupled with an online learning management platform where instructors posted course schedules, assignments, weekly tasks, and course resources, and where they set up online discussion groups. One of the assignments in this course involved keeping a journal on online readings and resources and classroom experience, based on reflection questions identified by the instructor. TCs shared their journals in their online discussion groups and commented on the ideas shared by their peers, in groups of 4 to 6 students. There were ten journal tasks assigned focused on different readings, resources, and activities from varied sources. For the purpose of facilitating the comparison with the second, shorter course, we used only four of those journal tasks. So, the sample selected for our analysis were these four journal tasks:

- Week 3 – Missing Numbers
- Week 5 - Growing Patterns
- Week 7 – Odds and Evens
- Week 11 – Area and Perimeter

The second course we studied was a mandatory computational thinking in mathematics education course, which had a duration of nine weeks, two hours per week, where the five odd numbered sessions were face-to-face, and the four even numbered sessions were online. The face-to-face sessions consisted of hands-on learning, using different coding platforms and digital tangibles to develop coding activities that support mathematics teaching and learning. The online component included the collaborative knowledge construction and reflection in small groups (4 to 7 participants) of mind maps through the online tool Popplet (popplet.com), which replaced the more-traditional text-based discussion forum. Below is the weekly outline of topics for the online weeks of the course:

- Week 2 – Algorithms, coding and CT in the context of geometry
- Week 4 – CT in the context of probability
- Week 6 – CT in the context of patterning and algebra
- Week 8 – CT and mathematics pedagogy in the context of measurement and number sense.

2.3 Method

Our data sources were the four journal tasks of the math methods course, and the four weeks of mind maps of the computational thinking course, which were analyzed through qualitative content analysis (Berg, 2009). First, we extracted all data from the online forums and mind maps, organized by weekly topics, we deleted any postings made by TCs not participating in the study, and we also deleted any identifiers (such as names). Then, guided by the elements in the CoI framework, we coded all discussion and mind maps. This allowed us to analyze student-to-student interaction in terms of their cognitive and social presence in the online discussions (both in forums and mind maps). The process of coding the data was aided with a QDA tool named NVivo. The data extracted from this process allowed us to see each category and its indicators in terms of frequencies.

In order to strive for trustworthiness in our findings, we used two types of triangulation. In the first place, we used investigator triangulation (Denzin, 2009). We included two researchers external to the case study who collected and analyzed the data. The first researcher (first author) performed all the categorization of the data, then the second researcher (second author) reviewed this categorization, discussing and confronting any point that seemed appropriate until a consensus was achieved. Second, we included a multi-method triangulation (Meijer, Verloop, & Beijaard, 2002), by using both frequencies analysis and qualitative data analysis to obtain our results. Through this process, we complemented the quantitative findings with a thick, rich description of the phenomena (Creswell & Miller, 2000).

2.4 Results and Discussion

2.4.1 Teacher Candidates' Interaction in the Threaded Forums

To evaluate TCs interaction in the threaded forums we coded all textual data into the CoI framework (Table 2). Below, in the comparison, we explain each category, along with some sample comments that will help illustrate how TCs interacted in the forums.

Table 2. Frequencies of appearance of each category and their indicators per week in forums.

Category	Week 03	Week 05	Week 07	Week 11	Total
Interpersonal Communication	102	10	13	11	136
Open Communication	149	146	154	119	568
Cohesive Communication	132	83	66	60	341
Total Social Presence	383	239	233	190	1045
Triggering Event	163	153	160	176	652
Exploration	127	123	105	84	439
Integration	20	17	9	11	57
Resolution	4	1	0	2	7
Total Cognitive Presence	314	294	274	273	1155

2.4.2 Teacher Candidates' Interaction in the Mind Maps

To evaluate TCs interaction in the mind maps, we coded all the data into the CoI framework. Because the data in the mind maps is not only textual, we also considered the images (or videos), connections, and layout as conveyors of meaning. So, images or videos that included comments on them were considered Triggering Events, connections between ideas were counted as Exploration, and coherent clusters of interconnected ideas were counted as Integration. Similarly, images that had an affective or humoristic connotation (such as emoticons and memes) were coded as Interpersonal Communication, and comments made to other student's entries, rather than creating a new idea, were considered Open Communication (Table 3) because they are the equivalent of *continuing a thread* in threaded forums, an indicator for Open Communication. Below, in the comparison, we explain each category, along with some sample comments and images that will help illustrate how TCs interacted in the mind maps.

Table 3. Frequencies of appearance of each category and their indicators per week in mind maps.

Category	Week 02	Week 04	Week 06	Week 08	Total
Interpersonal Communication	92	80	43	32	247
Open Communication	90	140	78	94	402
Cohesive Communication	107	70	42	33	252
Total Social Presence	289	290	163	159	901
Triggering Event	180	172	150	144	646
Exploration	136	134	112	99	481
Integration	32	25	15	13	85
Resolution	2	0	0	0	2
Total Cognitive Presence	350	331	277	256	1214

2.4.3 Social Presence

As explained in the framework section, the social presence is understood as the way TCs communicated openly and cohesively as a part of their group. As shown in tables 1 and 2, the social presence for the online forums was higher than for mind maps, which translates into a more intense connection among participants in the forums, as explained below in further detail.

2.4.3.1 Interpersonal Communication.

Interpersonal communication is an important condition for students to engage in meaningful discourse through the expression of their personalities. Indicators of interpersonal communication are affective expression, self-disclosure and the use of humor. Below is an example of a comment representative of interpersonal communication from the online forums:

> *I have not yet shown this to my husband, but I am excited to as he's an electrical engineer (lots of math every day for him) and we've had heated discussions on how teaching in the past was not what student's needed to understand and appreciate math.* (Forum Comment)

Because the forum activity was a journal, we had expected many comments like the one shown above. However, this was only the case for Week 2. After that, the interpersonal communication messages decreased, giving way to more messages of open and cohesive communication.

On the other hand, even though in the mind maps we observed an initially lower interpersonal communication, it was sustained over the weeks, obtaining higher frequencies than for the online forums. The visual affordance of the mind maps allowed students to share more images and comments that represented humoristic and emotional remarks (Figure 3).

Figure 3. A sample of interpersonal communication in the mind maps

2.4.3.2 Open Communication

The element of open communication ensures in a learning community "a climate of trust and acceptance that allows questioning while protecting self-esteem and acceptance in the community" (Garrison, 2017, pp. 45–46). Indicators of open communication are: continuing a thread, quoting or referring explicitly other's messages, asking questions, complimenting, and expressing appreciation or agreement. Below is an example of a quote expressing open communication from one of the TCs:

> *I liked your post this week. I like that you mentioned different perspectives and commented on gifted and learning disabled students.* (Forum Comment)

As is evident in Table 2, for online forums the open communication was the highest element in social presence, with a total frequency of 568 and a consistent presence throughout all weeks. Comments like the one shown above were very common in the online forums. For the mind maps, open communication was also the highest frequency in social presence. However, the frequencies for mind maps were lower than for the online forums, especially for the last two weeks. We believe that as weeks progressed, students in the mind maps started focusing on creating and connecting ideas, rather than commenting on others' posts.

In both scenarios, we believe that an important factor that fostered open communication was the face-to-face encounters where students became familiar with each other. This, we speculate, also had an effect in cohesive communication as we explain below.

2.4.3.3 Cohesive Communication

Cohesive communication or group cohesion is the higher state of social presence, where personal and group identity achieve a delicate balance. Indicators of cohesive communication are: addressing or referring to other participants by name, addressing or referring to the group using inclusive pronouns (we, us, our) and using communication that serves a purely social function. This is an example of cohesive communication from the forums: "*Hey guys sorry I'm posting this on Monday! I got swept up into Thanksgiving*".

As is shown in tables 1 and 2, in the forums the frequencies for cohesive communication exceeded the frequencies for the mind maps, which indicated that in the forums, TCs identified with the group and perceived themselves as a part of a CoI more than when using mind maps.

2.4.4 Cognitive Presence

The cognitive presence facilitates the sharing of meaning and understanding in a community of learning through discourse. Comparing the frequency for the cognitive presence in forums and mind maps, it is possible to note the mind maps had a larger total frequency, even though the distribution of that frequency among different categories is not always higher. Below, we explain details for each category.

The descriptors of cognitive presence (triggering event, exploration, integration and resolution) are based in the model of Practical Inquiry (Dewey, 1933). So, based on the nature of both activities (journaling and brainstorming), regarding the cognitive presence, we anticipated a large frequency of triggering events, and a lower number of exploration, integration, and resolution. The reason for this is that the tasks mainly asked for TCs to comment about insights they had while reading and viewing the materials, and make comments on their peers' posts. Our results, as shown in Tables 1 and 2, confirmed our expectations. However, there were also large frequencies in exploration, as we explain below.

2.4.4.1 Triggering Event.

This phase is associated with evocative and inductive practice, and it is present when students conceptualize a problem or issue (Garrison, 2017). Indicators for triggering event are recognizing the problem and expressing a sense of puzzlement. This is an example of a triggering event comment from the forums: "*I began to wonder about my own education in mathematics. Is it possible that it wasn't the math I hated, but the way it was taught?*"

For the mind maps, other than comments as the one above, we also included posts that contained images or videos that triggered students' reflection about a topic (Figure 4).

As shown in Tables 1 and 2, the triggering event had the highest frequency of all categories. This is consistent with the nature of the activities, where TCs were required to write about their experience, insights and thoughts about a topic. It is also possible to note that, the frequency for each week both in mind maps and online forums is close to the amount of participants (143), which shows that many of the threads in the forums started with a triggering event, or that each student posted a triggering idea in the mind maps. This is expected within the CoI framework.

Figure 4. A sample of triggering event in the mind maps

2.4.4.2 Exploration.

The phase of exploration consists of a search for additional information (Garrison, 2017). Indicators of this phase are: "brainstorming ideas; offering supportive or contradictory ideas and concepts; soliciting narratives of relevant perspectives or experiences; and eliciting comments or responses as to the value of the information or ideas" (p. 66). Below is an example of an exploration comment from our case study:

> *You are quite right when you say that this lesson crosses a multitude of mathematical strands. I would also like to add; the lesson also crosses disciplines. It touches on literacy, especially oral communication and not to mention reinforces peer work which is an essential social and academic skill. (Forum Comment)*

From table 1 it is possible to note that the exploration phase in the online forums had the second highest frequency in the cognitive presence. However, it is also noticeable how the frequencies dropped each week. For the mind maps, frequencies were slightly higher than for forums in exploration. However, the scenario is similar as the one observed in the forums: frequencies dropped as weeks progressed. We infer that as weeks went by, TCs gave priority to publish their original post (triggering event), and did not explored as much into their peers' posts. This is consistent with the total frequencies for cognitive presence, which also lowered week by week. We speculate that as time progressed, TCs lost the thrill and novelty they had when doing the activity for the first time in Week 2.

2.4.4.3 Integration.

The integration phase is considered a tentative connection of ideas (Garrison, 2017). In this phase, indicators are the convergence or integration of information, synthesizing, and providing a rationale, justification or solution. Below is an example of an integration comment from our case study:

> *Now thinking about it, some students may not like to participate as much as others do due to anxiousness, shyness or just not as social as others. […] I like your notion of giving the students options on if they want to participate or not. […] As a teacher, I may make my students do both types of work independent and group work and then let them choose which they feel more comfortable with, that way the can experience both and can get a sense of what type of learner they could be. (Forum Comment)*

As shown in Table 1, in the forums frequencies for integration were low if compared to triggering and exploration. Comments as the one above where TCs would continue to build up on an initial idea after a mere exploration were rare in our sample. We attribute this to the nature of the activity which required very little teaching presence, so the higher-order inquiry was difficult to foster only by the TCs participating in the forums.

As for the mind maps, besides comments as the one above, we included in this category the organized clusters of interrelated ideas (Figure 5). This kind of composition was very common in our mind maps and this resulted in a slightly higher frequency of integration than the one observed for online forums.

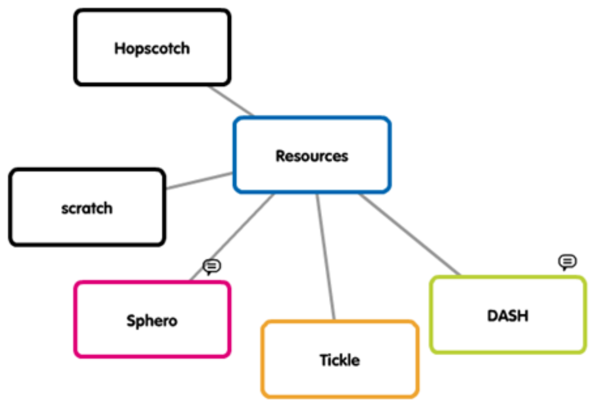

Figure 5. A sample of integration in the mind maps.

2.4.4.4 Resolution.

Resolution is considered to require a deductive test or application of a solution (Garrison, 2017). Indicators are applying, testing or defending a solution. Although rare in our case study, both for forums and mind maps (see Tables 1 and 2), comments as the one below could be found within the sample. In this particular group, TCs were discussing the use of a string as a manipulative to teach area and perimeter.

> *I taught a 2D shape unit to kindergarten students, for one activity I used a string as a manipulative for students to make 2D shapes...they loved it! This hands on/ physical manipulation can be used inside/ outside and in groups or individually. It is amazing to watch young children process and manipulate one piece of string into different shapes. (Forum Comment)*

2.5 Conclusion

Generally speaking, we were able to see only a slight difference between the use of threaded forums and mind maps for the purpose of supporting online discussion. Looking at total frequencies, we obtained a deeper social presence in the threaded forums and a higher cognitive presence in the mind maps. However, the difference in numbers for each category and each week was not large enough to be significant. We believe that a reason for this small difference is that the prompts for the activities were similar in nature, meaning that they asked for TCs to reflect on readings or viewings, and share their insights with their small groups. This resulted in similar patterns of interaction, such as similar amounts of triggering events and exploration comments. Changing the prompt to one that requires a conclusion or a synthesis of the discussion may lead to an increase in integration and resolution comments for both scenarios.

For the social presence, we observed large frequencies in open and cohesive communication both in forums and mind maps. We believe this level of group cohesion was fostered by the face-to-face sessions, because their inclusion “can have an accelerating effect on establishing social presence and can shift the group dynamics much more rapidly toward intellectually productive activities” (Garrison, 2017, p. 48).

In the cognitive presence, for both scenarios, the high numbers in exploration translate into more brainstorming, asking questions and confronting ideas, which is consistent with the high frequencies in cohesive and open communication because this means TCs were confirming their peers’ postings, complimenting them, adding ideas to contribute to one initial thought and asking more questions to clarify or go deeper into a topic. We also observed that in mind maps TCs included more images and videos as triggering events, as opposed to the text only comments they included in the forums. Additionally, the ability to visually connect ideas in the mind maps led to slightly higher frequencies of integration than for the threaded forums.

Also, there are some implications of high group cohesion that could explain why in the cognitive presence our TCs remained mostly within the triggering event and exploration phases, and why for the mind maps the frequencies in cognitive presence were higher as the social presence were lower. When there is too much social presence in a community, it can constrain divergence among participants, creating a “pathological politeness” that encourage surface comments and does not challenge students (Garrison, 2017). We believe that this scenario generated large amounts of supportive comments in the forums and lower amounts of connections and criticism. For this reason, the third element of the CoI framework, teaching presence, is intended to ensure an intellectually stimulating and productive community. In further research, we intend to further explore the impact of the teaching presence, which includes task structure and associated instructions given by the instructor, both in threaded forums and mind maps.

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Chapter 3

3 Online Discussion Tools in Teacher Education: Threaded Forums and Collaborative Mind Maps in a Mathematics Education Program

Currently, a major trend in teacher education is the use of blended learning, which allows institutions to use the advantages of online learning while maintaining the regular course structure and professors' role. As noted by Means, Bakia and Murphy (2014), "blended approaches are often perceived as less threatening to faculty, as the instructor remains the course orchestrator, deciding what portions of instruction to provide through online systems and resources and how to use classroom time to best effect" (p. 50).

In addition to the practical advantages related to the implementation of blended learning, it can also be argued that the integration of technology in teacher education programs has the added purpose of shaping the technological literacy required from teachers in today's educational system. When a blended learning modality is introduced in a teacher education program, it is expected to increase future teachers' familiarity with some technological tools or strategies that relate to their professional roles (Gudmundsdottir & Vasbø, 2017).

For the reasons described above, it becomes necessary to understand and evaluate how the online elements are introduced in teacher education as a support of face-to-face sessions and the role of technology in teacher candidates' (TCs') preparation as teachers. According to Armstrong (2011) "by investigating ways that students perceive and interact with the learning environment, it may be that the design of the online learning environment can be better developed to support learning" (p. 223).

In this chapter, the authors present a case study of a mathematics methods course in a teacher education program at Western University. In this blended course, the online component consisted of three elements: (1) online modules publicly available at researchideas.ca/wmt, (2) online journal assignments through threaded forums, and (3) collaborative mind maps through Mindomo (https://www.mindomo.com). In this research, the authors looked specifically into the latter two online components with the intention to respond the question: What are the roles that each online activity played in the participants' education as teachers? In this context, a role is understood as a function or effect, intended or not, that a particular tool had in TCs learning experience.

3.1 Background

There are three interrelated topics that can inform the research developed in this chapter: (1) technology in teacher education, (2) online discussions in education, and (3) collaborative mind mapping in education. In this section, the researchers present previous research differentiated in these three categories to better understand the conceptual scope of the study.

3.1.1 Technology in teacher education

The inclusion of technology in teacher education can take a variety of forms. Collis and Jung (2003) identified four categories of technology applications in teacher training: (1) main content focus, (2) core delivery technology, (3) part of content or methods, and (4) facilitating or networking technology. This means that the inclusion of technology for teacher training can take these forms: First, technology can be included either for TCs to learn how to use it in the classroom, or only as the medium for training, and second, technology can be included either as the core or as the complement of curriculum contents. According to Jung (2005) many teacher education programs include technology into their training process as an integrated training environment, which additionally allow TCs to experience technology-based pedagogies. This is the approach that has been taken in the case study of this chapter.

Steketee (2005) reviewed the different approaches to technology integration into teacher education programs and the levels of success these approaches obtained. She concluded that when TCs use technology in the context of their subject area, the integration is more successful than in standalone technology courses. Furthermore, in cases where technology training is tied to TCs practicum experiences, they better integrate technology into their own classroom.

In addition, the inclusion of online tools as a part of a teacher education program may have many purposes. Davis (2010) defined three specific reasons to incorporate information and communication technologies (ICT) in teacher education programs: (1) prepare preservice teachers to use technology for educational purposes, (2) prepare them to teach content related to ICT, and (3) apply ICT for their own professional education. Keengwe & Kang (2013) expanded on these roles by looking at a decade of research in the subject. They found that implementations of blended learning in teacher education are designed in the same way as in other programs, and they argue that there's a need to design specifically for teacher education programs because preservice teachers require a wider scope of technology usage.

Over the years, different researchers have described the roles that online activities play in teacher education. For example, Hunt (2015) showed that discussions through online tools, such as forums, can help foster a personalized inquiry-based learning and teaching experience, and other researchers (e.g. Clement Lamb and Phillip 2009; Unwin 2015) show that the same elements can be developed through online discussions during the first years of teaching practice.

As a second example, Gudmundsdottir and Vasbo (2017) explained that the use of a blended environment can increase TCs' professional digital competence (PDC), which includes general skills to teach and learn in a digital environment, the particularities of a subject when taught with digital technologies, and the profession-related tasks through digital technologies, such as classroom management and communication with the school community. Also in the realm of teacher competence, an often-cited model to explain the relationship between technology and teacher education is the technological pedagogical content knowledge (TPACK), introduced by Mishra & Koehler (2006) and developed continually by many other researchers (See http://matt-koehler.com/tpack2/tpack-bibliography/).

A final example of the roles of online tools in teacher education is presented in Hathaway and Norton's (2017) study, where TCs engaged in a process of reflection about their own experiences with blended learning, understanding this modality both from a student and a teacher perspective.

3.1.2 Online forum discussions

Previous studies have shown that asynchronous tools for online discussions, such as threaded forums, can help not only achieve course goals (Means, 2009; Means et al., 2014), but also improve argumentation skills (Ishtaiwa & Abulibdeh, 2012), foster creative and critical thinking (Cheung & Hew, 2006; Lim, Cheung, & Hew, 2011) develop communities of practice (Barcellini, Delgoulet, & Nelson, 2016; Pratt & Back, 2009), and provide connection between face-to-face and online activities (Blumberg, Torenberg, & Sokol, 2004)

Salient research that has served to build up this study has been developed at the University of Calgary for almost two decades. Since its publication, the article Critical inquiry in a text-based environment: Computer conferencing in higher education (Garrison, Anderson, & Archer, 1999) has generated significant interest amid online learning researchers, and the Community of Inquiry (CoI) framework has been used in many publications (Befus, Cleveland-Innes, Garrison, Koole, & Vaughan, 2014). Today, CoI has been established as a theory that describes how students and teachers communicate and construct knowledge in an online learning environment (Garrison, 2017).

In a Community of Inquiry there are three fundamental elements or presences: social presence, cognitive presence, and teaching presence. First, the social presence is a fundamental element in the model, which is defined as “the ability of participants to identify with a group, communicate purposefully in a trusting environment, and develop personal and affective relationships progressively by a way of projecting their individual personalities” (Garrison, 2017, p. 25). Social presence is constructed through interpersonal communication, open communication, and cohesive communication. Second, the cognitive presence is “the extent to which learners are able to construct and confirm meaning through sustained reflection and discourse” (Garrison et al., 1999, p. 11), and it is shaped by the four phases of inquiry: triggering event, exploration, integration, and resolution. Finally, the teaching presence is defined as “the design, facilitation and direction of cognitive and social processes for the purpose of realizing personally meaningful and educationally worthwhile learning outcomes” (Anderson, Rourke, Garrison, & Archer, 2001, p. 5). Teaching presence is constituted by the elements of instructional management, building understanding, and direct instruction. The relationship between these three presences is known to have a significant impact in students' perceived learning and satisfaction in the course (Akyol & Garrison, 2008)

3.1.3 Online collaborative mind mapping

Previous research has found that learners benefit from collaboratively constructing graphical representations in learning environments, because it helps them express their particular cognitive processes (Andriessen, Baker, & Suthers, 2003; Van Amelsvoort, Andriessen, & Kanselaar, 2007; Van Drie, Van Boxtel, Jaspers, & Kanselaar, 2005). Particularly, Suthers and Hundhausen (2003) describe the three roles that a representational aid plays into collaborative work: (1) initiating negotiations of meaning, (2) serving as a representational proxy for purposes of gestural deixis, and (3) providing a foundation for implicitly shared awareness.

In Suthers and Hundhausen’s (2003) study, they evaluated the influence of tools for representation on collaborative learning processes and outcomes. Their work demonstrates that “representational guidance of collaborative learning is worthy of study and suggests several lines of further investigation” (p. 183). A later and very similar research conducted by Van Drie, Van Boxtel, Jaspers, & Kanselaar (2005) studied the effects of constructing external representations on domain-specific reasoning in CSCL (Computer Supported Collaborative Environments). Results suggest that each tool has different affordances and constraints, and it can be argued that each tool requires further investigation on how students interact with it for collaborative construction purposes. Van Drie et al. (2005) also suggest that “the representational tool does not only function as a cognitive tool that can elicit elaborative activities but also as a tool through which students communicate and elaborate” (p. 598).

Van Amelsvoort, Andriessen, and Kanselaar (2007) studied collaborative argumentation and how it can be supported by using an online representational tool. In this study, they used a more detailed qualitative approach on students' experience. They found that diagramming can help students to learn by allowing non-linearity of discourse, linking of ideas, and offering a clear overview of a topic. However, diagrammatic representations can only improve collaborative learning when they are used in a co-constructive way, that is, when students use the representations to start a discussion about their collaborative text, as opposed to only copying information from the diagram into the text.

While the studies mentioned above did not actually refer to mind mapping or the closely related structure of concept-mapping , other studies have focused on describing student collaboration during the online construction of concept maps. One example is provided by Komis, Avouris, and Fidas (2002) who describe concept mapping as a tool for social thinking, and they study peer synchronous interaction during concept-mapping. Another example is presented by Madrazo and Vidal (2002) who looked at how students build relationships between pairs of concepts through an online tool developed by the same authors. Both studies' results are consistent in showing the effectiveness of online concept-mapping, the first in relation to problem-solving, and the second in relation to meaning making.

Another research worth highlighting is the study conducted by Wu and Hou (2014). In their research, concept-mapping is used as an alternative to online discussion activities during project-based learning. The results suggest that integrating concept-mapping tools into online discussion activities is more appropriate for the planning phase of project-based discussion activities than it is for the implementation phase.

3.2 Researchers' Framework

In this study, researchers adopt a social constructivist perspective, which is the theoretical foundation of collaborative learning. It is based on Vygotsky's (1978) view that knowledge is constructed in interactions with others. However, in this view, "others" not only refers to humans such as other learners, teachers and other significant people, but it also refers to digital artifacts that exist in our new media culture. The online artifacts that

TCs engaged within this study (such as online modules, threaded forums, and mind maps) are viewed as actors in the TCs' learning milieu, whose affordances affect their thinking and acting. In this sense, humans-with-media (Borba & Villarreal, 2005) form a collective where new media also serve to disrupt and reorganize human thinking. The researchers share Levy's (1997) view that technological artifacts are not simply tools used for human intentions, but rather they play different roles in the cognitive ecology formed when humans interact in a technological environment. Specifically, in this chapter, the authors look at the roles that two tools played in participants' education as teachers.

3.3 The Case Study and Methods

In this research, the authors used a case study approach, which has the purpose of collecting in-depth stories of teaching and learning. The 'bounded system' (that is, the thoughts and actions of participants in a particular education setting) was studied so as to understand it in the way it functions under natural conditions (Yin, 2014). The case was limited to the five sections of the K-6 teacher education program in the Faculty of Education at Western University. The five sections were treated as a single case, as TCs participated in the same online environment and completed the same tasks.

Participants were 194 TCs who agreed to participate and were registered in a mandatory mathematics methods course. The course used a blended learning delivery mode where online activities supported face-to-face sessions. In face-to-face sessions, which happened once a week, TCs engaged hands-on with mathematics activities. This was coupled with an online learning management platform where instructors posted course schedules, assignments, weekly tasks, and course resources, and where they set up online discussion groups.

In this blended course, the online component consisted of three elements: (1) online modules publicly available at researchideas.ca/wmt, (2) online journal assignments posted and discussed in a threaded forums, and (3) collaborative mind maps through Mindomo (https://www.mindomo.com). Regarding the first element, the modules were developed by the second author, based on work developed over more than 10 years researching approaches to mathematics education with an explicit focus on students (a) experiencing mathematical surprises, and (b) being able to share these surprises with family, friends and the wider community (G Gadanidis & Borba, 2008; G Gadanidis & Hughes, 2011; George Gadanidis, Hughes, Minniti, & White, 2017).

In regards to the second online element of the course, one of the assignments involved keeping a journal in response to online resources and classroom experience, based on reflection questions identified by the instructor. TCs shared their journals in their online discussion groups and commented on the ideas shared by their peers, in groups of 4 to 6 students. There were nine journal tasks assigned that focused on different readings, resources, and activities from varied sources. Six of these tasks were developed using threaded forums as a discussion tool. Below is an outline of the forum discussions contents:

- Week 3: Teachers as Mathematicians
- Week 5: Growing Patterns
- Week 7: Odds and Evens
- Week 9: Infinity and Beyond
- Week 13: Parallel Lines
- Week 14: Symmetry

The threaded forum tool used for this activity was in the Sakai Learning Management System (LMS) of Western University. Figure 6 illustrates the interface of the forums. The reader should note that the text in Figure 6 is not intended to be readable. The image serves only to show the general layout of the site and the conversations carried in this environment.

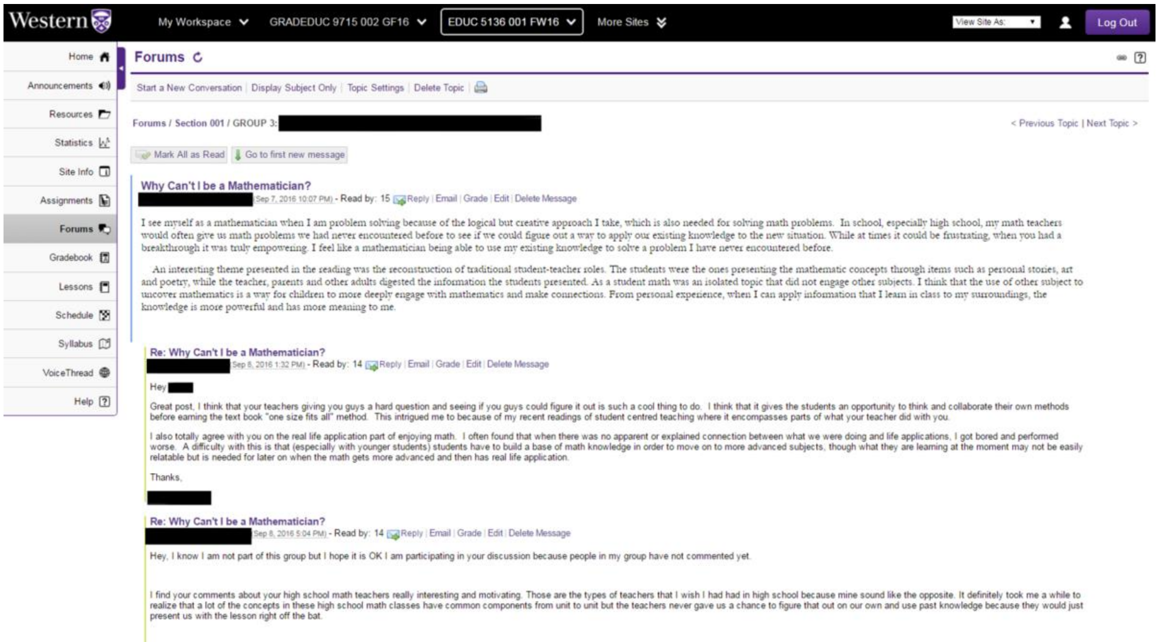

Figure 6. Screen capture of a threaded forum discussion in Western University's LMS. Participants' names have been covered.

Additionally, as an alternative to online forums discussion, mind maps were introduced in the course through the collaborative tool Mindomo (https://www.mindomo.com). The activity consisted of the collaborative knowledge construction and reflection in small groups (4 to 6 participants) about readings, resources and classroom experience, guided by initial prompts or questions made by the instructor. Figure 7 shows the sample of a mind map. This image serves only as an illustration of the activity and the layout of the tool, so it is not supposed to be readable as the mind maps were large structures that cannot be displayed in their entirety on a single page.

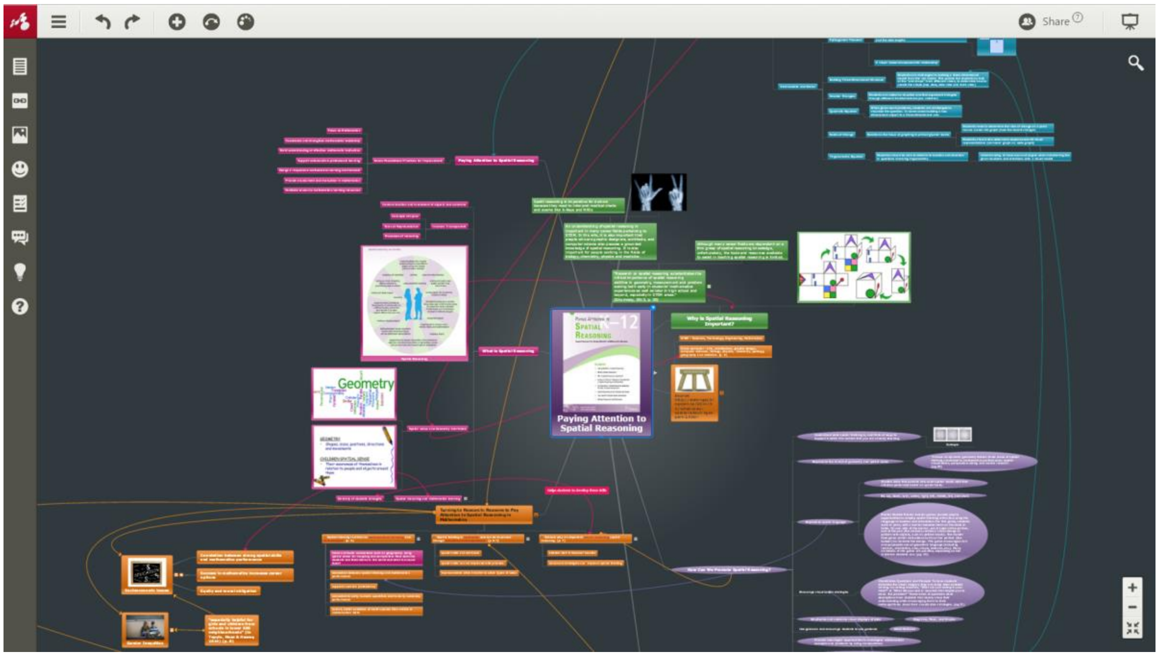

Figure 7. Screen capture of a mind map in Mindomo.

There were three mind map tasks, which are outlined below:

- Week 10: Paying Attention to Fractions
- Week 11: Area and Perimeter
- Week 12: Paying Attention to Spatial Reasoning

It is relevant to mention that the group of students in our case study was familiar with the use of mind maps before attempting these tasks because they were registered in another course that implemented a mind mapping activity in a previous term. However, in the prior course, participants used a different mind mapping tool (Mindmeister - https://www.mindmeister.com)

Data sources were all the forum discussions and mind maps. Guided by the questions of the study, the authors used qualitative content analysis (Berg, 2009) to identify comments about TCs' experience with the online activities, or samples (comments or mind maps images) that represented different roles played by that online activity. First, the researchers extracted all data from the mind maps and reflection assignments. Any data from students not participating in the research was deleted, as well as any identifiers (such as names). Then, the researchers used a manual content analysis by reading and observing patterns in all of the forums and mind maps, while coding the text into open subcategories and themes (See Table 4 for a comprehensive list of the topics), then identifying how these related to two main categories, based on the question of the study: (a) the role of threaded forums and (b) the role of mind maps in participants' education as teachers. The researchers identified these themes by observing patterns, taking notes and developing an initial analysis. This process is known as conventional qualitative content analysis (Hsieh & Shannon, 2005).

Finally, with the preliminary roles that emerged from this process in mind, the researchers proceeded to do interviews with participants for confirmation and further build up. A total of seven TCs participated in these interviews. All seven participants took part in online interviews, and one participant additionally took part in a face-to-face interview. Questions in the interviews were open-ended, allowing for additional themes to emerge from a conversation with participants. However, the questions shown in Appendix E served as a guide for interviewing.

Table 4. Codes and frequencies obtained from NVivo.

Codes	Threaded Forums	Mind Maps	Interviews
Discussing Class Activities	133	98	20
Discussing Online Resources	120	87	16
Discussing Practicum Experiences	86	80	4
Opinions about the mind map activity	2	16	7
Positive	2	14	5
Negative	0	2	2
Using an online resource during practicum	67	63	7
Applying a class activity during practicum	72	80	5
Showing support, complimenting	110	42	0

Opinions about the forum activity	0	5	7
Positive	0	0	1
Negative	0	5	6
Student Roles	118	50	0
Teacher Roles	107	70	0
Mathematics Pedagogy	96	120	5
Mathematics as a subject matter	32	47	0
Student Engagement	104	97	0
Questioning and challenging ideas	123	53	0
Connecting ideas	52	156	2
Arranging, organizing ideas	10	131	0
Planning the activity	3	54	0
Summarizing	15	56	0
Metacognition, pointing out how something was learned	19	83	0
Visualization as a learning strategy	28	54	3
Using images	2	142	0
Using videos	1	71	0
Talking about collaboration, group work	20	80	5

3.4 Findings

This section proceeds with a description of the topics and most important elements that emerged from the content analysis and pattern observation of threaded forums and mind maps. Findings are organized by each discussion tool. Direct quotes from participants and mind map screenshots are used to give depth and richness to key topics and observations.

3.4.1 Threaded Forums

One main affordance of both tools was the opportunity to integrate face-to-face sessions, online experiences, and practicum developments. Two representative samples of this type of comments from the forums are presented below:

> Example 1: *I found it interesting for example, to draw connections between the different shapes. I found, for example, that if you were to rotate the last odd shape, it would return to its original every other 90 degree turn, or every 180 degrees. This was similar to the theory that we explored in class involving rotations and flips in certain directions and the relationship to odd or even numbers*

> Example 2: *I also really like how the questions in the activities sections gave opportunities for inquiry-based learning, as they asked for students to create their own patterns. One way I would extend this to include the open-ended question techniques we talked about in class is to ask them to come up with the situation where that pattern would occur in real-life.*

In Examples 1 and 2, a teacher candidate is discussing in the forum their insights about an online module. In the last sentence of each example, the participant relates the online module to a face-to-face session. In some cases, TCs also commented on their practicum experience, as shown in the sample comments below:

> Example 3: *This reminded me of an experience I had in practicum. I had a student in my Grade 3 class who, as he always told me himself, was "not the best reader or the best writer". However, when I taught a coding lesson, he is the student who caught on to the concepts the fastest, and he would say "Madame! I found a shortcut to what you're doing!"* [Quotation marks present in participant's original text]

> Example 4: *For my first practicum, I have been placed in a kindergarten class. I am inkling to see how I can adapt these kinds of activities for a kindergarten class. I know that it will not function in the same way for a class of such a young age range, but incorporating a story into a counting game will make it fun and easy to understand.*

In Example 3, the participant is relating a past experience in the practicum with something they just saw in the modules, while the participant in Example 4 is talking about their intention to apply an element of the modules in their future practicum.

Another pattern that was noticeable in threaded forums was that in all conversations participants agreed with others' comments and shared complimentary or supportive messages. Examples of this are shown below:

> Example 5: *Great post. I too was still a little unsure about the ideas of permutations after Monday's class as well. I am someone who needs quite a bit of time to grasp concepts, so if the class was longer I might have been more successful.*

> Example 6: *I enjoyed reading your "long reflection post" so do not apologize! You raise a number of great concerns regarding your experience with math that I too feel need to be stressed.*

Example 5 was a post in response to an apprehensive comment made by another student and related to understanding one of the class' concepts, while in Example 6 a participant is complimenting a peer on their post, and reassuring that their "long reflection post" was appreciated.

Beyond this, the amount of posts that elicited debate or raised new ideas that built up the conversation were limited. Because of this, some TCs perceived the activity as unnecessary for their learning. In interviews, two students expressed that only their original contribution (and not the action of reading and commenting others' posts) was helpful for their own learning. One student further explained this and said that the forums weren't constructive enough because participants would choose to comment on the posts that expressed similar thoughts to their own, so as to avoid confronting ideas.

Another theme that TCs repeatedly wrote about was the different roles that students and teachers usually play in the classrooms, and what are the roles they should ideally play to create a meaningful learning experience. These topics were elicited by the weekly topics and viewings that generally disrupted traditional approaches for learning. However, some comments were related to participants' experiences in classroom and in class. Below are two examples of students discussed the roles of students and teachers:

Example 7: *I found in my practicum that students really enjoyed math when it became a game, but sometimes the students got extremely off track and did not realize there were things to be learned! [...] I find students learn a lot better when they feel more connected to the topic and are able to share their learnings with others (taking ownership)*

Example 8: *A great way to keep junior students engaged in math is by providing them with material that's going to challenge them. Python Programming and Scratch are fantastic programs to have students code their own work and equations in many areas of mathematics*

In Example 7, the teacher candidate is discussing students' engagement through games and how to channel their excitement while allowing them to take ownership of their learning. This has implications for teachers as creators of social experience, and the students as owners of knowledge. In Example 8, the teacher candidate is stating the importance of keeping students engaged by challenging them and letting them work on their own, showing a change in expectations for student's involvement.

The last key finding observed in the threaded forums was the questioning of currently established knowledge, as TCs gained increasing agency in determining what students need and who they are as teachers. The following two examples show expressions of this:

Example 9: *My practicum was in a grade 2 class and I agree that this lesson would be challenging for my students as I had many students who could not read yet and many were "lower" than grade 2. But, I think it would be interesting to see if this could be introduced, perhaps, very slowly and gradually. Maybe they would in fact surprise us? It would be interesting to find out.*

Example 10: *As I mentioned last week in class, I am a strong believer in teaching students and NOT curriculum. But how? I too believe that there is too strong of a focus on the grade specific content that teachers may be missing key factors that would assist children's development. One question still remains - how can we ensure*

> *that we are challenging our students to better their communication skills in mathematics?*

In Example 9, a teacher candidate is considering the role of their students in class, and the level they believe students could achieve. But, at the same time, the teacher candidate shows interest in considering other paths and more sophisticated strategies that would change the way classes are usually conducted. The teacher in Example 10 is directly challenging the focus of grade specific content in the curriculum while posing a question on how to extend students' skills.

3.4.2 Online Mind maps

In mind maps, as well as in forums, students found the opportunity to connect face-to-face, online, and practicum experiences. However, in mind maps they were able to do it in a more direct and explicit way. Figure 8 shows an example of how TCs developed the linkage of the three environments in the mind maps. In the mentioned image, the participant connected to their own name the three environments (Math4Teachers is a common name that TCs gave to the online modules).

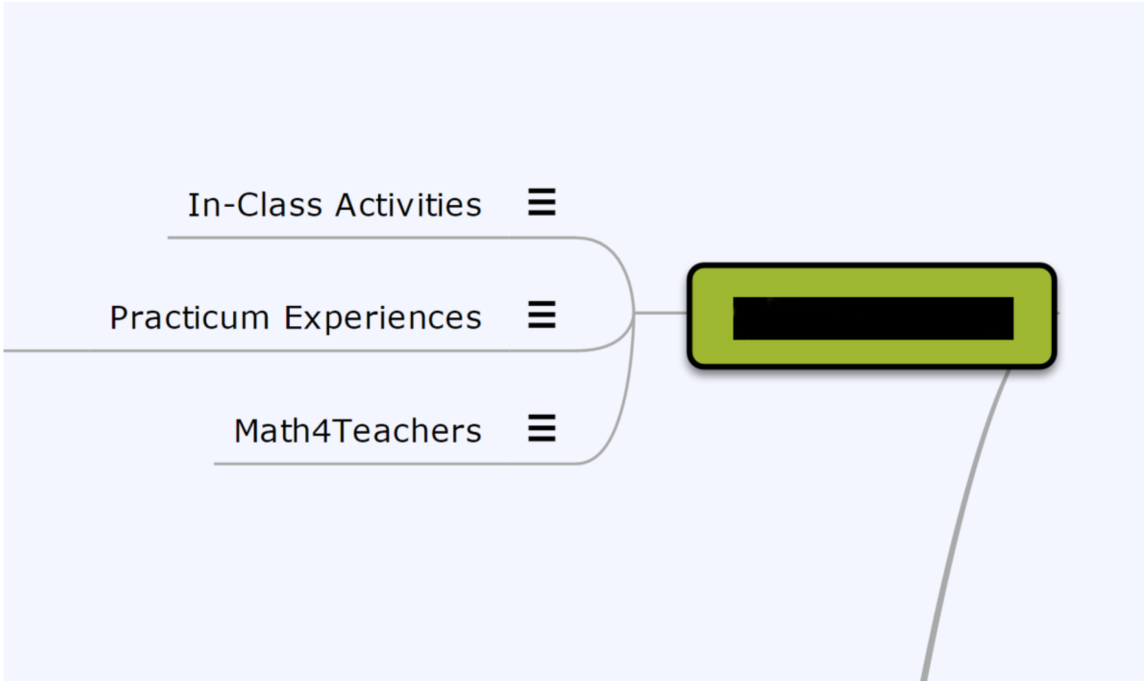

Figure 8. An example of how continuity was observed in mind maps. Participants' names have been covered.

Each node in the mindmap was expanded through brief notes, which were displayed by clicking on the three-line icon at the right of each node. These notes were used to add larger descriptions, but in rare cases these exceeded three or four sentences, which differed greatly from the way participants expressed in forums. Figure 9 shows an example of these notes. In this case, the participant is describing their experience in practicum.

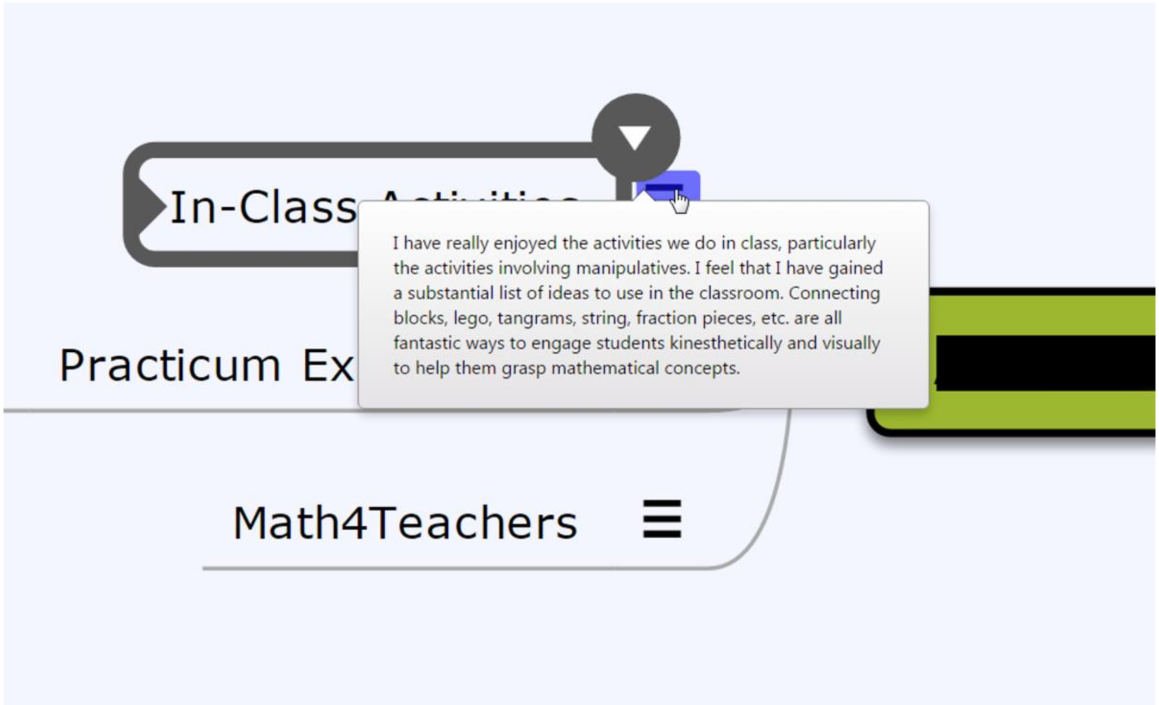

Figure 9. An example of a note added to a concept in a mind map. Participants' names have been covered

Another element that was observed in mind maps is related to how TCs were able to organize complex ideas or topics by making arrangements and connections which were very different from group to group. For example, Figure 10 shows two different ways in which students organized the discussion for the same week. In the upper mind map, each teacher candidate was assigned a topic and developed that topic in the mind map, where others would add ideas if necessary. In the lower mind map, TCs divided the reading amongst members of the group and dedicated one section of the mind map to each set of pages.

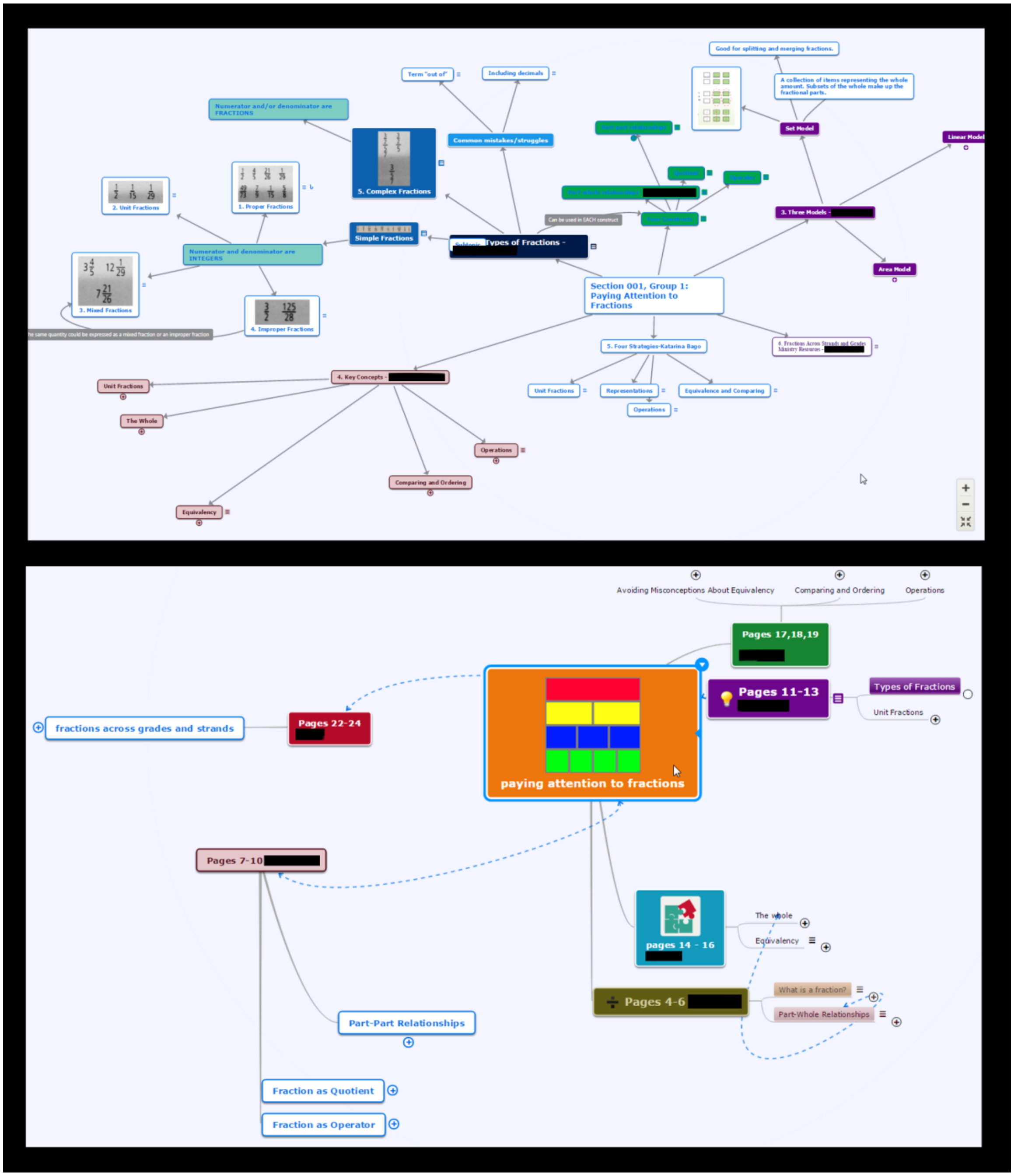

Figure 10. A comparison between two different ways in which TCs organized the discussion for the same week. For the sake of clarity in the screenshot, some branches of the mind map have been hidden. A plus sign within a circle appears in every node where branches were hidden. Participants' names have been covered.

Other groups did not guide the construction by the topics on the reading, but rather by the more individual contribution of each participant. This means, creating a topic for each participant's name and building individual sections for each person's insights, which were then connected to others' ideas. Figure 8 shows an example of this kind of structure.

These patterns hinted researchers about some form of organization happening among participants in a group to decide how the mind maps would be developed. So, in interviews, researchers asked about what TCs learned by using mind maps, what did they like about that activity, and how did they develop the group mind map. Most students (five out of seven) commented about organizational features of the mind maps. For example, one student wrote that mind maps "made information easy to be sorted and viewed", and another one commented that in contrast to forums, in mind maps they could see everyone's participation in a glimpse and decide very easily where they wanted to include their contributions. Regarding the groups' organization of work, one teacher candidate wrote that they "liked seeing the mind map transform into what [they] wanted as a group". Another participant explained that, prior to the activity, their group decided on the color that each member would use for individual contributions, and they agreed that when connecting concepts they would use a connector with the other person's color in order to better visualize relationships between ideas.

Beyond the array of the topics, there were also different ways in which students connected ideas. For example, the researchers observed that connection were made between topics to create concept clusters, such as the one in Figure 11, or the connection was made between concepts in different clusters, such as the one in Figure 12.

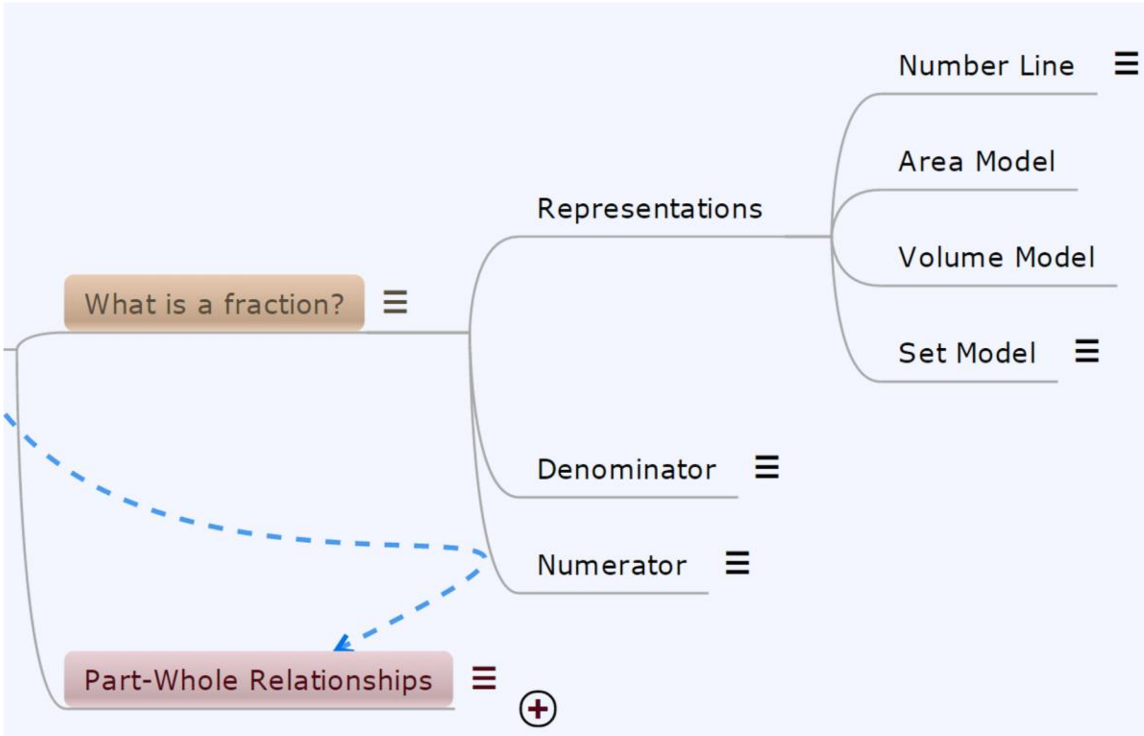

Figure 11. An example of integration in the mind maps by creating clusters of concepts.

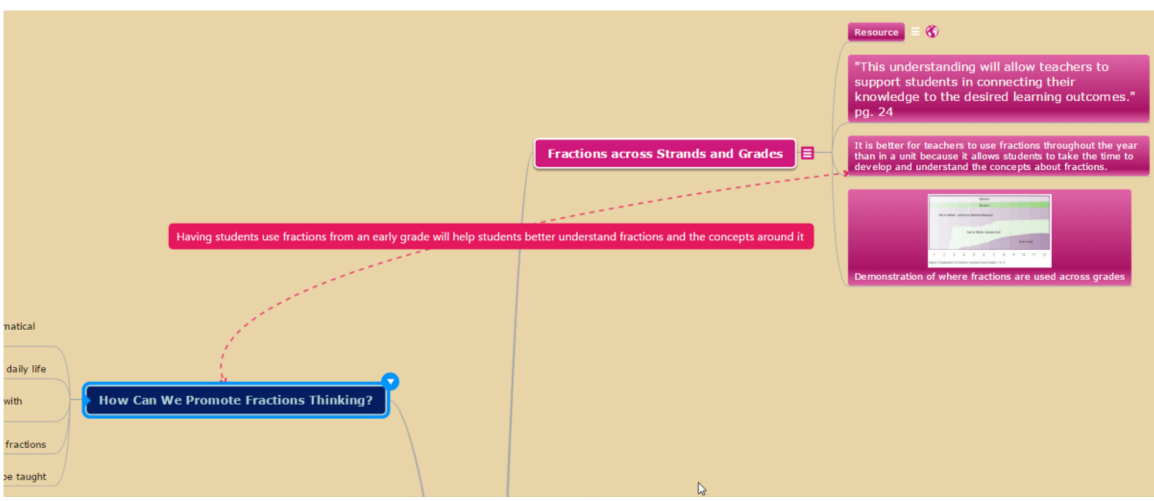

Figure 12. An example of integration in the mind maps by connecting concepts from different clusters.

Figure 12 is also a good example of how mind maps allowed TCs relate different strands of a topic, which could not be done as easily in forums. In interviews, one participant mentioned how interesting it was for them to connect the contributions made by two, three, or more students, and they emphasized that they never did this in the forums, where each person's post was isolated from others and ideas would repeat without making a significant connection.

Finally, by the third week of creating mind maps (week 12 - paying attention to spatial reasoning), the researchers noticed an increased dexterity from participants in the use of the tool. By the third week, TCs were comfortable enough with Mindomo to create more complex and extended mind maps. Figure 13 shows an example of this complexity in a third-week mind map, compared to the same group's work from the first week of mind mapping (week 10 - paying attention to fractions). The use of more images in the third week (19 vs. 14), more connections (17 vs. 9), and the inclusion of a video also serve as evidence of this development, noting that participants had the same amount of time to develop mind maps from scratch in both weeks, attributing these increments to time is not possible.

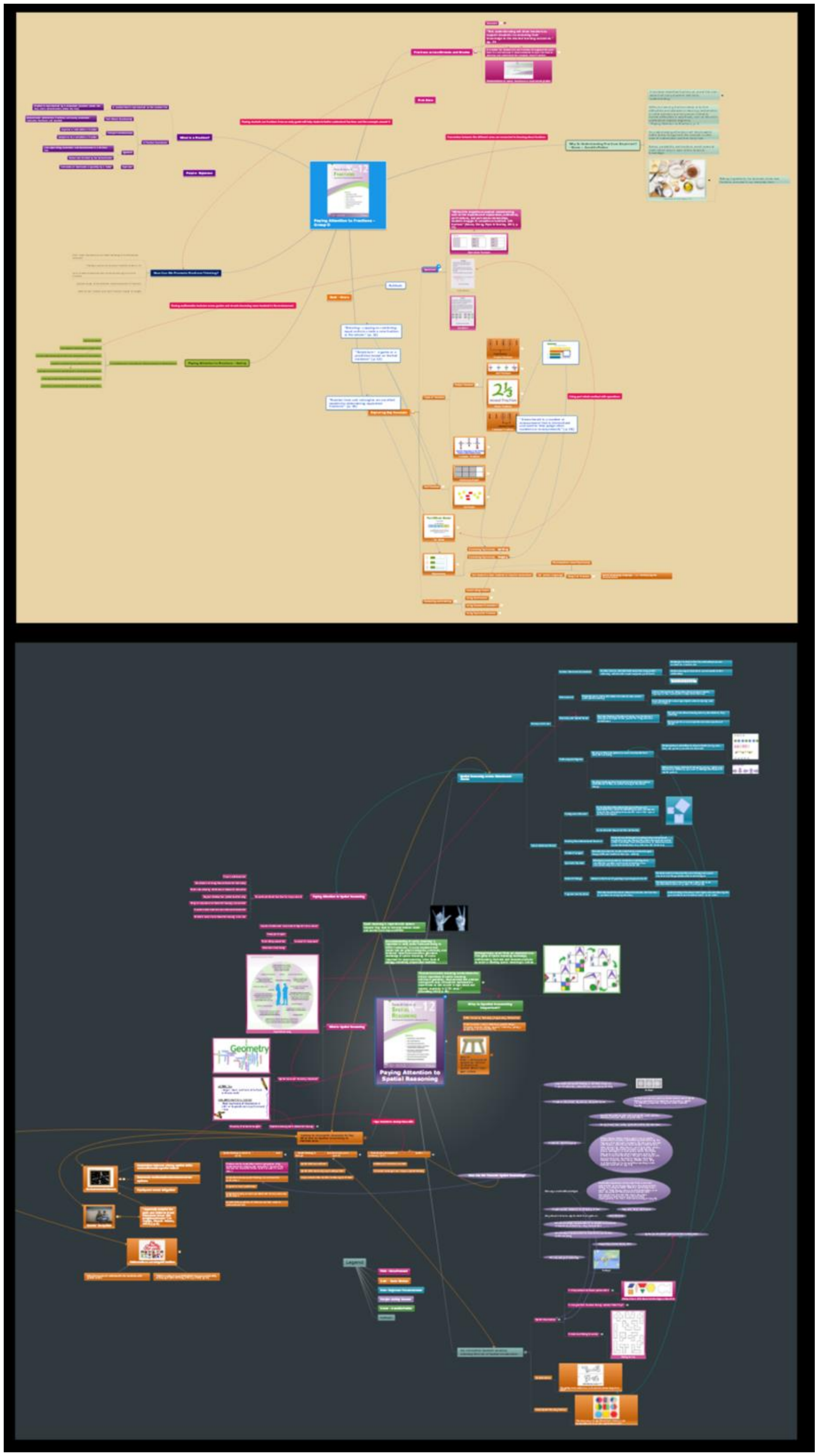

Figure 13. A comparison of the increasing complexity in mind maps from the first week of use (above) to the third week of use (below).

Beyond familiarity with the tool, TCs also identified other elements they learned from the mind maps, such as possible uses of the tool in their teaching, and the possibility to work collaboratively in groups. During the interviews, one participant expressed that creating a mind map as a group was the most important learning taken from the activity. Another participant spoke about using mind maps in mathematics to summarize and visualize concepts, or as a presentation tool. One example of how this tool could be used to present information to students is shown in Figure 14.

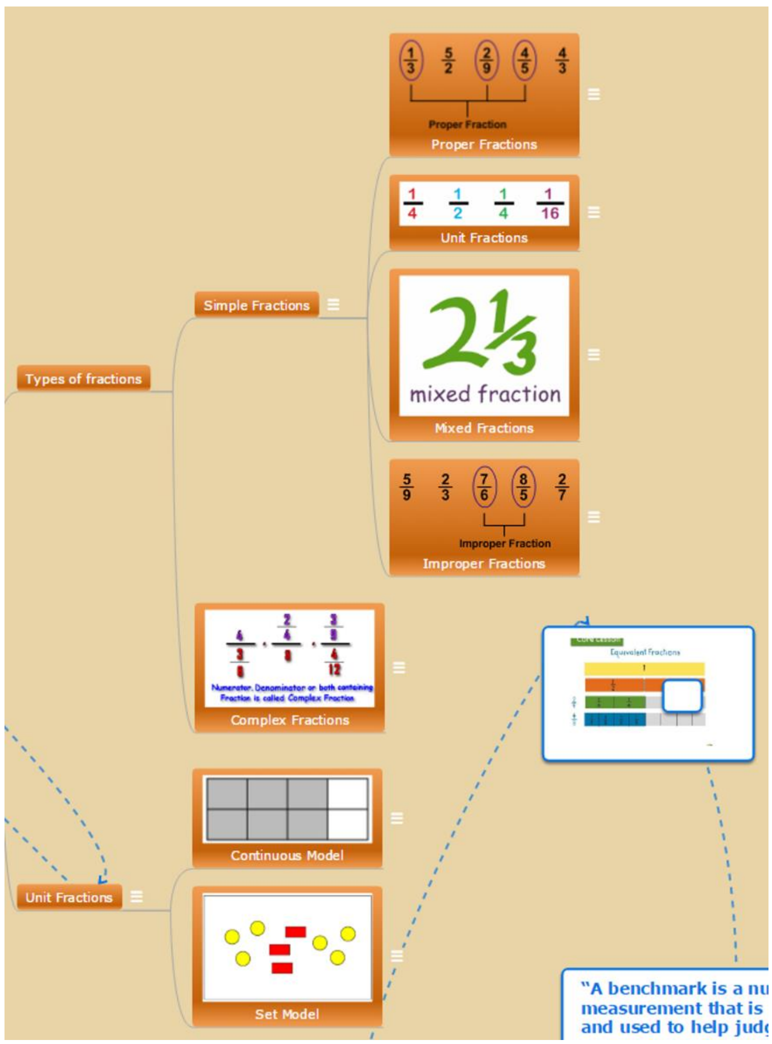

Figure 14. An example of how Mindomo could be used to visualize and present information.

3.4.3 Summary of Findings

Table 5 summarizes the key findings derived from content analysis, observation and interviews. These constitute the most salient themes and patterns in the data which sustained the subsequent discussion and final determination of the roles that the discussion tools played in the participants' education as teachers. It is important to note that most of these findings can be attributed to the frequencies displayed in Table 4, but others come from the process of analysis within each code and category, from relating different codes, and from the segregated results of each week.

Table 5. Summary of Findings

Tool	**Findings**
Threaded Forums	1. Participants made connections between face-to-face, online, and practicum experiences. 2. Participants engaged in comments of support and compliment, rather than eliciting debate or knowledge construction. 3. Participants expressed new understandings about the roles of teachers and students. 4. Participants showed criticality about currently established knowledge.
Mind Maps	1. Participants made connections between face-to-face, online, and practicum experiences. 2. Participants organized the group work to display ideas and topics that varied from group to group. 3. Participants connected the ideas and concepts in varied ways and the connections were made between posts of different participants 4. Participants showed increased dexterity in using mind maps as weeks progressed.

3.5 Discussion

The findings summarized in Table 5 were analyzed, compared with existing literature and presented in this section. The researchers labeled each finding in the way other authors have used to describe the specific events observed in this case study. So, the roles of the discussion tools identified are: continuity, open communication, shifts in participation, transformation of identity, organization, integration, and development of professional digital competence. The following discussion is organized by these roles.

3.5.1 Continuity

The possibility to make connections between different activities of the curriculum as observed in our discussion tools is referred to in the literature as continuity and is defined by Blumberg, Torenberg, and Sokol (2004) as the possibility to "link issues raised by the students online to those made in a successive class" (p.152). Continuity emerged as a role both in forums and mind maps, as students would comment on their experience during classroom sessions. Also, when they related face-to-face and online activities to their practicum session, as in Examples 3 and 4, and in Figure 8, the tools were providing an additional level of continuity to the learning experience.

In many cases, continuity is an intended aspect of blended learning. According to Hathaway & Norton (2017), each environment has particular affordances and the key is to use their differentiated strengths to facilitate the course goals, while making sure that one activity leads to another in a seamless way. This is also consistent with Steketee's (2005) review technology integration, where cases that obtained more success were those that provided a higher level of continuity between technology-mediated learning experiences and the practicum.

3.5.2 Open Communication

The large amount of supportive and complimentary posts, as the ones presented in Examples 5 and 6, show a high level of open communication. In a community of inquiry framework (Garrison, 2017), open communication is described as the element that ensures "a climate of trust and acceptance that allows questioning while protecting self-esteem and acceptance in the community" (p. 45-46). Another indicator of open communication is observed in Example 6, where the participant opens with a purely social sentence which has the purpose to comfort their peer.

In a previous study by the authors (Cendros Araujo & Gadanidis, 2017), student-student interaction in forums was described as highly social, and the authors explain that "TCs identified with the group and perceived themselves as a part of a CoI more than when using mind maps" (p. 811). On the contrary, the same study showed that the amount of concept exploration and integration was lower in forums than in mind maps. This was observed as well in the case study of this chapter, where a vast majority of comments were complimentary and supportive, rather than criticist or contradicting. So, the salient role of the forums in participants' education as teachers was to provide an open space to share and confirm ideas, and not to discuss or debate.

Despite the perception of some TCs about not learning much from these supportive messages, a space for sharing ideas, even if only intended to include original posts and not respond to others', plays a relevant role in teacher education. According to Jung (2005) more attention should be paid to the role of technology in "helping overcome teachers' isolation, connecting individual teachers to a larger teaching community on a continuous basis, and promoting teacher-to-teacher collaboration" (p. 100). An open space for communication could help achieve that because it creates the foundation for a community of practice (Barcellini et al., 2016; Pratt & Back, 2009). This relates to the following two roles.

3.5.3 Shifts in Participation

In the case study, the researchers were able to view the two indications of learning within a community of practice, as posed by Clement Lamb & Phillip (2009), which are: shifts in participation and transformation in identity, explained in the following section.

The first indication, shift in participation, happens when teachers pose "different kinds of questions to students in an effort to learn from and with their students, or teachers discussing with other teachers their changing expectations for students' classroom participation" (Clement Lamb & Phillip, 2009, p. 18). This was observed when participants wrote about the different roles that students and teachers usually play in the classrooms, and the roles they should ideally play to create a meaningful learning experience. Examples 7 and 8 show such shifts in participation.

There are other studies of online discussions that have seen indicators of shifts in participation. For example, in Hunt's (2015) study, a blended learning experience prepared TCs to understand what their learners might experience in the classroom, and what they might feel when undertaking the teaching practices displayed in the course.

Also, Pratt and Back (2009) study, observed similar events in discussion boards, where math teachers shifted from identifying students as the only learners in the classroom, to both students and teachers as learners.

3.5.4 Transformation of Identity

Closely related to shifts in participation, the second indication of learning within a community of practice is transformation of identity, by which teachers become “less dependent on the text as the arbiter of knowledge, questioning previously taken-for-granted practices, and becoming curious about individual children’s mathematical understandings and how to extend those” (Clement Lamb & Phillip, 2009, p. 18). This was observed when students questioned currently established knowledge, as they gained increasing agency in determining what students need and who they are as teachers. Examples 9 and 10 show transformations of identity.

For Wenger (1998), identity is formed through interaction and communication with peers and studies have found that online discussions can foster professional identity development. For example, in Pratt and Back (2009) the transition from student to teacher could be documented in contributions to discussion boards and in Hunt’s (2015) study, the online environment also served as a place for questioning as students used each other as experts and sought their perspectives. Also in Hunt’s study, in online journals students expressed an increasing sense of power to apply the teaching strategies portrayed in that course, in the same way that happened in the case study of this chapter.

3.5.5 Organization

The organizing function of mind maps is well known in the literature. Hanewald and Ifenthaler (2014) mention that mind maps’ main role in education is “to organize and present information [and] as an ‘advance organizer’, that is a global overview of the material” (p. 13). In the present case study it was possible to observe that this feature extends to collaborative work in online settings, as presented in Figure 14.

This is consistent with previous research, such as the study conducted by Wu and Hou (2014). In their research, concept-mapping is used as an alternative to online discussion activities during project-based learning. The results suggest that integrating concept-mapping tools into online discussion activities is useful for the planning phase of project-based activities, which require high levels of negotiation and organization.

The role of organization can be compared to the property that Suthers and Hundhausen (2003) identify as providing the foundation for explicitly shared awareness, by which the shared visual representation "serves as a group memory, reminding the participants of previous ideas (encouraging elaboration on them) and possibly serving as an agenda for further work" (p. 185)

3.5.6 Integration

The organizational role of mind maps also relates to the concept of integration in a CoI (Garrison, 2017). Integration is a phase of the cognitive presence where participants synthesize or connect ideas. In this case study, integration was observed in concept clusters, such as the one in Figure 11, or the connection made between concepts in different clusters, such as the one in Figure 12.

In a previous research conducted by the researchers (Cendros Araujo & Gadanidis, 2017), they observed that the phase of integration was achieved more frequently in mind maps than in forums. This is because visual representations, such as mind maps facilitate non-linearity of discourse, linking of ideas and clearly overviewing of a topic (Van Amelsvoort et al., 2007), which are crucial elements of concept integration.

The role of integration can be compared to the property that Suthers and Hundhausen (2003) identify as serving as a representational proxy for purposes of gestural deixis, by which collaboratively constructed visual representations "facilitate subsequent negotiations, increasing the conceptual complexity that can be handled in group interactions and facilitating elaboration on previously represented information" (p. 185)

3.5.7 Development of Professional Digital Competence

Another role observed in the mind maps was the development of TCs' professional digital competence (PDC). This role was more intended than naturally developed through the tool usage, as the instructor purposefully selected Mindomo as the provider because it is approved by the Ontario Software Acquisition Program Advisory Committee (OSAPAC), which advises the Ministry of Education on the acquisition of provincial licenses for publicly-funded schools in Ontario. So, by including the use of Mindomo, it was expected that TCs developed familiarity with a visual tool they could use in their classrooms. PDC is constituted by three elements (Gudmundsdottir & Vasbø, 2017): (1) generic digital competence, which includes general skills to use a digital environment; (2) subject/didactic digital competence, which includes the particularities of a subject when taught with digital technologies; and (3) profession-oriented competence, which are the profession-related tasks through digital technologies, such as classroom management and communication with the school community.

An indication that PDC, specifically generic digital competence, was developed using mind maps was that by the third week of using mind maps (week 12 - paying attention to spatial reasoning) TCs showed more dexterity in using the tool. Although in our case study this was only an observation and it was not confirmed by the participants, in a previous study (Hunt, 2015) TCs expressed feeling "empowered by using [...] online tools, often for the first time, and the resulting skill development was clearly evident in many journal reflections" (p. 54).

Also, there was evidence that TCs developed subject/didactic digital competence. This type of competence captures the specifics about teaching a subject using technology, in this case, mathematics. For example, three TCs during the interview identified the mind map as a way to present information in the classroom. This role of technology in teacher education was also identified by Davis (2010) as the affordance to prepare preservice teachers to use technology for educational purposes.

Finally, to a limited extent, TCs showed profession-oriented competence by developing the negotiation and organization skills described earlier. In previous research by Suthers and Hundhausen (2003), they identified one of the roles of visual tools as initiating negotiations of meaning. This means that when a participant wished to add to or modify a visual representation "may feel some obligation to obtain agreement from one's group members, leading to negotiations about and justifications of representational acts" (p.

185). So, the use of mind maps in this case study had influence in participants' negotiation and collaboration skills, which are profession-oriented competences of teachers.

3.5.8 Summary of the Roles that the Online Tools Played in Participants' Education as Teachers

In sum, threaded forums offered TCs a space for open communication and a sense of belonging to a community. This, in turn, generated shifts in participation and transformations of identity, which constitute indicators of a developing community of practice. On the other hand, online mind maps served as a space to organize information and complex topics, to facilitate the integration of ideas, and develop TCs' professional digital competence. Both tools additionally had the role of providing continuity to the curriculum. Figure 15 shows a visual representation of the roles discussed throughout this section.

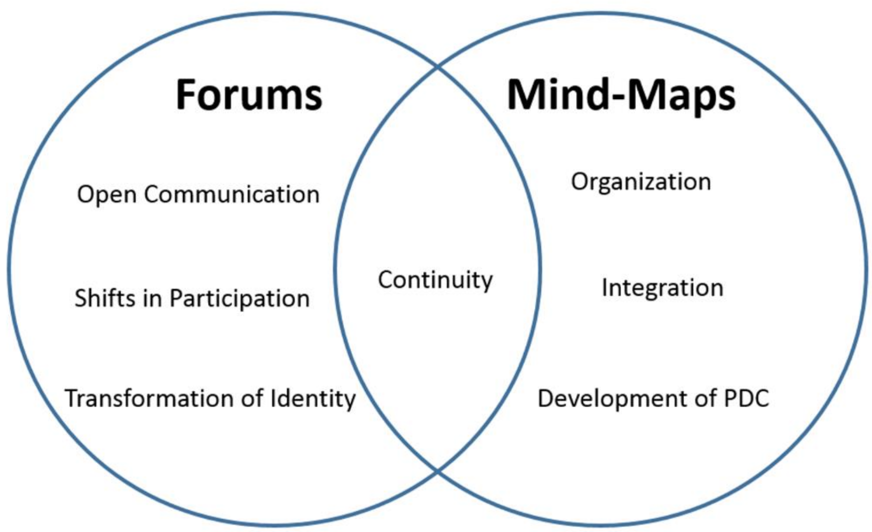

Figure 15. Summary of the roles that the online tools for discussion played in TCs' education.

By taking a broad view of these roles, it is possible to see connections to the researcher's framework of social constructivism. By interacting and creating a sense of community with other students and with the tools, TCs constructed knowledge collaboratively and developed professional competences. The threaded forums and the mind maps affected TCs thinking and acting. Especially with the inclusion of mind maps where the visualization affordance disrupted and reorganized the way in which TCs interacted.

3.6 Recommendations for Future Implementations

To develop the following set of recommendations, the researchers used input from interviews with TCs to gain insights on how to improve participants' experience when using the online tools.

Regarding the use of forums, as weeks progressed, it was noticeable that the amount and length of comments decreased. In interviews, participants expressed that, at the beginning, there were many new and interesting ideas explored in the readings, so they had many topics to discuss. In later weeks most of the general ideas were the same in the readings, so conversation in forums was more repetitive. One teacher candidate suggested to include more specific prompts or questions in later weeks. Open prompts such as "what insights did you have while doing this reading?" work fine in the first three or four weeks, but participants need more than that to maintain a conversation when many basic ideas have been covered in the final weeks.

Regarding the use of mind maps, three participants in the interviews described it as harder work than forums. One student suggested starting the discussions in the first week with mind maps instead of forums so that a later inclusion of the tool is not perceived as "extra work". Researchers, on the other hand, perceived that the mind maps created a different task to break the repetition of forums week after week. Then, for future implementation, the mind maps could be introduced in Week 7, late enough to prevent the repetition of forums, and soon enough in the semester to avoid the perception of TCs that it is more work.

Also, two TCs expressed that at first they felt overwhelmed by having so much information to view all at once in the mind maps. Perhaps Mindomo's feature to hide some branches would be helpful to reduce the amount of information displayed at the same time. So, in future implementations, this would be something to address in the initial induction given to participants before using Mindomo. On the other hand, one participant in the interviews expressed that they appreciated that the introduction to Mindomo was very basic because they had the opportunity to learn by doing. So, it is recommended that future inductions use the approach of a workshop where participant learn hands on to use the tool by discovery, but including some major or important points to be covered along the way.

In general, the researchers recommend that implementation of blended approaches in teacher education are accompanied by an evaluation of the roles that each tool plays in participants' learning, in order to gain insights about how technology affects learning, and in turn, how to improve its implementation. This study has provided some ideas of the elements to look for and to evaluate in online tools. Figure 15 presents a summary of these key roles, which can be applied to other tools in addition to forums and mind maps.

3.7 Future Research Directions

Technology in teacher education is a changing field, as many new advances and possibilities emerge on a regular basis. Research as the one presented in this chapter shows that the study of a single tool can become entangled with many different opportunities to develop as teachers through online teacher education. It is the task of researchers, program developers and instructors to see that these roles are explored and encouraged using new technologies. This study, with a narrow focus on two tools, has provided a possible framework to approach the evaluation of blended learning implementations in teacher education. Figure 15 offers indicators that can be applied to other case studies.

Currently, the authors are focusing on further research related both to the use of collaborative online tools and mathematics preservice teacher education related to teacher practice. Based on this case study, the researchers pose some questions related to technology and teacher education that could be explored in future studies. These questions are presented below.

On the topic of using threaded forums to support discussion in teacher education:

- How could the online discussion be structured to improve the development of a community of practice?
- How can the importance of engaging in a community of practice be communicated to TCs so that they value the discussion activity?

On the topic of using mind maps in teacher education:

- What was the role that multimodal expression played in TCs' development of PDC?
- How could the activity be structured to emphasize teamwork and collaboration as a part of profession-oriented competence?

On the role of technology to support teacher preservice education and the transition to teacher practice:

- What opportunities do technological tools offer to support the transition from preservice teacher to practicing teacher?
- How do TCs use online tools in their practicum?
- How much of what TCs learned was translated into their teaching practice?

3.8 Conclusion

In this chapter, the authors aimed to answer the question: What are the roles that each online activity played in the participants' education as teachers? Through a case study approach and a qualitative data analysis of TCs' online discussion (both in online forums and mind maps), we found the roles summarized in Figure 15.

With respect to threaded forums, the identified roles were: (1) provide a space for open communication, (2) elicit shifts in participation, and (3) develop transformations of identity. These roles are fundamental elements to develop a community of practice in teacher education that could support transition and establishment into teacher practice. On the topic of collaborative mind maps, the identified roles were: (1) facilitate organization and (2) integrate complex topics and ideas, and (3) develop TCs' PDC. Hopefully, these elements will help TCs to use and integrate technology in their future classrooms. Finally, both tools had the role of providing continuity to the curriculum, offering a space to connect experiences from face-to-face sessions, online activities, and practicum developments.

In general, this study has offered some ideas of components to look for and evaluate in online tools for teacher education. The researchers recommend that more research is conducted about the roles that other tools play in participants' learning, in order to gain insights about how technology affects teacher education, and in turn, how to improve its implementation.

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Chapter 4

4 Engagement, Representation, and Expression in Online Mind Mapping Activities[1]

Today's classrooms and learning materials are filled with images. After many years of research about pedagogy, learning psychology, and neuroscience, it would be unthinkable to teach complex concepts without the facilitative aid of a diagram, an illustration, or a photo. In this context, mapping – as in mind mapping and concept mapping – is understood as an alternative form of thinking (Hyerle, 2009).

Mind maps are defined as "visual and graphic holistic thinking tool[s] that can be applied to all cognitive functions, especially memory, creativity, learning, and all forms of thinking" (Buzan & Buzan, 2010, p. 31). The main characteristic of a mind map is that it has a central image or word, and ideas branching out of it. This is referred to as a radiating structure and has been related to a more creative and aesthetic approach to thinking. According to Brown and Czerniewicz (Brown & Czerniewicz, 2014, p. 93), "As a genre, mindmaps enable certain semiotic possibilities that conversation and writing do not." These possibilities include more options in arranging items, sizing, highlighting, linking or separating ideas (Gao, Zhang, & Franklin, 2013). Using these elements, instead of relying on pure language to describe a concept and its relationships, increases the conceptual complexity that can be handled in a discussion (Suthers & Hundhausen, 2003). Mind maps also encourage brainstorming, which adds different discourse characteristics to discussions and allows a quick view of the main concept (Ng & Hanewald, 2010).

Beyond these advantages, technology has increased the possibilities of mind mapping. For example, Ng and Hanewald (2010) compared manually created concept maps to electronic versions and noted that digital mind maps allow the flexibility of hypertext, which enables infinite changes and the insertion of media (images, videos, hyperlinks and others). In the 21st

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century, visual representations for education have had an upturn with the rise of Universal Design for Learning (UDL) and its correspondence with many curricular trends, such as *multiliteracies*, a pedagogical approach that emphasizes multimodal forms of linguistic expression and representation (Kalantzis & Cope, 2015). According to Eisner (2002, p. 148), curriculum needs to consider that “humans employ different knowledge systems to acquire, store, and retrieve understanding, and they use different performance systems to express what they know about the world.”

In terms of UDL, mind maps have the potential to include multiple means of representation and expression by providing ways to improve remembering, understanding and knowledge organization through different modes that combine text, images, colour and layout. This chapter will present a descriptive case study of the Mathematics Education program at Western University, wherein online mind mapping has been included as a strategy for collaborative work for over three years. For this purpose, three different tools - Popplet, Mindmeister, and Mindomo – were used in the courses. This chapter describes the development of the mind mapping activities, along with general reflections in terms of Engagement, Representation, and Expression.

4.1 Rationale

Some studies have documented how visual representations have helped students with diverse learning needs and preferences to understand concepts. For example, Balım (2013) showed that concept maps done in teams led to more active and participatory learning during lessons because they increased comprehension and recall. Similarly, Himangshu-Pennybacker (2016) found that collaborative concept maps had a positive impact on knowledge visualization and concept linkage. This is supported by other studies that show how concept maps can highlight students’ contradictions (Johnson, 2016) and that mind maps can be useful to help students identify misconceptions and knowledge gaps (Wilson, Copeland Solas, & Guthrie-Dixon, 2016).

Also, some studies have documented student engagement and participation during collaborative building of visual representations. A key finding is that visual representations, whether concept maps or mind maps, can increase motivation and interest towards learning (Ahmed & Abdelraheem, 2016; Balım, 2013; Lin, Chang, Hou, & Wu, 2016). Specifically, Wilson et al.

(2016) found that building mind maps affords a creative and fertile learning environment that can be motivating to students and supportive of varied learning needs.

Presenting information in multiple formats and providing options for students to participate and express their understandings are key aspects of inclusive learning. Mind maps can provide a new range of multimodal possibilities, such as layout, colour, image and video, that can enrich student interaction through multimodal collaboration, discussion, and assessment. In this chapter, the UDL guidelines (CAST, 2018) will be used as a framework to describe and analyze results. The following sections will detail the development of the mind mapping activities used in the math education program at Western University, along with general reflections in terms of engagement, representation, and expression.

4.2 Application in Practice

Online mind mapping activities were incorporated using online activities as a support for face-to-face learning in three blended courses in the math education program at Western University. Three different mind mapping tools – Popplet, Mindmeister, and Mindomo – and different scaffolding techniques in terms of prompts and number of participants per group were explored. Each course will be treated as a case and is described below (see summary in Table 6). It is relevant to note that the focus of this chapter is the mind mapping implementation through the lens of UDL. For a more thorough description of the case studies along with experiential and learning outcomes comparing the three different tools and two different kinds of prompts, the reader may refer to Cendros and Gadanidis (2017).

Table 6. The three cases and their characteristics

	Term-Year	Course	Tool Used	Prompt	Participants
Case 1	Winter-2016	CT+ Math Education	Popplet	Topics List	143 (Set A)
Case 2	Fall-2016	CT+ Math Education	Mindmeister	Topics List	194 (Set B)
Case 3	Winter-2017	Math Methods	Mindomo	Questions	194 (Set B)

4.2.1 Case 1

The first case was a computational thinking in mathematics education course in the Winter of 2016. It had a duration of nine weeks, two hours per week, where the five odd-numbered sessions were face-to-face and the four even-numbered sessions were online. Participants were 143 teacher candidates (TCs) who agreed to participate in the research, out of a total of 157, distributed among five sections. Each online week included the collaborative knowledge construction and reflection in small groups (4 to 7 participants) of mind maps through Popplet (http://popplet.com/), which replaced the more traditional, text-based discussion forum. Popplet was chosen initially due to its simplicity. The instructor and researchers believed that fewer features would facilitate an easier introduction to the activity.

There was a total of 31 small groups across the five sections. The mind mapping activity was implemented during every online week (Weeks 2, 4, 6, and 8). Prior to each online week, TCs received a link with access to their group's mind map, which was initially blank. For weeks 6 and 8, each group used only one canvas; so for week 8, students continued ideas and topics within the mind map that they had begun in week 6. The prompts used by the instructor to guide TCs to develop the mind maps included an explanation on how Popplet can help students make connections between the online and in-class activities, a list of suggested topics to address in the mind map, and a video on how to use the tool. Figure 16 shows a mind map created by a group of students in Case 1.

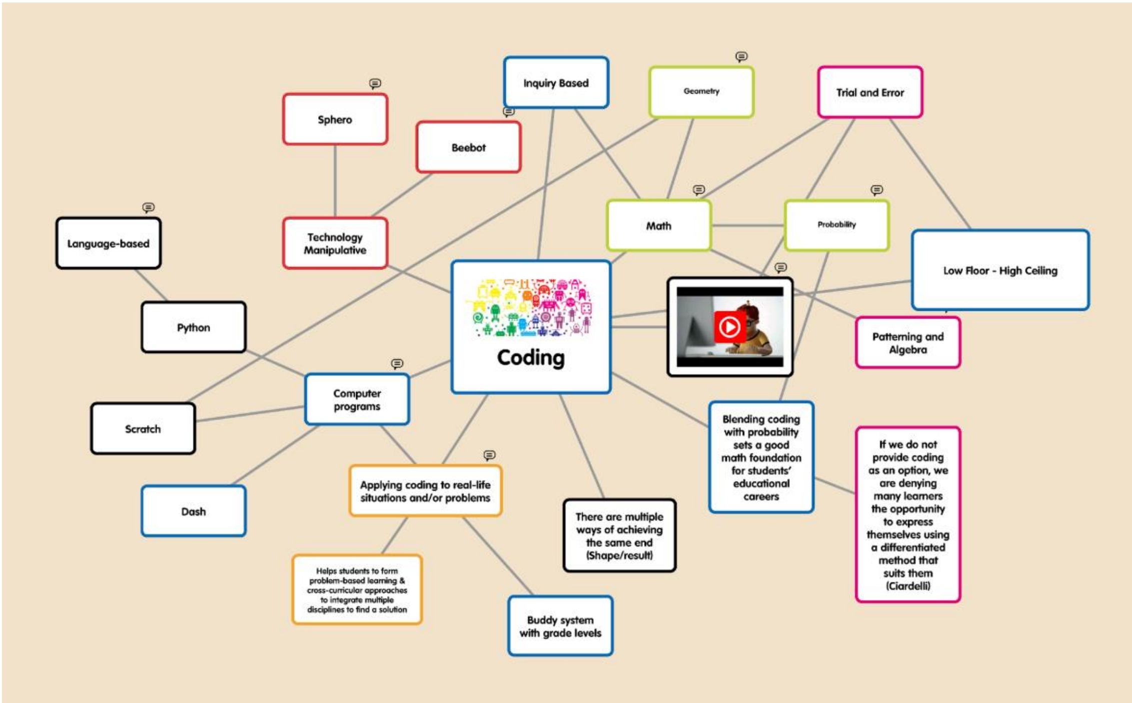

Figure 16. Sample mind map created by participants in Case 1 (http://bit.ly/case1map).

4.2.2 Case 2

The second case was a new cohort of the computational thinking in mathematics education course, in the following fall 2016. Characteristics of this case were the same as in Case 1 in terms of duration, mode of delivery, and contents. However, in this case, the number of participants was larger than in the first case, with 194 TCs (out of the 240 enrolled) agreeing to participate in the research. In regard to mind map construction, this case included the collaborative knowledge construction and reflection in larger groups (8 participants, as compared to 4-7 in Case 1) using a different online tool, Mindmeister (https://www.mindmeister.com). The instructor and researchers decided to use Mindmeister after facing technical problems in the previous experience with Popplet. In this case, only weeks 2 and 4 required mind map construction. As a result, a total of 60 mind maps were created (30 from week 2 and 30 from week 4).

As in Case 1, TCs received a link with access to their group's mind map and a prompt to guide construction that included a list of suggested topics to address. In addition, an instructor-led live presentation was added in each section to provide opportunities for students to ask questions about how to use the tool. Additionally, tutorial videos about the use of Mindmeister were made available for students in their online course site. Figure 17 shows a mind map created by a group of students in Case 2.

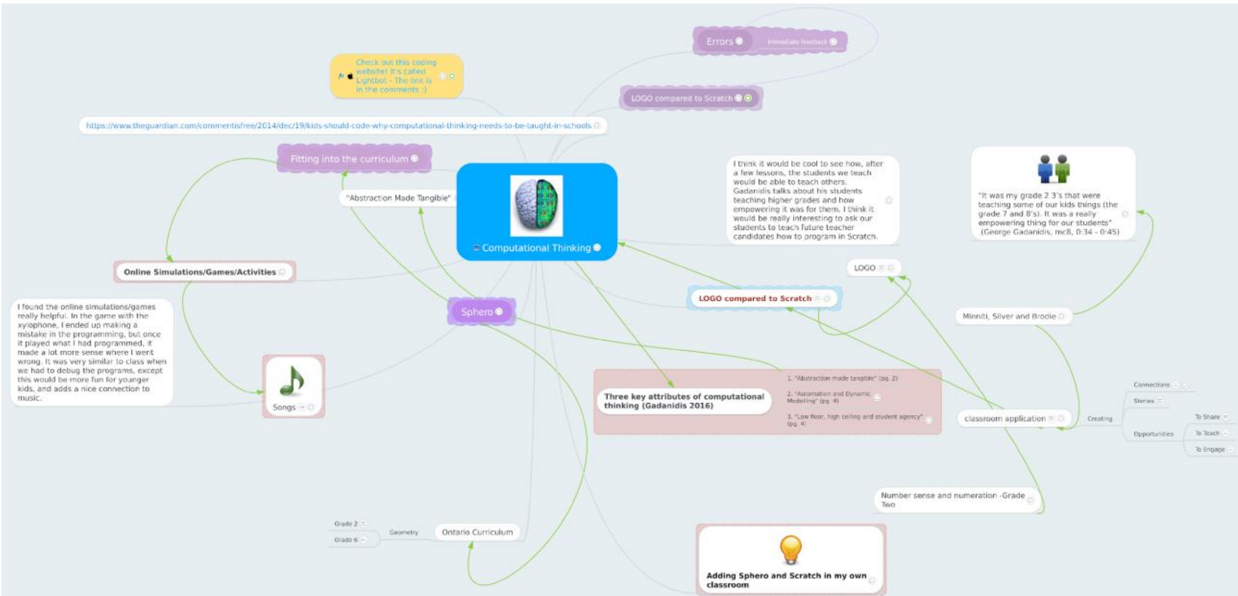

Figure 17. Sample mind map created by participants in Case 2 (http://bit.ly/case2map)

4.2.3 Case 3

In the Winter of 2017, instructors decided to include the mind map activity in the math methods course for TCs. Since students in this program register for the entire year in sets of courses for the subject of their choice, participants of the mathematics education stream were simultaneously enrolled for the CT in mathematics education and the math methods courses. So, participants from Cases 2 and 3 belong to the same cohort (194 participants that gave permission, out of 240 enrolled). The math methods course had a total duration of 17 weeks, using mainly a face-to-face delivery mode coupled with an online learning component that included discussion groups and mind map development. The mind map activity was used during Weeks 9 to 11.

Collaborative knowledge construction and reflection was done in groups of 6 to 8 participants using a third online tool, Mindomo (https://www.mindomo.com/). In this case, the tool was chosen by the instructors because it is provided to teachers for free by the Ontario's Ministry of

Education. A total of 96 mind maps were obtained from this case (32 for each week). Figure 18 shows a mind map created by a group of students in Case 3.

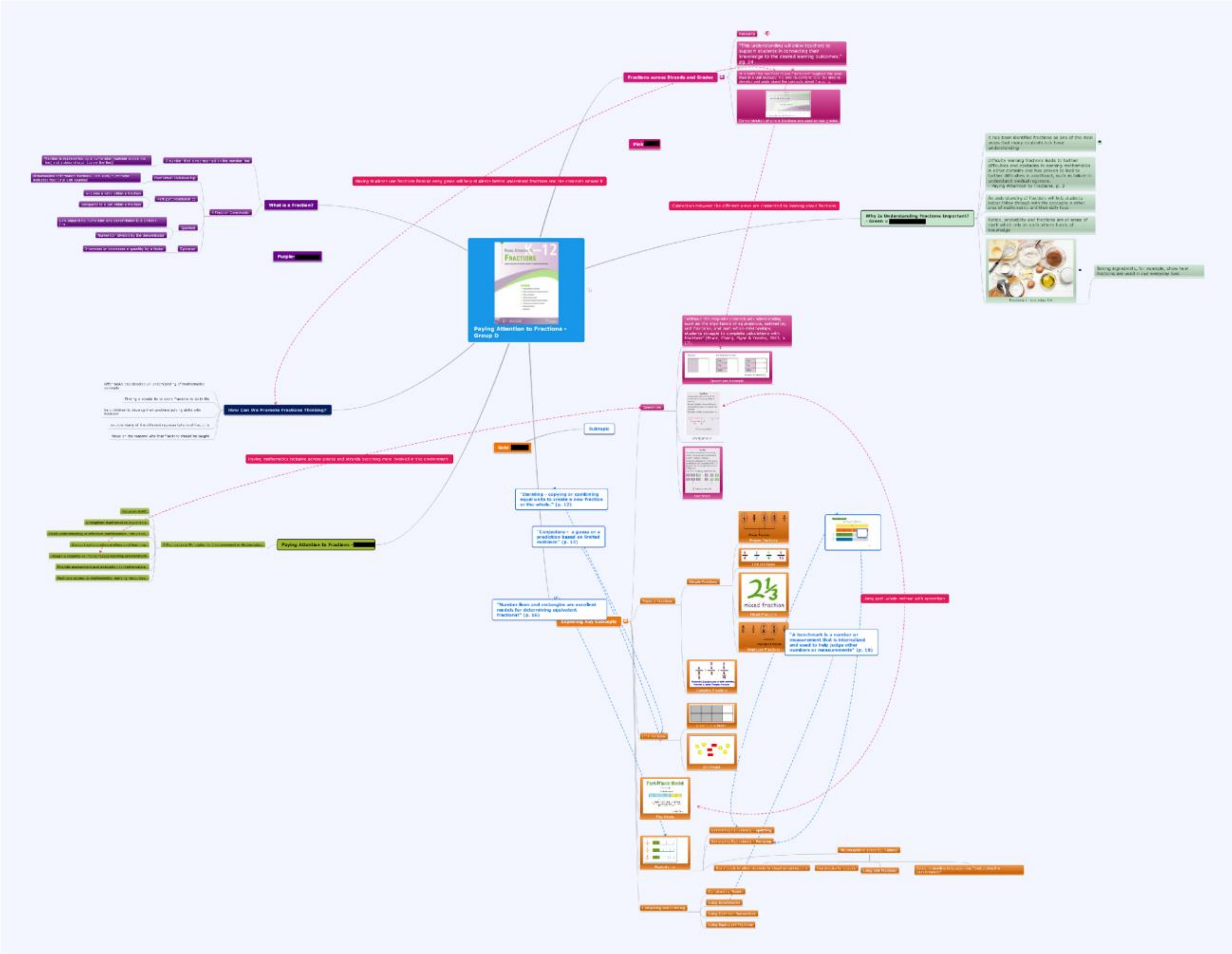

Figure 18. Sample mind map created by the participants in Case 3 (http://bit.ly/case3map).

Since this group of participants had prior familiarity with collaborative mind maps, instructors only provided a video about the tool and prompted TCs to create their own mind maps and invite the instructors to view them (rather than the instructors creating blank canvases and sending the links to the TCs). In this case, instructors decided to use questions as prompts to guide the activity.

4.3 Reflections about UDL and the Online Mind Mapping Application

The following reflections are derived from observation and analysis of the three cases. The author participated in all three implementations as a support for the instructors, then observed and recorded notes about the implementation, and collected the digital products (mind maps). Case 2 also included interviews with seven participants to further elaborate on the mind mapping experience. These data sources (observation notes, digital products, and interviews) were analyzed looking for evidence of Engagement, Representation, and Expression.

4.3.1 Engagement

The principle of multiple means of engagement was considered at the planning stage of these courses. Mind mapping was incorporated to foster variety in the online discussions by providing access to a new tool as an alternative to threaded forums. During the mind map activities, instructors observed evidence of negotiation and organization as group members worked together to complete the tasks. For example, some groups decided on the colour that each member would use for individual contributions. They then agreed that when connecting concepts, they would use a connector with the other person's colour in order to better visualize relationships between ideas.

Furthermore, the use of Mindomo in Case 3 responded to a need to increase relevance, value, and authenticity. The instructors purposefully selected this tool because it is approved by the Ontario Software Acquisition Program Advisory Committee (OSAPAC), which advises the Ministry of Education on the acquisition of provincial licenses for publicly-funded schools in Ontario. So, using Mindomo in the course provided TCs with an opportunity to become familiar with a visual tool they could later use in their own classrooms.

4.3.2 Representation

Even though the mind mapping activities were not intended to be presentations, they did seem to have impacts on student perceptions of the topics during the discussions. In end-of-course questionnaires, many students commented about organizational features of the mind maps. For example, one student wrote that mind maps "made information easy to be sorted and viewed."

Another student described how the mind maps made it possible to see everyone's participation at a glance, which enabled students to decide easily where they wanted to include their contributions.

It is important to note, though, that this visual way of representing the discussion was found to be overwhelming for some students. Some expressed that seeing all contributions at a glance, with all the different colours and images, made it harder for them to understand what was going on in the discussion. This study did not assess if these students had particular difficulties in other academic activities or their daily lives, but perhaps the visual aspect of the mind mapping experience was an inadequate match for their learning style or individual learning needs. However, the tools do offer ways of customizing the information displays, allowing participants to select between outline and diagram views, and future implementations could inform students of this tool feature.

4.3.3 Action and Expression

Promoting multiple forms of action and expression was key in the mind mapping activity, as students were able to organize, display, and elaborate using images, words, and connecting lines to show their understandings. Variability in action and expression was evident in the mind maps, with some students using images, very little text (only concept headers) and lots of connectors to express their knowledge and others using long text notes attached to concepts to explain their thoughts. This kind of flexibility allowed participants to choose a mode of action/expression that suited their needs.

4.4 Conclusions and Recommendations

There are many online tools that can provide multiple ways for viewing, organizing, and engaging with course content. In order to meet students' diverse learning needs, it is beneficial for course developers and instructors to consider UDL guidelines when designing online learning experiences, whether it is as support of face-to-face courses or fully web-based ones. Online mind mapping implementations, such as the one described in this chapter, have the potential to cover some important UDL curricular guidelines (CAST, 2018), including:

- Vary demands and resources to optimize challenge (checkpoint 8.2).

- Foster collaboration and community (checkpoint 8.3).
- Optimize relevance, value, and authenticity (checkpoint 7.2).
- Offer ways of customizing the display of information (checkpoint 1.1).
- Illustrate through multiple media (checkpoint 2.5).
- Provide options for expression and communication (guideline 5).

Based on observations from the mind mapping cases described in this chapter, the involved researchers and instructors have been able to continue to improve these activities to implement with new student cohorts. In sum, lessons learned along the way have generated several guidelines –

- Allow participants to choose how to contribute to the mind map, whether it be through long text notes or concept imagery and connections. The prompts used should encourage and support multiple approaches.
- Inform students about display options for the visual information on mind maps. Demonstrate how to change the visualization of the mind map from a diagram to an outline.
- In the activity prompt, emphasize the importance of collaboration. Encourage participants to negotiate how they will distribute the concepts, colours, and layout and collectively decide on how they will respond to others' contributions, such as through connectors, notes, and additions of concepts to the same branch.

Finally, opportunities for further research emerge in the ways that online collaborative mind mapping can benefit people with disabilities who require support for reading, spelling, and/or handwriting. Beyond the power of visualization, perhaps mind mapping activities would provide supportive and mistake-tolerant access for these individuals.

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Chapter 5

5 Grounded Theory with Online Multimodal Data: The Case Study of Online Collaborative Mind Maps

In the 21st century, visual representations for education have had an upturn with the rise of multimodality and multiliteracies within the field of curriculum. With the inclusion of technology, writing –and the general use of language- becomes only one part of the learning process, as a number of different ways to express meaning shape the “multimodal character of new technologies” (Jewitt, 2006, p. 53). For this reason, much of the recent work related to visual representations for learning is also related to educational technology (e.g. Hanewald & Ifenthaler, 2014; Kwon & Cifuentes, 2007; Ng & Hanewald, 2010).

In this context, mind mapping is a technique to “represent understanding of a subject matter in multimodal forms” (Hanewald & Ifenthaler, 2014, p. 4). Mind maps are defined as “visual and graphic holistic thinking tool[s] that can be applied to all cognitive functions, especially memory, creativity, learning, and all forms of thinking” (Buzan & Buzan, 2010, p. 31). Its main characteristic is that it has a central image or word referencing a topic, with sub-topics branching out of it. This is referred to as a radiating structure and has been related to a more creative and aesthetic approach to thinking. Mind maps benefits for learning include being an alternative to text-based interaction and featuring a model of non-linear communication that increases student motivation, conceptual understanding, and interconnection.

With the use of online technologies, collaborative mind mapping has been introduced as learning technique where participants can collectively conceptualize and organize ideas surrounding a topic, with the inclusion of text, image, video, and hypertexts. Another advantage of this online activity is that participants can make infinite changes, and have more options in arranging items, sizing, highlighting, linking or separating ideas (Gao et al., 2013). An example of a collaboratively created online mind map can be seen in Figure 19.

However, despite the aforementioned advantages, previous research has focused on very particular applications, and at present, there is no theory that describes the abundance of multimodal information contained in online collaborative mind mapping, nor that interprets the elements of meaning which have significance for learning construction.

Therefore, my research asked *how do students construct knowledge during online collaborative mind mapping?* I addressed the issue using a case study of online collaborative mind mapping in the context of a computational thinking and mathematics courses for preservice teachers at a Canadian University. There were a total of three courses (a total of 337 participants) in a period of two years. Each course used a different mind mapping software. Table 7 summarizes the characteristics of the three courses (treated as cases in my study).

Table 7. Characteristics of the three case studies

	Term-Year	Course	Tool Used	Participants
Case 1	Winter-2016	CT+ Math Education	Popplet	143 (Set A)
Case 2	Fall-2016	CT+ Math Education	Mindmeister	194 (Set B)
Case 3	Winter-2017	Math Methods	Mindomo	194 (Set B)

The data collected for this study consisted of collaboratively constructed online mind maps by groups of 4 to 8 students (Figure 19). The mind maps included all comments and visual constructions made by students, as well as the interaction logs of the whole mind mapping process (Figure 20). Additionally, a video version of the interaction was obtained by recording the process of mind map construction. Examples of this construction can be seen in the following URLs: https://youtu.be/gqunumR5aeY and https://youtu.be/Bpt-RdhP17I.

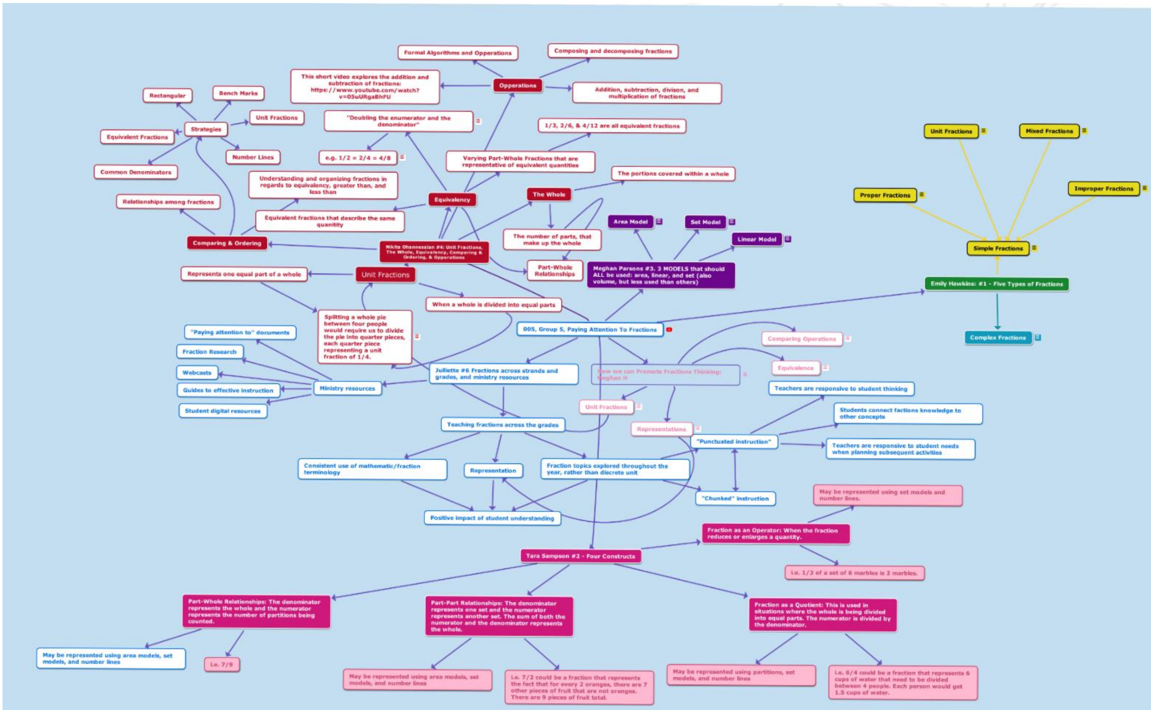

Figure 19. Sample mind map created by the participants in the study.

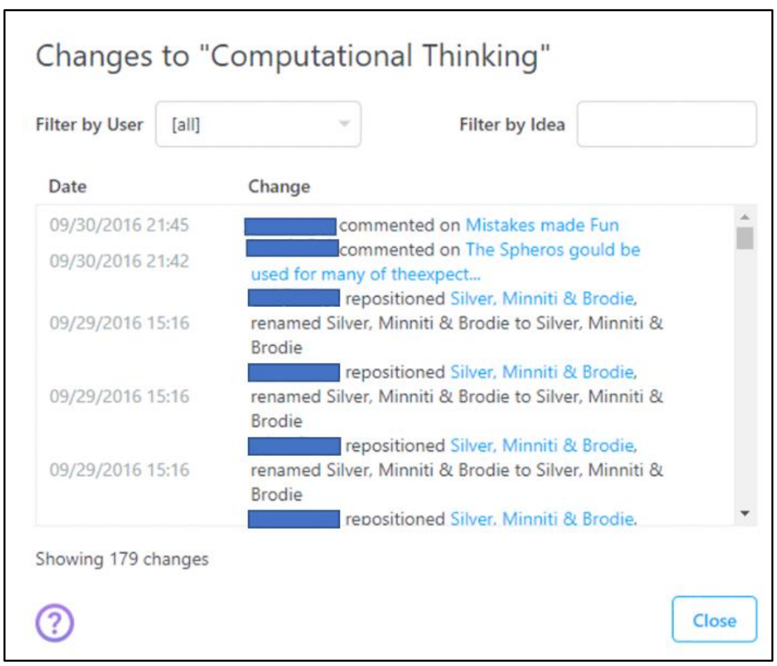

Figure 20. A sample of activity logs obtained from Mindmeister. Participant names have been covered.

These sources of data characterize for being highly visual, including numerous images and elements such as colors, highlights, different fonts, lines, shapes, and positioning of the text. The data also encloses processual information, such as the time and sequence in which elements were added or modified in the mind map, including information that was deleted from the final version. The purpose of this paper is to not to present findings, but to describe my approach to analyze these digital and multimodal sources of data using grounded theory techniques.

5.1 Researcher's Perspective

The theoretical underpinnings that guided my views as a researcher are framed in constructivism (Vygotsky, 1978), which emphasizes the central role of social interaction in the development of cognition. As a constructivist researcher, I understand that learning is a social process that happens in the context of human relationships and activities, and not just inside each individual. Through the lens of constructivism, the social context is not just a place where learning happens, it also affects how learning happens and how things are learned (Dudley-Marling, 2012). Language, signs, and tools are part of this environment and have a significant effect on how learners communicate and construct knowledge. In the context of collaborative mind maps, the visual software acts as a social mediation tool.

Also, the study is framed under the theories of Multimodality, a development on the field of social semiotics that emphasizes on how modes, such as music, speech, sound, and visual communication are developed into a set of agents- not just resources- that interact with humans in meaning making (Jewitt, 2006). According to Bezemer and Kress (2016) because technology makes alternative modes to speech and writing – such as colour, layout, and music- are more readily available than they used to be, it makes their inclusion, not only possible but essential. The multimodal theory is a suitable approach to research on knowledge building during collaborative online mind mapping because it focuses on meaning-making not only through text but also through image, colour, layout and video in an online environment.

5.2 Method

I decided to use grounded theory methods after concluding that there were no theories that explained student collaborative knowledge construction dealing with the abundance of multimodal information contained in mind maps. Grounded theory methods are a set of "systematic, yet flexible guidelines for collecting and analyzing qualitative data to construct a theory from the data themselves. Thus, researchers construct a theory 'grounded' in their data." (Charmaz, 2014, p. 1). The characteristics of being flexible, yet *grounded* in empirical events and experiences, make this method useful in the field of online learning to produce models of how students engage, build knowledge, and create communities of practice. Grounded theory methods encompass well with multimodal methods of analysis, which often focus on the relationship between modes of expression and interactions (Jewitt, 2013), but the goal of grounded theory (and of my research) is to generate a model of a social process.

I chose constructivist grounded theory (Charmaz, 2014) rather than the more traditional approach to the method (Glaser & Strauss, 1967) because it embraces the position of seeing reality as a construction and interpretation of social contexts and interactions. This worldview is more consistent with my own positioning as a researcher under the sociocultural framework (Vygotsky, 1978), and it relates to the way I view the phenomena of mind mapping itself; a social knowledge construction achieved by interacting participants and technological tools. It is important to note that during the process of analysis, all modes present in the mind maps were considered (i.e. colours, images and layout) to search for actions and meanings, but no micro analysis of the multimodal texts was employed because the focus of the research was the mind map development as a process, as well as participants' actions and interactions in knowledge building. As a researcher, I made a decision not to focus on the specific meanings conveyed through the different modes, but rather focus on the broad events that were occurring during mind map development.

Finally, although this research was not an ethnographic study, I found valuable help in terms of strategies to deal with online data in Kozinet's (2015) Netnography methods. In the next section, I outline some challenges I encountered while collecting, organizing, coding, and analyzing the data, with some considerations regarding the method.

5.3 Conclusions derived from the process: Considerations for doing grounded theory with online multimodal data.

While most of the grounded theory research involving extant documents use it as an auxiliary source, it has also been used as the main source, and in some cases "a grounded theorist's research question may focus solely on documents" (Charmaz, 2014, p. 52). These documents can be digital constructions, and they are not just containers of data, but actors in a process (Prior, 2008). When researchers analyze what a digital document does, they are looking at what its creators intended to accomplish and the actual process of producing the document, among other elements. In my research, I intended to look at the process through which students construct knowledge in online mind maps.

As I developed a grounded theory derived from digital and multimodal sources, I faced some challenges that led me to adjust the typical process of constructivist grounded theory. Below, I outline some considerations regarding (1) data collection and informational richness, (2) ethics, (3) multimodal memo writing, and (4) theoretical sampling.

5.3.1 Data collection and informational richness.

All mind maps and interaction logs were created through digital tools (Popplet, Mindmeister, and Mindomo), and then exported into Microsoft Word documents. As previously mentioned, a video version of the interaction was also obtained by recording the process of mind map construction through a motion screen capture software. This data collection strategy is named videographic representation and is useful both for data capture and for eventual research presentation (Kozinets, 2015). Samples of these videographic representations can be seen in the following URLs: https://youtu.be/gqunumR5aeY and https://youtu.be/Bpt-RdhP17I .

The data was a clear example of the *informational richness* (Lindlof & Taylor, 2019) that a set of online data can contain, not only because of the amount of information and the detailed nature of the content (personal comments, interaction logs, and history of changes), but also because it included "graphical, visual, photographic, audio, and video information as shared online, as well as […] text in context, including font, colour, size, placement, and so on" (Kozinets, 2015, p. 172). A challenge I faced with these amounts and richness of data was the major time investment to capture, review, understand, code, and analyze it. "Big amounts of data draw us almost inexorably to more mechanical methods that encourage us to code and view at less contextualized and particularistic levels" (Kozinets, 2015, p. 174). To help with this endeavour, I used the QSR NVivo 10 software, which allows to import and code multimodal sources of data.

5.3.2 Ethics.

Because this research was part of a larger project investigating the use/effect of the resources and related teaching methods (including online resources and strategies) on the development of teacher mathematical and pedagogical knowledge, the terms in the letter of consent signed by participants had to be broad enough to include many forms of in-class and online participation from students. The terms on the letter did not include details about all the rich data that is available online, such as dates and times of participation, and logs of all mind map changes (not just final products). However, as noted by Lindlof and Taylor (2019), the researcher needs to develop protocols to protect their participants' interests. Hence, participants were given an explanation on the nature of the data extracted from their mind maps in an effort to make them aware of the richness of data that they were giving away, and that this data was not only constituted by their comments. The researcher described the data to students, and for case 3, this description was accompanied by visual examples of previously made mind maps and interaction logs (with participant's names covered) such as the one in this URL https://youtu.be/Bpt-RdhP17I. The researcher also answered any question participants might have had about the process of collecting and analyzing the data, and the consent letter included the contact information of the researcher and The Office of research Ethics from Western University in case participants needed further information.

Another issue was preserving the confidentiality and anonymity of participants, and of those who decided not to participate in the study, but still needed to take part in the collaborative assignments. To ensure confidentiality and anonymity, I only analyzed mind maps where all participants had given consent to have their logs and comments recorded, and all identifiers, such as names and usernames, were deleted from the mind maps and comments.

5.3.3 Multimodal memo writing.

In grounded theory, memos are informal analytic notes that "chart, record, and detail a major analytic phase of our journey" (Charmaz, 2014, p. 162). As usually done, I wrote memos explaining my codes and recording my observations and insights about the data. However, more often than with other (textual) sources, I found the necessity to include screen images in the memos (Figure 21) to make sure no significant meanings were lost in my verbal analysis. According to Kozinets (2015), online data analysis "must include the graphical, visual, audio, and audiovisual aspects of online social interaction – the *experience* [emphasis in original] of it. Each experiential aspect is a communication event of importance" (p. 229).

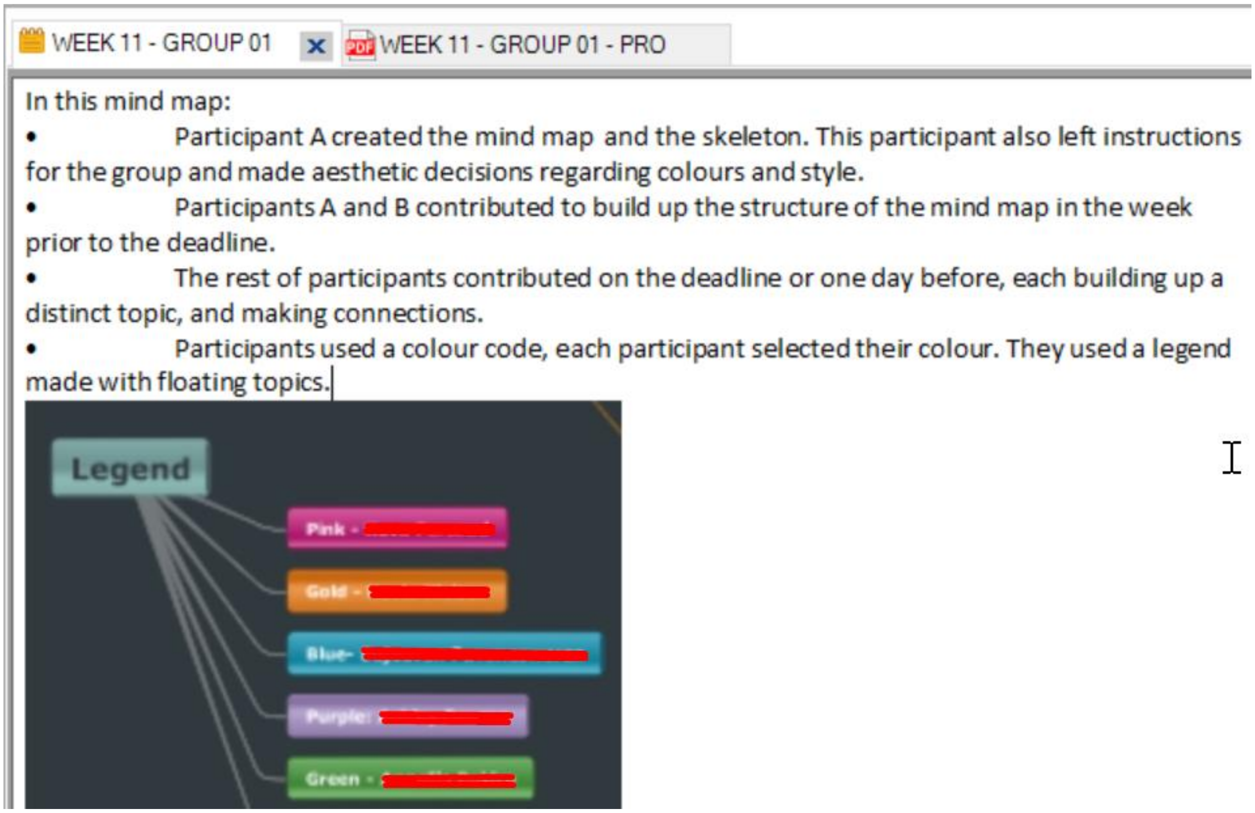

Figure 21. Screen capture of a memo created in NVivo. Example of how images were included as part of memos to make sure no relevant meanings were lost in the text description. Participants' names have been covered.

Another useful technique that involved visually and flexibly understanding and organizing my observations was *clustering*. Charmaz (2014) defines clustering as a "shorthand prewriting technique for getting started" (p. 184), and I found it useful in the early stages of analysis, at a point where I already had a sense of my codes and possible categories from an initial coding. Figure 22 shows an example of a cluster developed in the early stages of my analysis, showing tentative code relationships and categories. These clusters constituted external representations of my ideas that helped me move forward in the analysis.

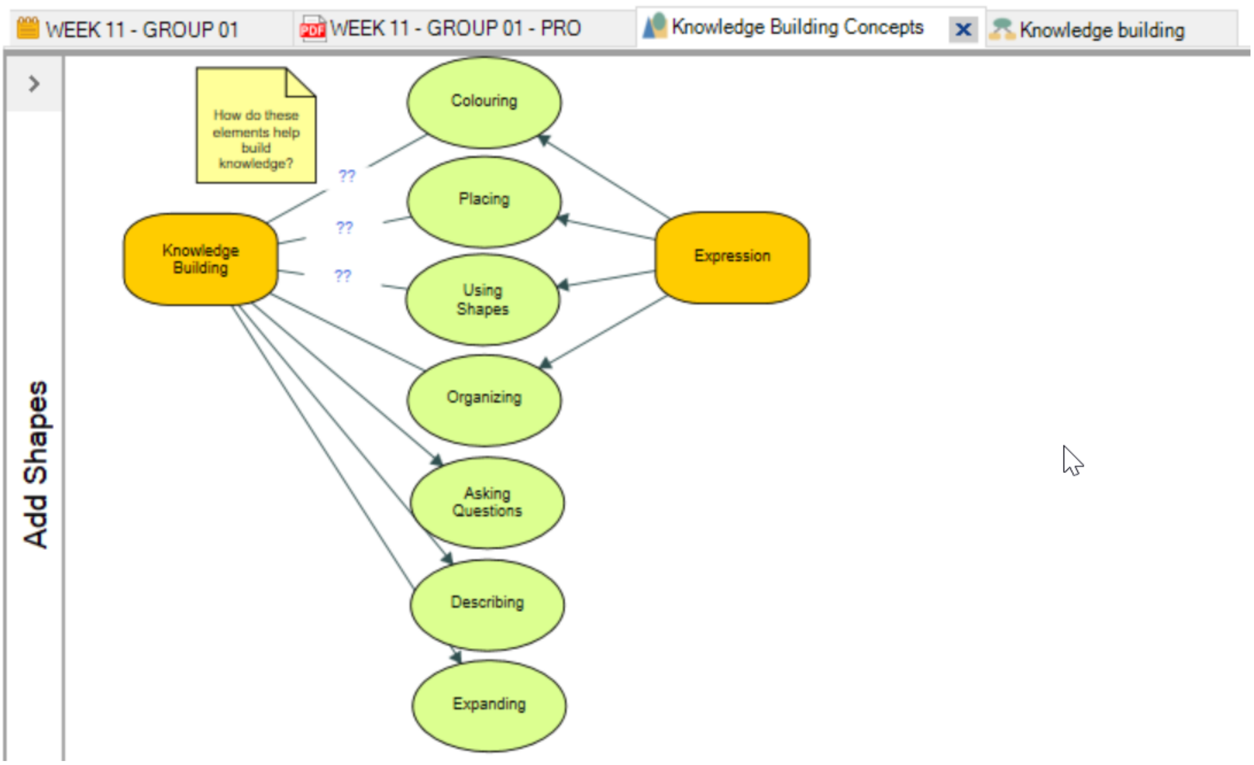

Figure 22. Screen capture of a concept map created in NVivo. Example of the clustering technique used after the initial coding stage

5.3.4 Theoretical sampling.

In constructivist grounded theory, data collection and analysis are conducted simultaneously in an iterative process (Charmaz, 2014). This involves going back to the field to seek pertinent data after an emerging theory has been drafted. This process is known as theoretical sampling and its purpose is to elaborate and refine the categories that constitute the theory. When using digital data, which is previously stored and readily available, going back to the field for pertinent data is not possible, so the theoretical sampling needs to adjust to this circumstance (Whiteside, Mills, & Mccalman, 2012). I achieved this by coding and analyzing a subset of the data, gain a sense of the emerging theory, and then theoretically sample using the rest of the data available. In my study, the dataset available was of adequate size to enable the process of theoretical sampling and the development of theory as described above, without the need of gathering new data in the field.

The process of theoretical sampling was also influenced by the multimodal nature of the data – and of the memo writing, because in a number of instances I had to compare sub-structures of mind maps that looked similar but the process that participants used to achieve these structures, or the content in them, was different. This also influenced the emerging theory, where one of the constructs, "visual expression" emerged because there was a pattern for participants to use similar layouts, colors, shapes, and connections to convey meaning.

5.3.5 Scholarly Significance of this Study

In this paper, I discussed a specific aspect of the intersection between qualitative and online research, which is still an incipient and promising field (Salmons, 2016). I illustrated how digital data that includes multimedia content can be collected, stored, and analyzed using qualitative methods, addressing some considerations of how constructivist grounded theory can be developed using multimodal data in educational research.

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Chapter 6

6 Online collaborative mind mapping in a mathematics teacher education program: A study on student interaction and knowledge construction.

In the 21st century, the use of mind maps in education has had an upturn with the rise of multimodality and technology. Jewitt (2006) explains that with the inclusion of technology, writing – and the general use of language – becomes only one part of the learning process, as a number of different ways to express meaning shape the “multimodal character of new technologies” (p. 53). Trends related to 21st Century Competencies often present technology, collaboration, and visualization as mutually related components. For example, the Ontario Government (2016) in their document Towards Defining 21st Century Competencies for Ontario defines clear connections between digital tools and resources, key transformational learning practices, and competency development. The document mentions graphing tools and concept mapping tools as technologies that can foster, amongst other competencies, coordination, communication, metacognition, analysis, problem-solving, and reasoning.

Mathematics education does not escape these trends in multimodality and technology. As Hoyles and Noss (2009) explain, “the very need for remote communication of mathematical ideas – either synchronous or asynchronous – provides a motivation to produce explicit formal expression of mathematical ideas” (p. 141). In teacher education, Gadanidis and Namukasa (2013) note that the affordances of new media help preservice teachers to communicate mathematics in multimodal ways and to see mathematics as a collaborative enterprise.

In this frame of ideas, we have included the use of collaborative mind mapping activities as an alternative to threaded forums in the elementary mathematics education program at Western University. We have done this for over three years in two different courses: a computational thinking in mathematics education course, and a math teaching methods course. In this paper, we present a grounded theory developed from these experiences of collaborative mind mapping. The emerging theory responds to the question *How do preservice mathematics teachers interact and construct knowledge while they engage in online collaborative mind mapping?*

6.1 Literature Review

In the field of mathematics education, there is plenty of research on how the use of new technologies and multiple modes of representation is beneficial for mathematics learning. Hoyles and Noss (2009) outline four categories of digital tools which have the potential to shift the way in which mathematics is taught and learned: "(1) dynamic and graphical tools, (2) tools that outsource processing power, (3) new representational infrastructures, and (4) the implications of high-bandwidth connectivity on the nature of mathematics activity" (p. 129). Documented research from all these categories can be found in volumes such as Martinovic, Freiman, and Karadag (2013) and Heid and Blume (2008).

Particularly, in mathematics teacher education, Gadanidis and Namukasa (2013) have studied the positive impact of online media in a mathematics education program to help preservice teachers learn new approaches to mathematics pedagogy. Other researchers have explored the potential of particular multimedia applications, such as online videos (LeSage, 2013) to improve learning about mathematics and mathematics pedagogy. In Gadanidis, Hoogland, and Hughes (2008), an environment that included multimodal communication and collaboration was proved helpful in the development of mathematical ideas for preservice teachers. Lavicza, Hohenwarter, Jones, Lu, and Dawes (2010) start from the premise that it is not enough for mathematics teachers to have access to a technology, they also need adequate support and collaboration to use it and integrate it to their classroom practice. They established a professional network which emphasized peer collaboration and resulted in more interest to investigate mathematical content, mathematics teaching, and higher-level reflection on teaching and technology.

On the other hand, many authors have documented the ways in which students construct knowledge in online settings. Particularly, Harasim (2017) and Garrison (2017) have developed influential theories that help researchers understand the processes that allow knowledge construction through online interaction. The collaborativism learning theory (Harasim, 2017) defines learning as *Intellectual Convergence*, the higher stage of a collective cognitive process. This theory describes three stages or phases that students need to go through to achieve learning: Idea Generating, Idea Organizing, and Intellectual Convergence. Additionally, the Community of Inquiry model (Garrison, 2017) describes how teacher and student participants develop roles while engaging in online discussion through three key elements or presences: the cognitive, the social, and the teaching presence. Other researchers have developed models to analyze online interactions to find evidence of knowledge construction (see Donnelly & Gardner 2011 for a comprehensive review of models).

While these theories and models help us understand how interaction through written discourse leads to knowledge construction, other research has shed light on how this might happen through visual representations. Particularly, Suthers and Hundhausen (2003) described the three roles that a visual aid plays into collaborative work: "(1) Initiating negotiations of meaning, (2) serving as a representational proxy for purposes of gestural deixis, and (3) providing a foundation for implicitly shared awareness" (p. 185). Also, Wu et al. (2016) found that concept maps enhanced group cognitive processing, and the technique also helped to lead learners to return to the main discussion from off-topic discussions.

The grounded theory developed in the present study seeks to fill a gap in the understanding of how preservice mathematics teachers interact and construct knowledge when they engage in online collaborative mind mapping.

6.2 Conceptual Framework

The theoretical underpinnings that guided this research are framed in socio-constructivism (Vygotsky, 1978), which emphasizes the central role of social interaction in the development of cognition. As researchers, we understand that learning is a social process that happens in the context of human relationships and communication, and not just inside individuals. Also, this social context is not just a place where learning happens, it also affects how learning happens and how things are learned. The environment, in the form of places, language, signs, and tools – including new media and technologies - has a significant effect on how learners communicate and construct knowledge (Vygotsky, 1978, 2012).

This process of interaction between humans and technology also relates to the theory of Distributed Cognition (Kirsh, 2006), Latour's (2005) Actor-Network Theory, Gibson's (1986) Theory of Affordances, Levy's (1997) model of Collective Intelligence, and Borba and Villarreal's (2005) Humans-with-Media concept. The general understanding of these authors is that both humans and non-humans have agency and that the presence of technology affords new ways of processing and constructing knowledge that would not be possible otherwise. A concept that is embedded in this idea is the power of external representations, or the knowledge structures in the external environment (Kirsh, 2010). In this context, mind maps can be understood as external representations collaboratively produced by students, which introduce new ways of sharing, processing, and constructing knowledge.

6.3 Context and Participants

In this research, we used a multiple case study (Stake, 2005) of collaborative mind mapping carried out in the undergraduate elementary math teacher education program at Western University. Participants were enrolled in blended courses (using online activities as a support of face-to-face learning) where at least two of the online activities used collaborative mind mapping for knowledge construction. Students used different mind mapping tools – Popplet, Mindmeister, and Mindomo – and received different scaffolding techniques in terms of prompts and number of participants per group. Each one of these courses is treated as a case and they are described below. Table 8 shows a summary of the cases and their characteristics.

Table 8: The three cases and their characteristics

	Case 1	Case 2	Case 3
Term-Year	Winter-2016	Fall-2016	Winter-2017
Course	CT+ Math Education	CT+ Math Education	Math Methods
Tool Used	Popplet	Mindmeister	Mindomo
Prompt	Topics List	Topics List	Questions
Participants	143 (Set A)	194 (Set B)	194 (Set B)
Total Maps Constructed	93	60	96
Maps Analyzed	47	25	33

6.3.1 Case 1

In the Winter of 2016, we studied a computational thinking in mathematics education course, which had a duration of nine weeks, two hours per week, where the five odd-numbered sessions were face-to-face, and the four even-numbered sessions were online. Participants were 143 teacher candidates who agreed to participate in the research, out of a total of 157, distributed among five sections. The online component included the collaborative knowledge construction and reflection in small groups (4 to 7 participants) of mind maps through the online tool Popplet (popplet.com), which replaced the more-traditional text-based discussion forum. Below is the weekly outline of topics for the online weeks of the course:

- Week 2 – Algorithms, coding, and CT in the context of geometry
- Week 4 – CT in the context of probability
- Week 6 – CT in the context of patterning and algebra
- Week 8 – CT and mathematics pedagogy in the context of measurement and number sense.

There was a total of 31 small groups across the five sections. The total amount of mind maps created was 93, distributed as follows:

- Week 2: 31 mind maps
- Week 4: 31 mind maps
- Weeks 6 and 8: 31 mind maps

Prior to each online week, teacher candidates received a link with access to their group's mind map, which was initially blank. For weeks 6 and 8 each group used only one canvas, so for week 8 students connected ideas and topics within the mind map they used in week 6. The prompts used by the instructor to guide participants to develop the mind maps included an explanation on the use of Popplet, a list of suggested -not mandatory- topics to address in the mind map, and a video on how to use the tool. The teacher presence in the mind maps was minimal, with only short responses in the mind maps for Week 2. Figure 23 shows a sample mind map developed by a group of students in Case 1.

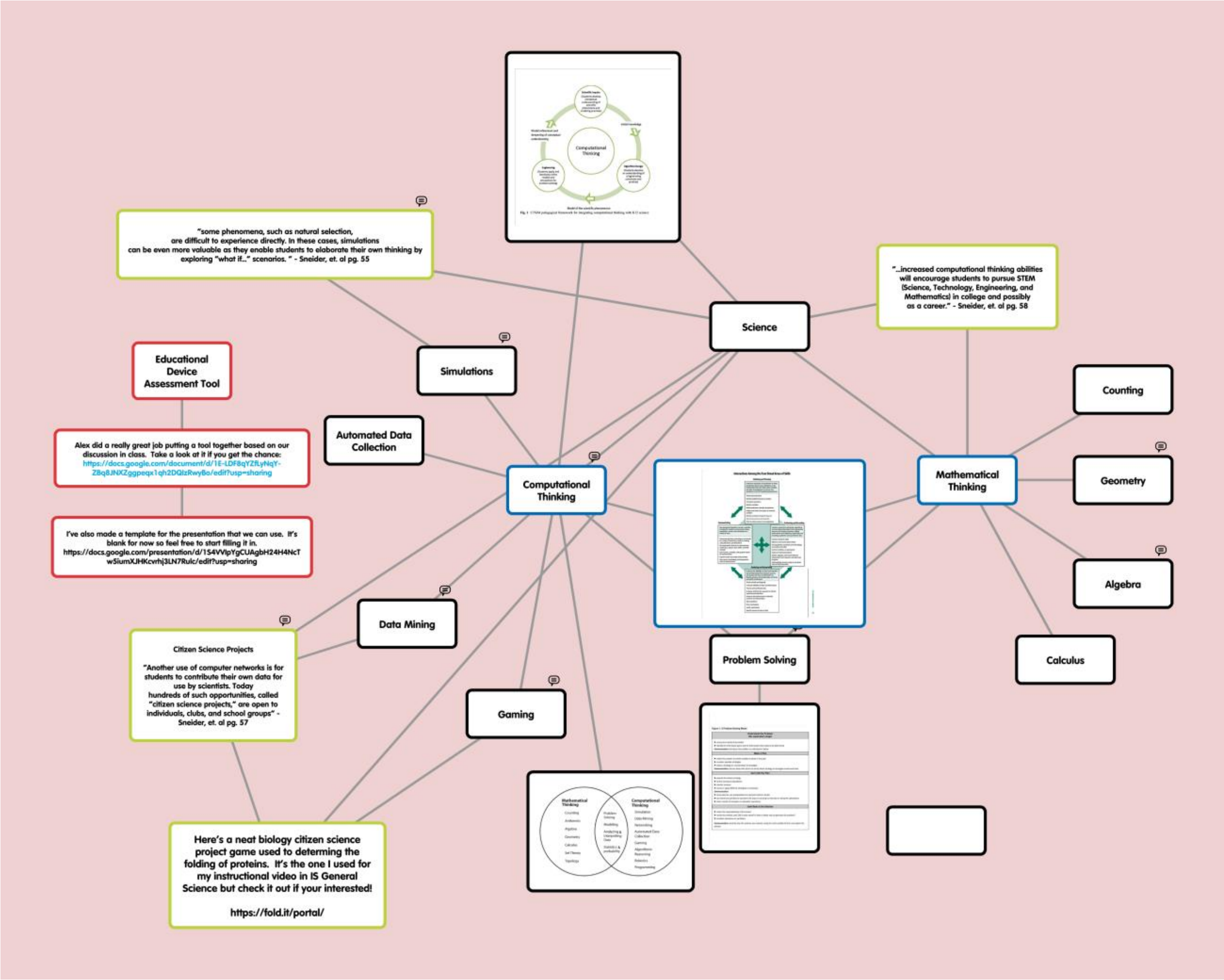

Figure 23. Sample mind map created by participants in Case 1 (http://bit.ly/case1-sample).

6.3.2 Case 2

In the fall of 2016, we studied a new cohort of the computational thinking in mathematics teacher education course. Characteristics of this case were the same as in Case 1 in terms of duration, mode of delivery, and contents. However, in this case, participants were 194 teacher candidates who agreed to participate in the research, out of a total of 240. In regard to mind map construction, this case included groups of 8 participants (groups were larger than in Case 1) through the online tool Mindmeister (www.mindmeister.com). In this case, only weeks 2 and 4 required mind map construction. As a result, a total of 60 mind maps were created (30 from week 2, and 30 from week 4).

As in Case 1, participants received a link with access to their group's mind map and the prompt used to guide the construction was a list of suggested -not mandatory- topics, but this time we included a live presentation with Q&A on how to use the tool (one for each section), with reinforcement videos made available for students. In this case, the instructor did not participate in the mind maps. Figure 24 shows a mind map created by a group of students in Case 2.

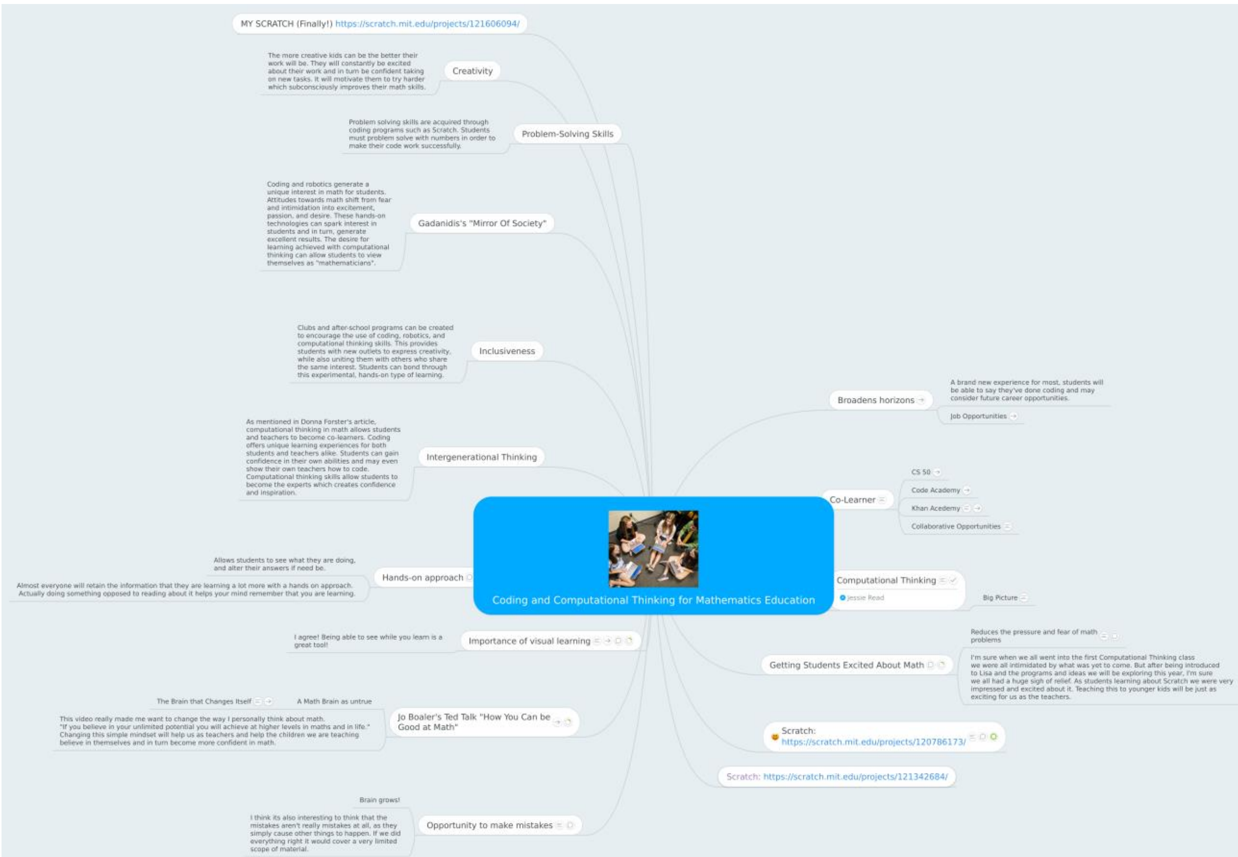

Figure 24. Sample mind map created by participants in Case 2 (http://bit.ly/case2-sample).

6.3.3 Case 3

In the Winter of 2017, instructors decided to include the mind map activity in the math methods course for teacher candidates. This cohort was the same who participated in Case 2. The course had a total duration of 17 weeks, using mainly a face-to-face delivery mode, coupled with an online learning component which included discussion groups and mind maps. The mind map activity was used on Weeks 9 to 12, which covered the following contents:

- Week 9 - Paying Attention to Fractions.
- Week 10 – Fencing the Dog (Area and Perimeter)
- Week 11 – Paying Attention to Spatial Reasoning

As in Case 2, this activity included groups of 6 to 8 participants through the online tool Mindomo (www.mindomo.com). A total of 96 mind maps were obtained from this case (32 for each week). Figure 25 shows a mind map created by a group of students in Case 3. Since this group of participants had already used collaborative mind maps, instructors only shared a video about using Mindomo and allowed TCs to create their own mind maps, asking to be invited to view them (rather than creating the blank canvas and sending a link to TCs). The instructors did not participate in the mind maps. In this case, instructors decided to use questions as prompts to guide the activity, such as the following:

> (a) What are some ways you can classify fractions? What are some fractions that would be part of each classification? (b) A fraction can be defined as a portion or division. Which definition means more to you? Explain. (c) Which is more important: fractions or decimals? How would you convince someone that you are correct? (d) What are some ways fractions and decimals are used in other areas of mathematics?

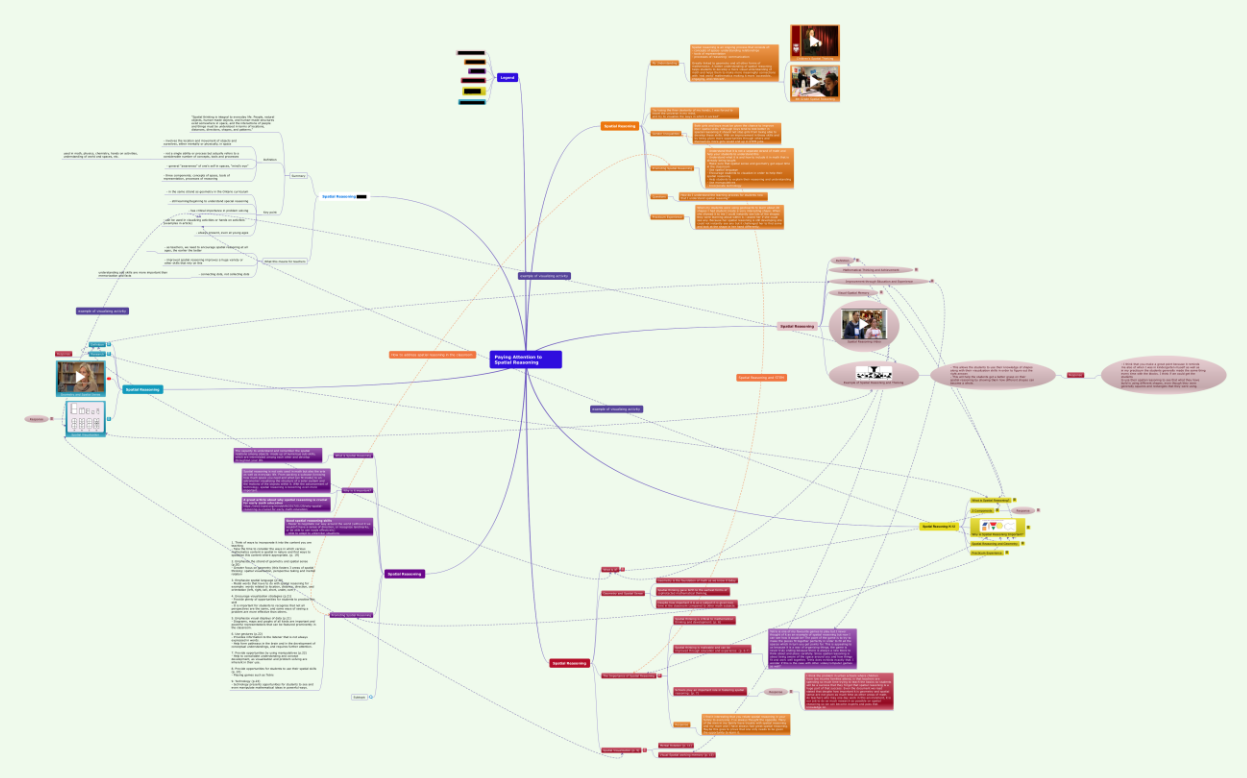

Figure 25. Sample mind map created by the participants in Case 3 (http://bit.ly/case3-sample).

6.4 Sources of Data and Sample

The data used in this study consisted of two elements. First, the artifacts (mind maps) created by the students as a final product, which included the students' texts, images, videos and layouts they used to represent knowledge (Figure 23, Figure 24, and Figure 25). The second source of data was the online records of students' interaction during collaborative mind mapping, obtained through Mindomo's, Mindmeister's and Popplet's history feature, which allowed researchers to look at the whole process of mind map construction (see Figure 26). Additionally, a visual version of the interaction was obtained by recording the process of mind map construction in the history feature. This data collection strategy is named videographic representation and is useful both for data capture and for eventual research presentation (Kozinets, 2015). Examples of this process can be seen in the following URLs:

- https://youtu.be/gqunumR5aeY - Sample of mind maps construction in Popplet
- https://youtu.be/Bpt-RdhP17I - Sample of a mind map construction in Mindmeister

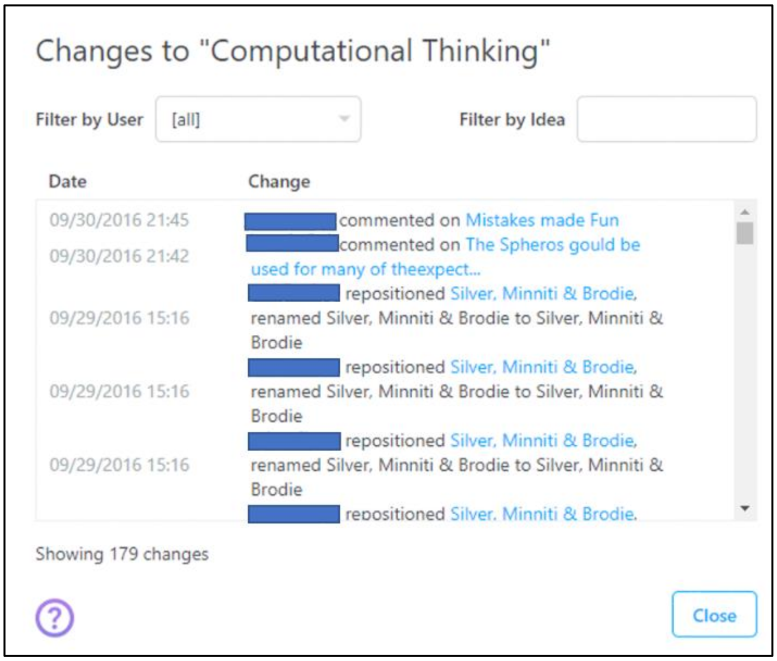

Figure 26. Sample of activity logs obtained from Mindmeister. Participant names have been covered.

Of the total amount of mind maps constructed in each case, for this study we only selected those where all students gave consent to participate. We were required to delete all comments and participation logs of students who did not give consent to participate. As a result, in mindmaps where some participant(s) contributions have been deleted due to lack of consent, there were gaps that could misinform the analysis in terms of the interaction – there are parts of the conversation, layout elements, and connections missing. For this reason, using only the mind maps where all students gave consent to participate generated a complete view of the interaction that resulted in a more accurate analysis and results. Consequently, the sample of mind maps analyzed in this study was: 47 mind maps (out of 93) for Case 1, 25 mind maps (out of 60) for Case 2, and 33 mind maps (out of 96) for Case 3.

6.5 Grounded Theory

According to Charmaz (2014) grounded theory methods are a set of "systematic, yet flexible guidelines for collecting and analyzing qualitative data to construct theory from the data themselves. Thus, researchers construct a theory 'grounded' in their data." (p. 1). These data are constructed through observations, interactions, and gathered materials, which are systematically examined, coded, and categorized to generate an "analytical product rather than a purely descriptive account. Theory development is the goal" (Hood, 2007, p. 154).

The process to analyze data using grounded theory methods involves coding and categorizing the data to find patterns, using memo writing and theoretical sampling as a part of the process. To help with this endeavor, we used the QSR NVivo 11 software, which allows to import and code multimodal sources of data such as the mind maps and interaction videos from our study. The following subsections describe the steps taken to perform the initial, focused, and theoretical coding.

6.5.1 Initial Coding

The initial coding in grounded theory helps researchers start to make sense of the data (Charmaz, 2014). In this research, coding started by looking for actions rather than themes, thus, using gerunds to label observable actions performed by participants in the activity. Using the comparative method of grounded theory, researchers looked at each instance in mind map construction, paying attention to newly emerging actions, as well as patterns that repeated from instance to instance. It is important at this point to remark that the initial coding stage was completed using only data from Cases 1 and 2. The reason behind this selection was to allow researchers to later conduct theoretical sampling using data from a new case (Case 3) [2]. As a trail of evidence, Appendix F shows all initial codes and frequencies, as generated in the initial coding stage. For a thorough description of each code, the reader may refer to Appendix G.

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[2] In constructivist grounded theory, data collection and analysis are conducted simultaneously in an iterative process (Charmaz, 2014). This involves going back to the field to seek pertinent data after an emerging theory has been drafted (theoretical sampling). This allows researchers to elaborate and refine the categories that constitute the theory. When using digital data, which is previously stored and readily available, going back to the field for pertinent data is not possible, so the theoretical sampling needs to adjust to this circumstance (Whiteside, Mills, & Mccalman, 2012). We achieved this by coding and analyzing a subset of the data (Cases 1 and 2), gain a sense of the emerging theory, and then theoretically sample using the rest of the data available (Case 3).

6.5.2 Focused Coding

During and after the initial coding, the researchers engaged in some focused coding. It is possible to note in Appendix F that some codes were grouped into some early categories. This grouping helped us define more relevant codes and facilitated subsequent coding. Once the initial coding was finished, we looked deeper into our codes, codes descriptions and data references to further group our initial codes into focused ones. This process is known as focused coding (Charmaz, 2014) or selective coding (Glaser & Strauss, 1967). At the end of this stage, four broad categories emerged: building concepts, developing discourse, developing leadership, and expression variations. Table 9 shows the four categories and its composition into initial codes.

Table 9: Focused and initial codes

Focused Codes	Initial Codes
Building Concepts	Introducing a topic, Building on topics, Making connections
Developing Discourse	Commenting, Asking questions, Referring to class activities and resources, Sharing life experiences
Developing Leadership	Building a base, Filling the blanks, Leaving blanks, Giving directions, Grouping topics, Highlighting, Making aesthetic decisions, Resolving issues, Leadership Obstacles (Ignoring initial plan, Contributing on the deadline).
Expression Variations	Collaborating in real time, Using descriptions, Using images, Using chat, Using videos.

6.5.3 Theoretical Coding

Theoretical coding is the stage where the grounded theory is built in terms of relating the codes and categories and generating (or raising) a core theme or category (Charmaz 2014). In this process, we used theoretical memos and integrative diagrams to establish relationships between our codes. Theoretical memos were written during the initial and focused coding stages, and in the theoretical coding stage they were analyzed and related to our focused codes. They also helped merge some codes and identify which of our categories (Building Concepts) could relate to all other codes, raising it to core category.

The second tool that helped us determine relationships between codes was the integrative diagram. We created integrative diagrams to relate nodes in each category, and then a larger diagram relating all four categories. Figure 27 shows our main integrative diagram created using Nvivo. Finally, with an emerging theory taking shape, we developed theoretical sampling, a process through which we tested our codes and categories with new data (Case 3), further refining their conceptualization and integration.

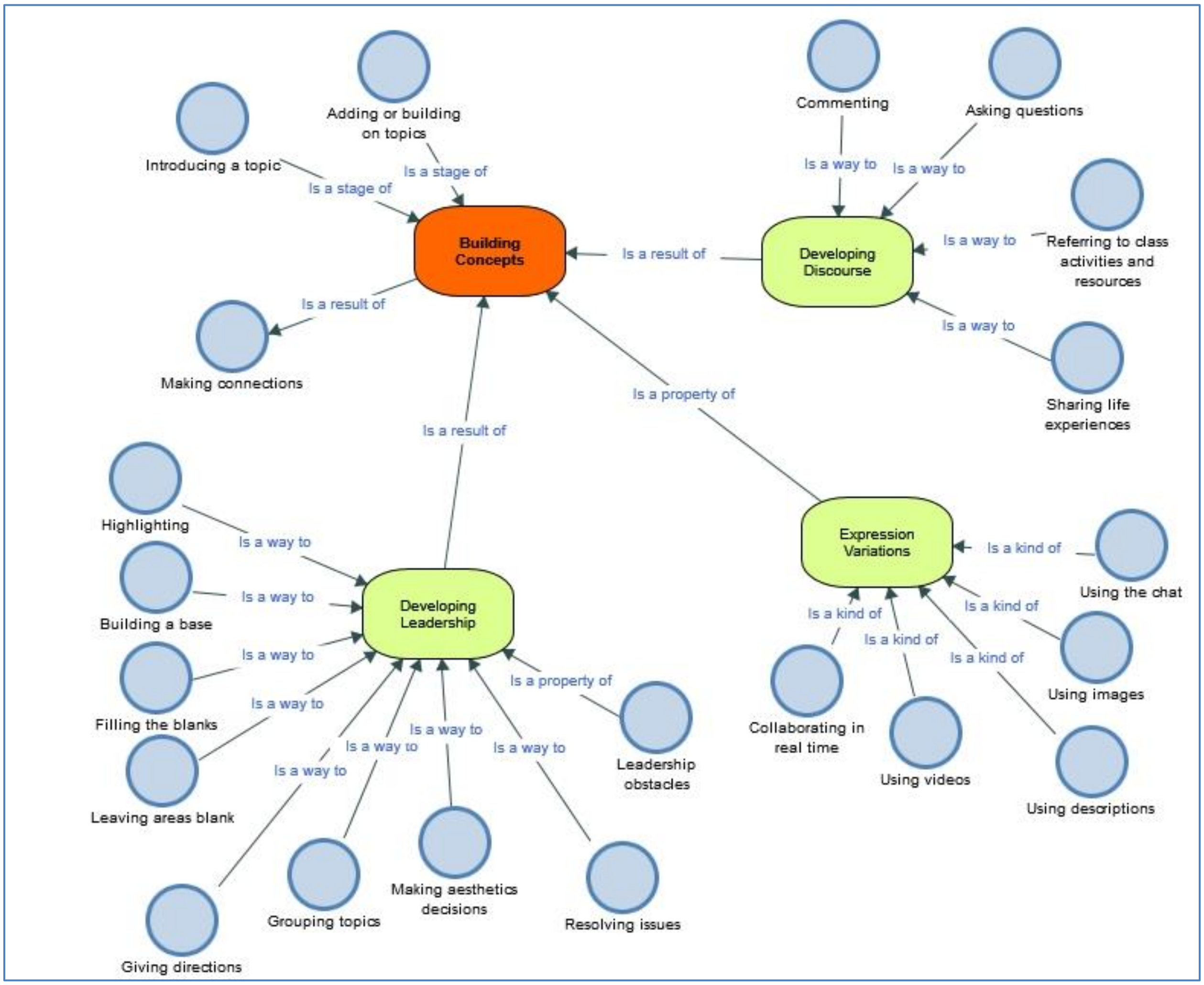

Figure 27. Integrative diagram showing the relationships between our codes and categories. Created using Nvivo.

We solidified the theory by naming it *Knowledge building through mind mapping*, which originated from the core category Building Concepts. Using the theoretical memos and integrative diagrams developed through the coding process, we created a narrative account of the theory, which includes the constructs: (1) Stages of knowledge building through mind mapping,

(2) Results of knowledge building through mind mapping, and (3) Expression variations in knowledge building through mind mapping.

6.6 Results: A Grounded Theory of Knowledge Building through Mind Mapping

While engaging in online collaborative mind mapping, participants follow a straight sequence (Construct 1: Stages of Knowledge Building). First, they introduce topics, which are built upon by adding subtopics. When a participant is done adding subtopics, they proceed to make connections to other participant's topics, and sometimes make small contributions to others' topics.

There are two byproducts of this process (Construct 2: Results of Knowledge Building), participants develop discourse by adding comments, asking questions, sharing life experiences, and referring to class activities and resources. And they also develop leadership by engaging in behaviors such as building a base, making aesthetic decisions, resolving technical issues, giving directions, grouping topics, highlighting, filling or leaving blanks, and by overcoming leadership obstacles.

Participants engage in collaborative mind mapping in varied forms, according to their preference or the nature of the content. We refer to these varied forms of participation as expression variations (Construct 3: Expression Variations in Knowledge Building) and they consist of using the chat, descriptions, images, or videos, all of which may or may not include collaborating in real time. Below, we elaborate on the constructs of our theory and discuss how these constructs relate to existing literature.

6.6.1 Stages of Knowledge Building through Mind Mapping

6.6.1.1 Introducing a topic

Each participant began their sessions by introducing a new topic to the mind map, unless a previous base of main topics was already built by a student leader (which happened in most mind maps). There were some variations in the kinds of topics introduced, which were greatly dependent on the prompt used by the instructor. When using a topics list (Cases 1 and 2) participants were more likely to introduce a topic related to something that stood out from class or from readings (e.g. the growth mind set, mathematical thinking, gaming), or to introduce a question (e.g. what is your previous experience with coding?). However, when using a question prompt, the topics introduced were more likely to come directly from the readings, in some cases even labeling a topic by the page numbers of the reading. Another common way to introduce a topic was labeling with the participant's name and adding many different topics to it (building an individual mind map inside the larger mind map). In this kind of structure there were some duplicated topics as each participant would include it under their own section of the mind map. Figure 28 shows examples of topics introduced.

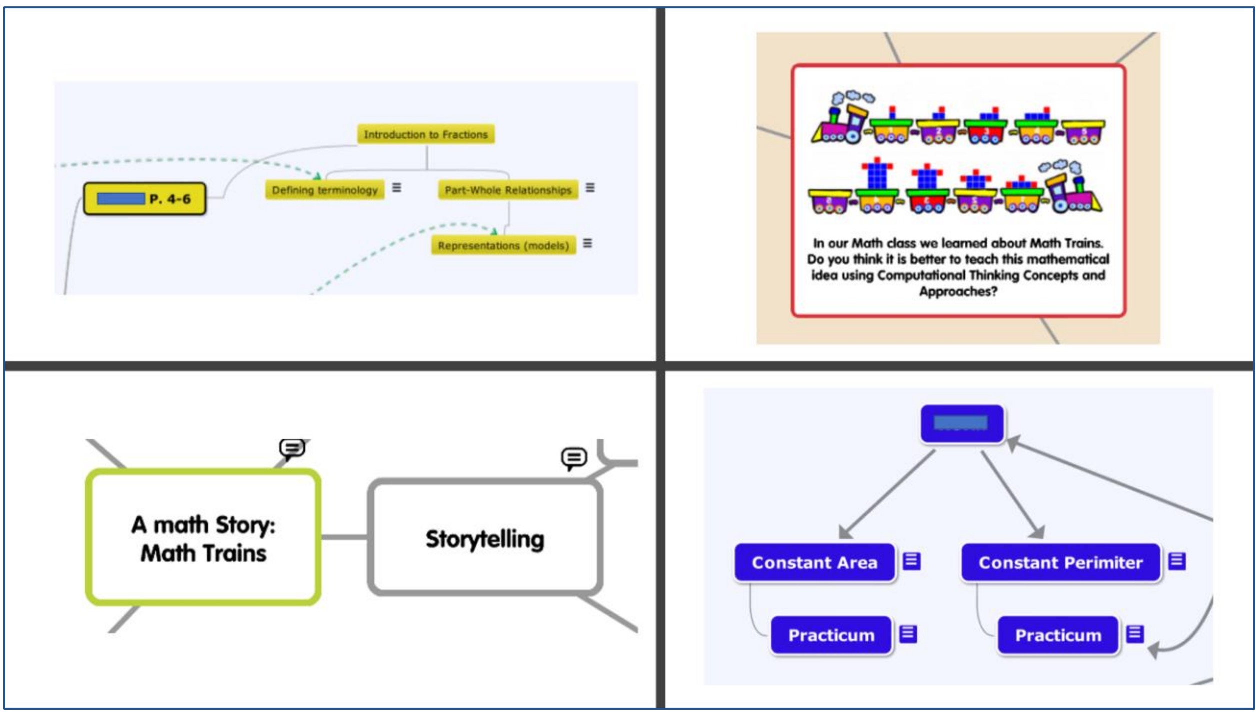

Figure 28. Different kinds of topics introduced in mind maps. Participants' names have been covered.

6.6.1.2 Building a concept

The process of building a concept is generally done by a single student (there is little collaboration at this stage). One participant adds all subtopics on a previously created topic, or on one they just created, and rarely adds to others' topics. Note in Appendix F that adding or building on (others') topics was only observed 2.95 times per mind map, lower than adding to their own topic (7.53 times per mind map) or adding a comment to other's post (13.24 times per mind map). So, the most common way to collaborate was not by adding sub-topics, but by adding comments. In Figure 29, which shows examples of concepts built, it is possible to note how some nodes are accompanied by a small icon with three lines. This icon represents that a text comment is attached to the node. We discuss this in more detail when we describe *Developing Discourse* as a result of knowledge building.

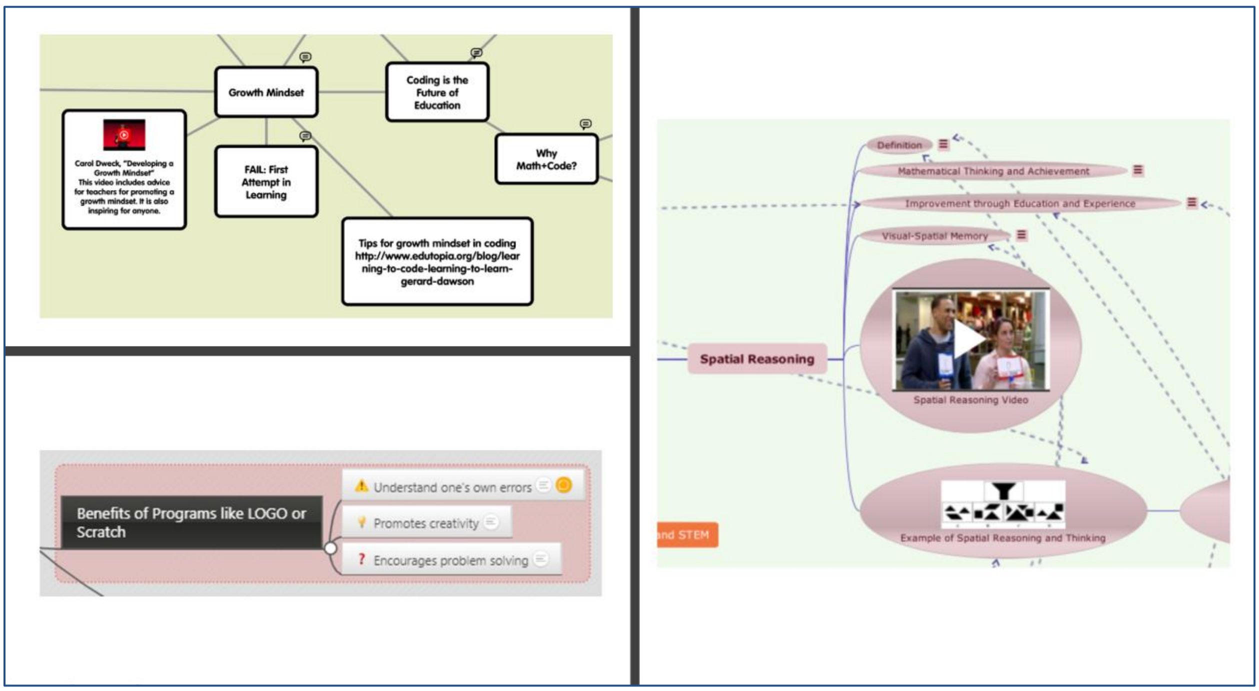

Figure 29. Examples of topics built in mind maps.

6.6.1.3 Making sense of the whole picture

This stage is where most of the collaboration happens. As stated before, when building a concept, participants tend to stay in their own topic and contributions to other topics are minimal. But when a participant finishes building their initial concept, they move to find ways to connect their ideas with others. We named this process "making sense of the whole picture" as this was the purpose of all the connections made. These connections result in a cohesive mind map that shows how collective ideas relate to each other. Other ways in which participants made sense of the whole picture was by arranging the layout, highlighting main topics or separating sections. However, this was done by only one or two students, if any, for the whole mind map.

Case 3 showed an addition to the process of making connections. Participants would extend the color they used for topics to the connections. This means that participants would use their assigned (or selected) color, which they had used to develop their concept, to make connections. The purpose behind this was to visually demonstrate that their participation was not limited to adding topics and comments, but that connections were also part of their work. An example of this can be seen in Figure 25. Finally, Cases 2 and 3 had the possibility of adding connecting words to connectors (a feature not available in Popplet - Case 1). However, connecting words were rarely used by participants.

6.6.2 Results of Knowledge Building through Mind Mapping

6.6.2.1 Developing Discourse

While mind maps have many visual features that would allow participants to develop a multimodal discourse, students mostly interacted through comments, by attaching notes to topics (see examples in Figure 30). Consequently, the prevalent mode of communicating ideas was written discourse. Sometimes, the structure of a mind map resembles a threaded forum, especially when participants construct their mind maps by name, rather than by topics (see section *Introducing a topic*).

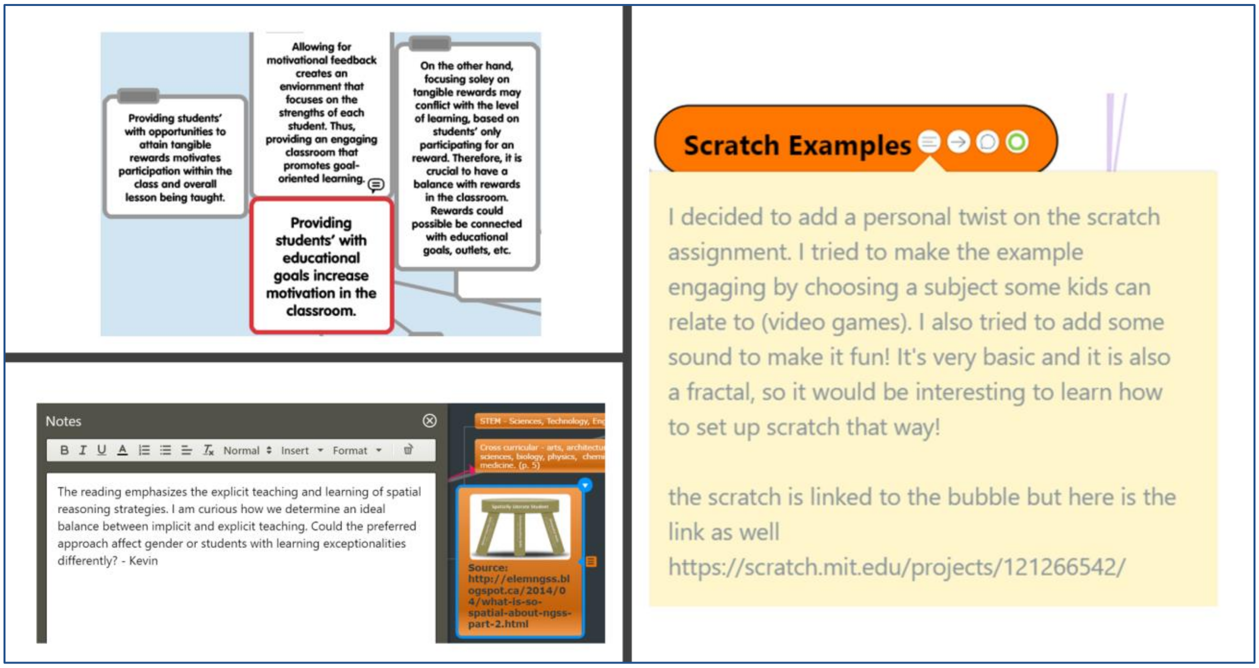

Figure 30. Examples of comments attached to nodes in mind maps.

In terms of content, the most common themes in participants' discussions were class activities and resources, and life experiences related to math and coding. While the discussion about readings and class activities was expected – since that was the purpose of the mind maps –, participants also communicated about life experiences such as: experiences and feelings towards coding; past (usually negative) experiences with math pedagogy, compared to the new pedagogical approaches they are learning; experiences from placement; and code developed as class activity or personal practice.

In terms of the nature of interactions through comments, they were generally of agreement and support. Disagreement, conflict, or debate were rare (observe the frequency of *Disagreeing* in Appendix F). Questioning was more often used as a conversation starter, such as a poll, or when a main topic was taken directly from the question prompt (Case 3). But participants rarely used questions to follow up conversations, and long conversation threads – of three or more back-and-forth comments- were not seen in the mind maps.

6.6.2.2 Developing Leadership

One important characteristic of mind map interaction is that most groups appeared to have one or two student leaders. These leaders seem to be executing his or her vision of the mind map. In Cases 1 and 2, where the maps were created by the instructor and participants were invited, the first student to access the mind map was generally the student leader. In Case 3, where participants created their own mind maps and invited the instructors, the leader is often the same person who creates the mind map and invites others. Some of the tasks that the leader performed were:

- They usually develop a base of main topics where the rest of participants build.
- They choose a colour and layout template for the mind map.
- They decide the colour that each participant will use for their contributions (in the instances where the group used a colour legend)
- They develop an initial topic – which structure is followed by all other members. For example, if the leader adds subtopics and concepts rather than a long comment to one node, all other participants will do so, too.
- They group topics together by proximity if they have many connections or common concepts. Sometimes they do it only for aesthetic purposes, to make it look more visually balanced – e.g. to have an equal number of sub-topics on both sides of the main topic.
- They highlight important parts by using shapes, fonts, or colour.
- They give directions on how to proceed with the mind map. Some of these directions are only visible in the history feature as they are deleted from the final mind map.
- They respond to other participants' technical issues by giving advice or ideas.

- Sometimes the leader logs in at the beginning of the activity to do the tasks mentioned above, and then logs in near the deadline to fill any gaps present, or to make sure all topics have comments.
- Sometimes we observed participants deliberately leaving some spaces open as they waited for other students to participate.

Besides these behaviors that contributed to the construction of a cohesive mind map, other behaviors were obstacles to this goal. In a high amount of mind maps (93% as per Appendix F), one or more participants in the group made their contributions on the day of the deadline. This allowed little time for their topics and comments to be integrated in the whole mind map. In other instances, participants would ignore the rules others were following, such as using the same color for all contributions of a participant, or filling a topic introduced by the leader. Contributions like this often stood out in an otherwise cohesive mind map.

6.6.3 Expression Variations in Knowledge Building through Mind Mapping

6.6.3.1 Collaborating in real time

Real time collaboration often happened near a deadline, and when it happened, participants worked in different parts of the mind map, staying within their own section. Chat communication in Mindmeister and Mindomo (Cases 2 and 3) show that they prefer not to use the software at the same time because it will not allow them to undo changes while two or more participants are connected.

6.6.3.2 Using descriptions

Descriptions added to a topic are heavily used as they are the main vehicle to develop discourse (see Developing Discourse). Descriptions is the only area where students share life experiences and emotions related to math and coding. Even in the cases where students share an image related to a life experience, it is accompanied by a description.

6.6.3.3 Using images

Images are included in mind maps for a variety of purposes as observed in the mind maps (see Figure 31 for examples):

- To discuss an image that stood out from the readings, i.e. screen captures, photos, or scans taken directly from a class resource.
- To show a finding as a triggering element for discussion, e.g. an infographic found online about the growth mindset.
- To share products of their work in class, e.g. a screen capture of a program developed in scratch.
- To exemplify a concept, such as fractions and their graphic representation.
- To illustrate a concept, as accessory, e.g. a photo of kids using a computer to discuss coding in mathematics education.

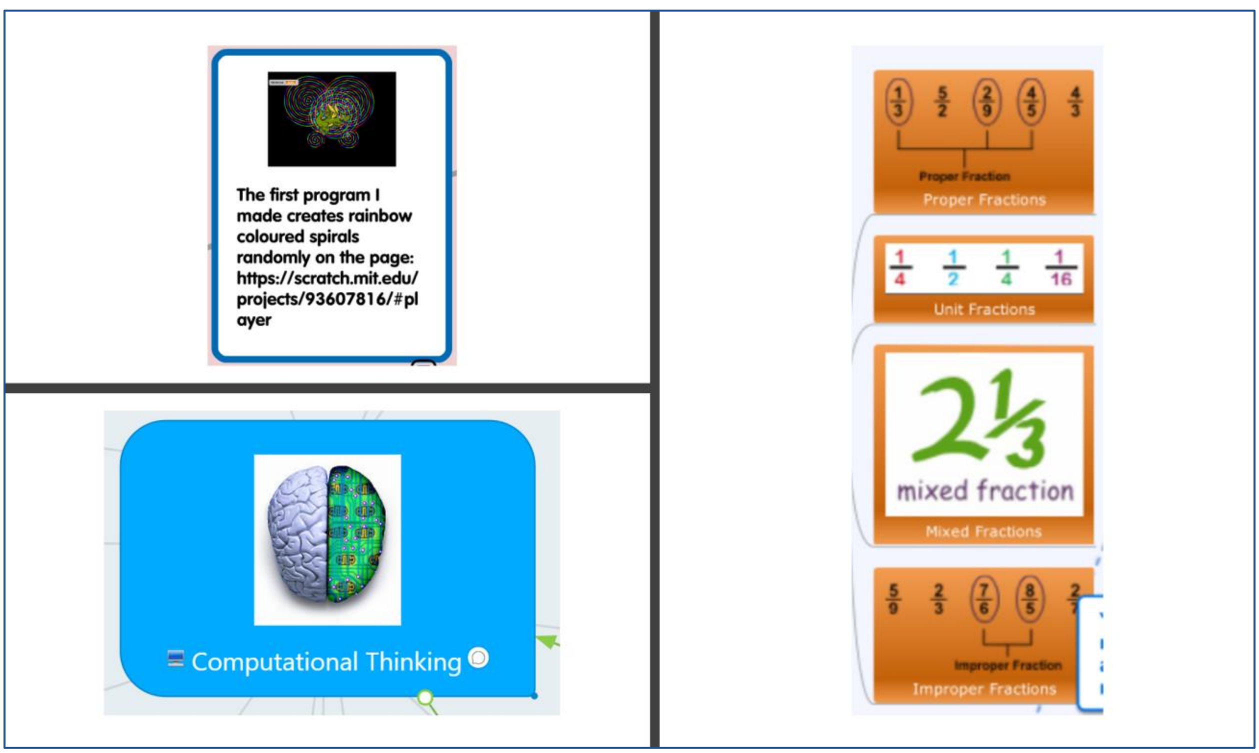

Figure 31. Examples of the use of images in mind maps.

6.6.3.4 Using videos

Videos are only used as triggering agents, since participants only use this feature to share web videos that sparked their curiosity or showed something of interest related to math education or computational thinking. This feature was only used in 40% of mind maps, as per Appendix F.

6.6.3.5 Using the chat

The chat feature was used rarely (only in 6.67% of mind maps, as per Appendix F), but when it was used, only organizational aspects were discussed, such as:

- Requirements of the mind map assignment or other class assignments.
- Task organization, i.e. who should contribute what and when, often with the intention to avoid using the mind map at the same time.
- Technical issues.

Below, we show an excerpt of a chat communication between two participants from Case 3 discussing mind map organization and submission:

A: how do I add pics from the reading?

A: if I want to use that as visuals

B: I haven't tried one from the readings. I usually search and link or save it and attach. Doc is PDF. Not sure how you could pull a pic from it.

A: okok

A: because, [another participant] was able to do it

A: so figured u may as well

B: i'll take a look. maybe she cropped a screen image? not sure.

A: ok

B: I was leaving areas blank but no sign of [two other participants]. Do we submit this or just leave it as is for them to look it?

A: we can leave it until around 9-10?

A: and if nothing is posted

B: do we even submit? [the instructor] already has permission to look at it.

A: we can send an email to [the instructor] and just finish up the mindomo

A: because it's only fair to give them a chance to use this day

6.7 Discussion

6.7.1 Stages of Knowledge Building through Mind Mapping

Participants in our multiple case study engaged in a process of knowledge building in accordance with Bereiter (2002) who, as a part of his connectionist model of the mind, defines knowledge as connections made through common goals, group discussion, and synthesis of ideas. The visual affordances of mind maps allowed for viewing, linking, and manipulating ideas, which are functions that contribute to collaborative knowledge building, in a way that threaded discussions cannot support (Scardamalia & Bereiter, 2003).

According to Borba and Villarreal (2005) the affordances of new media not only change how students perform, but also reorganize how they think. In this way, mind maps were an agent that reorganized the ways in which students thought about mathematics, computational thinking, and mathematics pedagogy. Instead of describing or commenting on different aspects of readings and class activities, as usually done in threaded forums, mind maps made students abstract the main topic or idea they wanted to communicate and build around that topic. While comments and descriptions were still part of mind maps, participants changed the ways they started discussions, and how they looked at concepts and the relationships among them.

Also, we found that our emerging three stages of knowledge building through mind mapping – introducing a topic, building a concept, and making sense of the whole picture – have some resemblance with the three intellectual phases of collaborativism (Harasim, 2017): idea generating, idea organizing, and intellectual convergence. Mind maps provide a visual way to see how topics are initially generated and then developed into organized clusters of information. The intellectual convergence, which "is typically reflected in shared understanding […], or a mutual contribution to and construction of a knowledge product or solution" (Harasim, 2017, p. 122), is evidenced in mind maps when participants connect, arrange, and/or highlight important ideas, which result in a shared product. In mathematics teacher education, promoting this level of shared understanding and encouraging participants to build shared knowledge products is an effective way to equip them to address the complexities of mathematics teaching. According to Lavicza, Hohenwarter, Jones, Lu and Dawes (2010), using this type of collaborative online activities result in "mathematics teachers' investigation of mathematical content, mathematics teaching, and higher-level reflection on teaching and technology" (p. 178).

However, in our multiple case study, there was still much space for improving collaboration throughout the whole process of mind map construction. A finding that stands out from our three cases is that the collaborative work that participants did was very limited. While the final products (mind maps) present as collaborative work, the construction process in its two early stages – introducing a topic and building concepts – shows mainly signs of cooperation, understood as a process "in which each member contributes an independent piece to the whole in a form of a division of labour" (Harasim, 2017, p. 121). In mind maps, contributions from all participants were visible, but these contributions were separated as each group member focused on developing a topic and then making comments or connections to relate concepts. This could be due to an issue of authorship, where participants do not feel comfortable adding to or editing work authored by another person.

In Gadanidis, Hoogland, and Hughes' (2008) study using collaborative writing in a wiki, participants also had difficulty allowing themselves to edit the work of others. They attribute this to a matter of ownership of ideas. "When a student's [product] is edited by peers, is that [product] still the original student's work?" (Gadanidis et al., 2008, p. 130). We believe that when a mind map is co-created by students they feel the need to set boundaries to their own work and that of others, so they can fulfill the purpose of demonstrating their knowledge and original ideas to the instructor.

6.7.2 Results of Knowledge Building through Mind Mapping

The constructs we called results of knowledge building through mind mapping – developing discourse and developing leadership – contain elements of the three roles that Suthers and

Hundhausen (2003) identified in collaborative visual representations. The first role refers to the need for students to share and discuss ideas before adding or modifying something in the visual representation. The mind maps showed that this negotiation happened when participants decided the topics to add, and which colours to use, taking in consideration the topics others have added. The role of the leader was also important in determining what topics were included and the general structure of the mind map.

The second role refers to the reference or pointing directly to a concept in the visual representation to explain one's ideas instead of relying on pure language to describe the concept and its relationships, which increases the conceptual complexity that can be handled in a discussion. While participants in mind maps relied heavily on language to describe concepts and express thoughts, they also used connectors, shapes, and colours to relate and highlight ideas as part of their discourse development. The third role refers to the fact that the visual representation serves as a group memory of the work, where participants are reminded of previous ideas and their implications. In mind maps, the topics introduced by others are visually available at all points of the interaction, so participants do not include those topics again and instead added comments if they agreed or had something to say about a previously included topics (except in cases where the mind map was organized by names of participants, where topics often repeated across the mind map).

Many authors have stressed on the importance of discourse to develop thinking (Harasim, 2017; Sfard, 2008; Vygotsky, 2012), build knowledge (Bruffee, 1999; Harasim, 2007; Scardamalia & Bereiter, 2003) and develop identity (Scollon, Scollon, & Jones, 2012). While discourse in online interaction – specifically so in mind mapping – is much more than verbal language, the main vehicle of interaction and expression in our case study was written discourse. Comments added to nodes were the most frequent way of expression used by participants, and the largest source of meanings in our data. This aligns with the view that "while discourse plays a key role in learning, text or writing is considered the most important type of conversation in knowledge building" (Harasim, 2017, p. 131). For Vygotsky (2012), articulating thoughts, or inner speech, to written speech requires a deliberate, complex, and detailed analysis. Henceforth, while the affordances of the mind maps allowed for more direct ways of communicating relationships, highlighting central ideas, and illustrating concepts through images and videos, and our participants used these features conveniently, they still relied on the power of the written speech to articulate and represent most of their thoughts.

Since the mind maps in our context were a case of self-directed learning environments – with minimal to none participation from the instructors -, there were many opportunities to develop leadership by participants. In Garrison's (2017) model of online interaction, instead of referring to a *teacher* presence, he refers to a *teaching* presence, since he observed that when the teacher withdraws from the discussion, participants develop the role of directing the cognitive and social processes. In our case study, the assumption of this role by some students was a natural response to the task, since the activity prompts did not include any role designations or instructions on how to start and organize the collaborative work. Scardamalia and Bereiter (2003) refer to this process as assuming epistemic agency and collective responsibility, by which students set goals and plan as they take responsibility for their own learning and the advancement of the group project.

6.7.3 Expression Variations in Knowledge Building

The prompts in the mind map activity did not encourage one mode of expression over the others. However, as explained in previous sections, participants relied heavily on descriptions to express their knowledge. This could be due to a general preference of students towards the *traditional* forms of assessment (Furnham, Batey, & Martin, 2011; Iannone & Simpson, 2015), in this case, essay type or written evaluations. However, there is much to gain by encouraging that students use multiple ways to represent their knowledge.

For example, Gadanidis et al. (2008) in their study with preservice mathematics teachers, concluded that "multimodal communication does make a difference in an online learning environment. And, this difference is not only in terms of having more ways of communicating; it is also a qualitative difference in the ideas that are communicated" (p. 126). The different expression variations afforded by mind maps did make a qualitative difference in what participants expressed. For example, life experiences were only shared through descriptions attached to nodes, while videos and images were used mainly as triggering agents that started discussion, and chat communication was limited to organizational conversations. Also, the integration of visuals and text in mind maps facilitated the integration of graphical, narrative, and symbolic realizations, which is an important indicator of math learning and math discourse development (Sfard, 2008).

Particularly, regarding videos, those included by participants in mind maps sparked discussions about computational thinking, mathematics, and mathematics pedagogy, which often related to past experiences with math. LeSage (2013) asserts that videos are a valuable instructional tool in mathematics for auditory or visual learners, and she continues to explain that the use of videos provides control to students and that “for elementary teachers with a history of negative mathematics experiences; being in control of mathematics is a novel yet welcome change” (p. 203).

6.8 Recommendations for Practice

Based on what we believe that worked well in our experience with collaborative mind mapping, we outline the following recommendations to implement this activity with preservice teachers:

- To introduce the activity and the software, a short presentation with Q&A should suffice. It works best when participants are allowed to explore the software capabilities by themselves.
- Instructor participation in the mind map could be of need if the goal of the activity is to achieve a higher cognitive level debate or knowledge production, but it is not required to organize the collaborative work and moderate the discussion since participants at this level assume well the roles of teaching presence.
- If the goal of the activity is to openly discuss many themes related to class, a topics list is a more desirable prompt. If the discussion should revolve around a single resource or issue, a questions prompt is more applicable. This will also generate more consistent (similar-looking) mind maps among groups.

- In the specific case of participants that are teachers or pre-service teachers, use a mind mapping tool to which they will have access to in their classroom practice. This will increase the relevance of the activity.

On the other hand, there are three aspects that we believe could be improved from our experience with collaborative mind mapping: (1) increasing collaboration throughout the mind mapping process, as opposed to cooperation, (2) improving collective responsibility over the mind map development, as opposed to leaving the leadership tasks to only one or two students, and (3) balancing the use of varied modes of expression, as opposed to relying heavily on long texts.

One action that could help further promote collaboration in mind maps is making participants aware of the history feature that allows instructors to see how the mind map was built step by step, including information of which student started and developed an idea, and which students only edited or added minor contributions. This could be explained as a part of the introductory presentation at the beginning of the activity. This, in turn, would create for the instructor a need to establish a rubric for student participation in mind maps, outlining what they consider more important or more aligned with the objective of the activity, whether that is developing a main topic or contributing to the development and connection of many topics. In this scenario, participants would need reassurance that the instructor will look at the history feature when evaluating participation, and not just at the final mind map. This rubric could also include indicators of leadership and collective responsibility over the final product, such as covering a predefined number of topics or filling blank areas. It could also include indicators such as representing concepts through visual examples or illustrations to encourage students to express in alternative modes to text.

6.9 Concluding Remarks

To sum up our findings of how preservice mathematics teachers interact and construct knowledge through collaborative mind mapping, we observed that they follow a straight sequence. First, they introduce topics, which are built upon by adding subtopics. When a participant is done adding subtopics, they proceed to make connections to other participant's topics, and sometimes make small contributions to others' topics. There are two byproducts of this process: participants develop discourse and leadership while using varied forms of expression according to their preference or the nature of the content.

Finally, the theory generated in this study is valuable to expand existing literature, especially concerning the use of visual tools for mathematics teacher education, and to inform practice and generate suggestions for teachers and developers to implement this type of learning experiences in other courses and/or other education levels, as well as set the stage for further research.

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Chapter 7

7 Integrative Chapter

There are three purposes that this final chapter fulfills. First, I summarize the five papers that compose this dissertation and I make explicit how they relate to each other. Second, I reflect on the process of writing these papers along with limitations and challenges I encountered during the research. Finally, I present the concluding statements that close the dissertation and form a base for future research.

7.1 Threading the papers

A longstanding tradition in educational technology research is to prove the efficacy of a target tool or approach (Friesen, 2009). We do this in an attempt to demonstrate that innovation is worth a try, or at the very least, prove that technology is as good as the traditional approach. Although as a researcher I advocate to move past this paradigm in educational technology research, I followed this tradition in the two first chapters of this dissertation. My intention in doing this was partially exploring collaboration in mind maps in comparison with the most used tool for online discussion (forums), but mostly, I intended to build a case or niche for my grounded theory research.

Following this purpose, in Chapter 2, I presented a study using a comparative approach of the interaction developed in threaded forums and online mind maps in a blended course (Case 1). The framework used to compare interaction was the Community of Inquiry (CoI) model (Garrison, 2017) and I reached the conclusion that a deeper social presence was achieved in the threaded forums and a higher cognitive presence was achieved in the mind maps. While the difference in numbers for each category and each week was not large, the totals for each presence were high enough to make a difference in the interaction. I speculated that the visual affordances of mind maps would allow higher frequencies of integration (the ability so summarize and connect topics within a concept), and more exploration was necessary to determine if this was the case.

After finishing this paper, I realized that the CoI framework is not entirely suitable to analyze interaction and knowledge construction in collaborative mind maps. Discourse in mind maps may resemble that of online discussions carried out through forums, but it has little in common with these forms of linear text. According to Brown and Czerniewicz (2014), “as a genre, mindmaps enable certain semiotic possibilities that conversation and writing do not” (p. 93). These possibilities include, but are not limited to, more options in arranging items, sizing, highlighting, linking or separating ideas (Gao, Zhang, & Franklin, 2013). Using these elements, instead of relying on pure language to describe a concept and its relationships, increases the conceptual complexity that can be handled in a discussion (Suthers & Hundhausen, 2003). Mind maps also encourage brainstorming, which has different discourse characteristics to discussions and allows a quick view of the main concept (Ng & Hanewald, 2010). Consequently, a more open and holistic approach of analysis was needed to fully understand the processes of interaction and knowledge constructions that participants developed in collaborative mind mapping.

With this purpose in mind, I approached the comparison from a different perspective in Chapter 3. In that paper, I used the comparative approach to view altogether the affordances of threaded forums and mind maps in relation to teacher education. Through a descriptive case study, I looked into the online components of a blended course (Case 3) with the intention to determine the roles (understood as functions or effects, intended or not) that threaded forums and mind maps had in teacher candidates’ learning experience. The content analysis was conventional (not directed), which allowed for themes to emerge from discussions and observation. I concluded that threaded forums fostered continuity, open communication, shifts in participation, and transformation of identity, while mind maps fostered continuity, organization, integration, and development of professional digital competence.

The analysis in Chapter 3, with a non-directed approach, allowed for an opportunity to triangulate the results in Chapter 2. By contrasting findings in both papers, it is possible to note that threaded forums have an important role in developing processes that have a more social purpose (i.e. open communication, shifts in participation, and transformation of identity), while mind maps have roles that lean towards cognitive purposes (i.e. organization, integration, and development of professional digital competence). This coincidence reveals that integrating the papers sheds light on the topic of online mind mapping in a more complex way than just the distinct parts presented separately.

A question that emerged from the study in Chapter 3 was regarding the specific role that multimodal expression had in participants' learning. I argue that Universal Design for Learning (UDL), an educational framework that emphasizes in accommodating individual learning differences, is a promising field in which the multimodal capabilities of mind maps have the potential to allow multiple means of representation and expression by improving remembering, understanding and knowledge organization. For this reason, in Chapter 4, I used the UDL guidelines (CAST, 2018) to look at the mind mapping activities and outline the specific roles they accomplished in the learning experience. I found that mind maps covered the following UDL curricular guidelines: vary demands and resources to optimize challenge; foster collaboration and community; optimize relevance, value, and authenticity; offer ways of customizing the display of information; illustrate through multiple media; and provide options for expression and communication.

Looking at Chapters 2, 3, and 4 of this dissertation, they blend together to assert that online collaborative mind maps have distinctive capabilities for interaction and knowledge construction, and other frameworks do not fit entirely with the multimodal elements present in mind maps. The idea behind the last two papers of this dissertation was to set up a new framework that allows researchers and practitioners understand the particular behaviors that emerge from students when they engage in online collaborative mind mapping. For this endeavour, I used constructivist grounded theory (Charmaz, 2014), which has the characteristic of being flexible, yet *grounded* in empirical events and experiences, making this method useful in the field of online learning to produce models of how students engage, build knowledge, and create communities of practice. Grounded theory methods can also incorporate multimodal methods of analysis, which often focus on the relationship between modes of expression and interactions (Jewitt, 2013), but the goal of constructivist grounded theory (and of my research) was to generate the model of a social process. Grounded theory allowed me to use an open approach to look at the data, and to include all the aspects that in previous papers were being left out.

It was not without challenges and limitations that I carried out the analysis of such rich sources of data. I dedicated Chapter 5 of this dissertation to outline and reflect around these issues. Considering online mind maps as extant, multimodal documents, the challenges of using them as data sources for my grounded theory study were in regard to informational richness, ethics, multimodal memo writing, and theoretical sampling. Thus, these issues were thoroughly discussed in Chapter 5 since they had no space to be discussed in Chapter 6, which presents the grounded theory of knowledge building in online collaborative mind mapping, which include examples and a systematic discussion of the results.

The grounded theory that emerged from my study describes that when constructing knowledge in mind maps, preservice teachers follow a straight sequence of introducing topics, building concepts, and making sense of the whole picture. In this process, participants develop discourse and leadership, while using varied forms of expression. Chapter 6 is the culminating piece of research, to which all the other papers led to.

The way I visualize the different papers coming together is shown in the diagram in Figure 32. A first phase, oriented to demonstrate how mind maps differentiate from threaded forums and how they can lead to inclusive learning, is developed through the first three papers. This sets a base and establishes a niche for the grounded theory of knowledge building through mind mapping, which is explained and developed in the two last papers. Finally, a summary of all the papers, their focus, methodology, and main findings can be seen in Table 10.

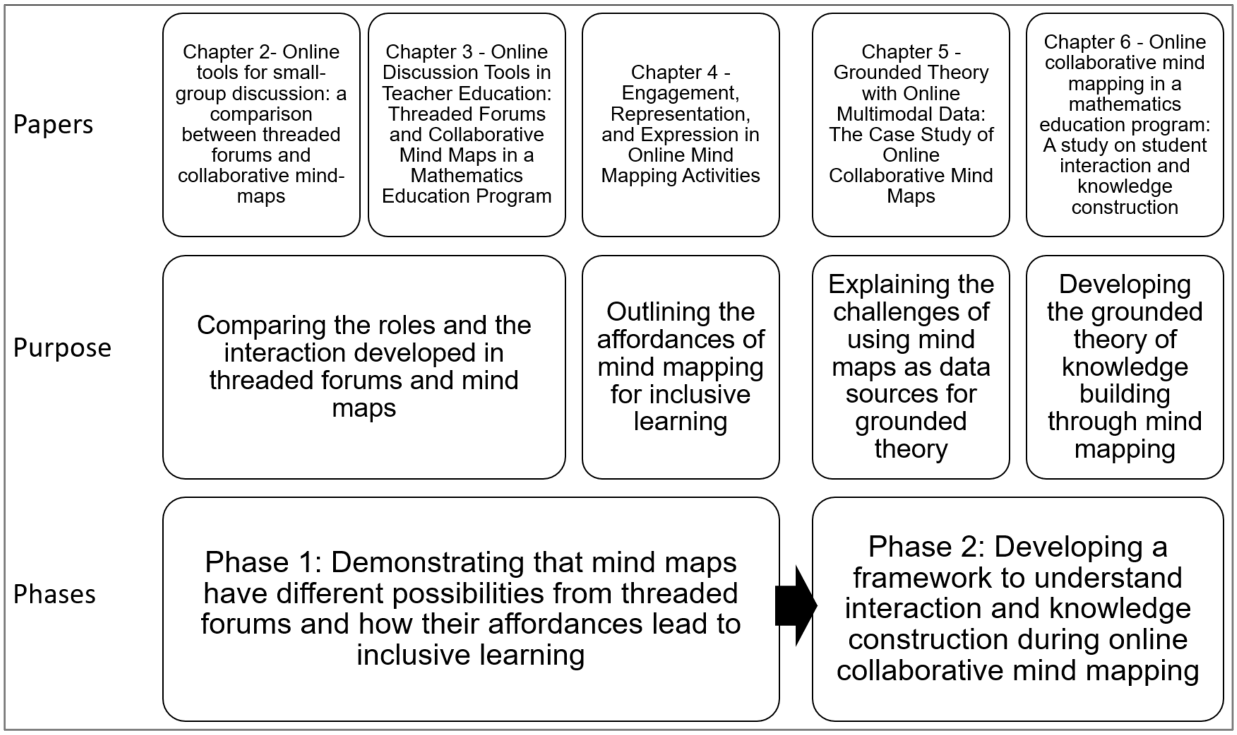

Figure 32. Structure diagram of papers, purpose, and phases in this dissertation.

Table 10. Summary papers, focus, method, and findings.

Chapter # - Paper Title	Focus	Method	Main Findings
Chapter 2- Online tools for small-group discussion: a comparison between threaded forums and collaborative mind maps	Interaction in threaded forums and mind maps	• Single case study approach (Case 1), • Directed Content Analysis (Hsieh & Shannon, 2005). • Framework: CoI (Garrison, 2017)	By only a small difference, a higher social presence was achieved in threaded forums and a higher cognitive presence was achieved in mind maps
Chapter 3 - Online Discussion Tools in Teacher Education: Threaded Forums and Collaborative Mind Maps in a Mathematics Education Program	Roles of threaded forums and mind maps in teacher education	• Single case study approach (Case 3), • Conventional Content Analysis, • Observation. • Interview	Threaded forums fostered continuity, open communication, shifts in participation, and transformation of identity, while mind maps fostered continuity, organization, integration, and development of professional digital competence.

Chapter 4 - Engagement, Representation, and Expression in Online Mind Mapping Activities	Affordances of mind mapping for inclusive learning	• Multiple case study approach (Cases 1, 2, and 3), • Observation • Framework: UDL (CAST, 2018)	Mind maps covered the following UDL curricular guidelines: vary demands and resources to optimize challenge; foster collaboration and community; optimize relevance, value, and authenticity; offer ways of customizing the display of information; illustrate through multiple media; provide options for expression and communication.
Chapter 5 - Grounded Theory with Online Multimodal Data: The Case Study of Online Collaborative Mind Maps	The mind maps as data sources for grounded theory	• Case study approach (the research is the object of study), observation.	Considering online mind maps as extant, multimodal documents, challenges of using them as data sources for grounded theory studies are in regard to informational richness, ethics, multimodal memo writing, and theoretical sampling.
Chapter 6 - Online collaborative mind mapping in a mathematics education program: A study on student interaction and knowledge construction	Interaction and knowledge construction	• Multiple case study approach (Cases 1, 2, and 3), • Constructivist Grounded Theory (Charmaz, 2014).	When constructing knowledge in mind maps, preservice teachers follow a straight sequence of introducing topics, building concepts, and making sense of the whole picture. There are two byproducts of this process: developing discourse and developing leadership. Participants follow the process while using varied forms of expression.

7.2 Reflecting on the process

This section contains reflections of the research process that are pertinent to wrap up the papers, or that did not fit in the papers included in this dissertation. These reflections are about the use of secondary data, the qualitative data analysis software (QDAS) NVivo, and the overall process of developing an integrated-article dissertation as opposed to a monograph.

7.2.1 About the use of secondary data

As mentioned in the dissertation preface, the data I have used for all papers in this dissertation was obtained in the frame of the project "Teachers as Mathematicians". I received permission from Dr. George Gadanidis to use his already collected data for my research (Appendix A). The summary of the groups of participants and how I used this data in the papers that compose this dissertation can be found in Table 11. To use this data, I bounded my procedures to the original letter of information and consent form of the study (Appendix B), where participants' data is confidential and must remain anonymous. To further ensure this, I only analyzed mind maps where all participants had given consent to have their logs and comments recorded for the original study (more information about this is found in Chapter 6, on the section related to the sample of mind maps selected for the study), and all identifiers, such as names and usernames, were deleted from the mind maps and comments.

Table 11. Groups of participants and chapter where each set was used

Set of Participants	Case	Chapter				
		2	3	4	5	6
Set A 143 out of 157	**Case 1** CT+ Math Education, Winter-2016	✔		✔		✔
Set B 194 out of 240	**Case 2** CT+ Math Education, Fall-2016			✔		✔
	Case 3 Math Methods, Winter 2017		✔	✔		✔

Quoting from the Ethics Protocol approved by Western's Research Ethics Board: "The study will investigate the use/effect of the resources and related teaching methods on the development of teacher mathematical and pedagogical knowledge, and attitudes/beliefs towards mathematics and its teaching." My study fits within this research mandate: (1) The mind maps I investigated were considered "teaching methods" integrated into the online platform of the course; and, (2) my research questions address the role of mind maps in "knowledge" creation (how students interact differently and how the "knowledge" they develop is different when mind maps are used).

The purpose of the primary research was to investigate the developing knowledge of teachers involved in math-for-teachers courses, using online course resources. The data collected for that study included online assignments such as forums, mind maps, and reflection essays, as well as interviews and classroom observations. My research used only a subset of this data, which is the threaded forums and mind maps as spaces for interaction and knowledge construction. The data was a good fit for my research because it contained all the necessary elements to answer my questions, such as students' initial comments, responses, connections made, and multimodal elements used to make meaning.

Due to my participation in the original research team, I had easy access to the data and I am certain about its quality. All data were collected and recorded through digital tools (Popplet, Mindmeister, and Mindomo), and mind maps are still available in each account. Besides from having the data still available on the servers of the mind mapping tools, all mind maps are also available in Microsoft Word format. Mindomo and Mindmeister made it possible to create and download these files automatically, while Popplet required a manual download of the information. This method was appropriate to collect comments and the final mind map but was not suitable to collect the history of mind map construction. This feature was only available on the servers of each tool, so I conducted videographic representation (Kozinets, 2015) to obtain a video version of the interaction.

In the process of data collection and analysis I was well aware of my role and assumptions as a researcher. This is particularly important because I participated in the research team that collected and analyzed the data for the original study about teacher candidates' knowledge on mathematics pedagogy and computational thinking (CT). I participated as a Research Assistant initially supporting some of the instructors and students in the use of the mind mapping tool, later in data collection, and finally by reading and coding all comments in these mind maps to find ideas about mathematics, mathematics pedagogy, and CT. For this reason, I risked bringing my own assumptions and being too confident about phenomena in the data (Hinds, Vogel, & Clarke-Steffen, 1997). To avoid this, I made an effort to take a fresh view of the data and to find disconfirming evidence to my conscious assumptions. The guidelines of initial coding in grounded theory helped me view and code participants' actions rather than my own interpretations. Also, I used theoretical sampling (as explained in Chapter 6) to challenge the early drafts of the theory through data evidence.

7.2.2 About the use of the QDAS NVivo

The qualitative data analysis software (QDAS) played a crucial role in the development of this dissertation. The grounded theory method required that I carried out three stages of coding to ensure rigorous results and NVivo helped me manage the large amounts of multimodal data for this process.

As described in the respective chapters, the sources of data I used were textual (discussions in threaded forums and mind maps, as well as interaction logs), visual (mind maps as final products) and videographic (recordings of the mind map construction process). NVivo allowed me to import all these sources of data and link them, facilitating a quick view and contextualization of cases. In an initial coding stage, NVivo helped me create either emergent codes (called Nodes in the software), as in Chapter 6, or use a preset codebook, as in Chapter 1. Each node was saved with a definition or description which helped clarify the “rule of inclusion” or the basis for counting (or excluding) specific document segments (Maykut & Morehouse, 1994). The codebook in Appendix F shows these definitions. I also wrote digital annotations or memos which I was able to attach to relevant sources or nodes. These annotations were in the form of comments, reminders and/or reflections on the documents, which often included image captures from the mind maps, as explained in Chapter 5. In the writing stage, it was a great help to have all these memos sorted and organized in NVivo.

In the focused coding stage, NVivo was helpful to easily go over all the initial nodes created, with a quick view of all coded segments and memos. This resulted in some nodes being grouped together into categories, and others being renamed. Gradually, the initial codes evolved into a more hierarchical structure of focused codes. At this point, theoretical patterns started to become apparent. The concept mapping feature of NVivo also allowed me to generate a visual structure of relationships between nodes and categories, which eventually led to the premises that related my themes. Through NVivo, I was easily and quickly checking on my theoretical constructions by going back and forth between source documents, memos, and diagrams.

This process was also a reflection of my social constructivist epistemology, and my own understandings of the role of technology in knowledge production. In an interaction of human-with-media (Borba & Villarreal, 2005), I produced a theory that would not have been possible -

or would have been very different – without the part played by NVivo as a qualitative data analysis software. How would the theory be any different had I used a manual process of data analysis? Though a hypothetical question, I am certain that the use of NVivo increased the quality and transparency of my research. In terms of quality, NVivo allowed me to do a more thorough analysis of the large amounts of data, while having a "continual connection and visibility between the original data and the classification taking place" (Bonello & Meehan, 2019, p. 496), ensuring that the grounding of the theory in the data was accurate. In terms of transparency, NVivo facilitated the creation of an audit trail, showing how codes were generated, linked to pertinent data segments and memos, categorized and theorized. The writing stage was also facilitated by having quick access to all coded segments, allowing me to present the most relevant and illustrative examples in the papers.

7.2.3 About the integrated-article format

Developing my dissertation in an integrated-article format with all its implications was the most enriching endeavour of my Ph.D. program. I identify two salient advantages of pursuing this approach rather than the more traditional monograph dissertation. The first advantage is in regard to research participation. The integrated-article approach allowed me to mix various perspectives and methodologies. Generating a few of medium-sized projects, rather than only one large study, developed my skills as a researcher by giving me the opportunity to quickly evaluate outcomes, learn from mistakes, and try new approaches during the program. This is something nearly impossible to achieve with one large project bounded by the time constraints of the Ph.D.

The second advantage is in regard to writing and knowledge dissemination. Writing articles, which are oriented to audiences inside and outside academia, is a great way to learn and practice the job of a researcher. Navigating the process of peer-reviewed publication is also a valuable competence to develop in the Ph.D., which is difficult to fulfill when the candidate must spend time on coursework, assistantship duties, and thesis writing. The integrated-article dissertation allowed me to accomplish several peer-reviewed publications that encompassed with my research assistantship role within the timeframe of the program.

The direct result of producing and disseminating articles during the Ph.D. was the opportunity to project my name in the academia. For example, the paper in Chapter 2 originated from a conference in which I participated in 2017. My conference paper was selected to appear (with further edits) in the volume “Research Highlights in Technology and Teacher Education 2017”. Having disseminated my knowledge and experience through these spaces, I later received an invitation to participate in other volume named “Universal Access Through Inclusive Instructional Design: International Perspectives on UDL”. The book chapter I contributed became Chapter 4 of this dissertation. These experiences have been enriching and would not have been possible had I spent all my time and effort in a monograph dissertation.

Also, another aspect of knowledge dissemination that is very specific to my field of research (educational technology and online learning) is that knowledge moves at an extremely fast pace. Research produced today will no longer be relevant in two or three years. Hence, time is of essence when disseminating knowledge. The time spent writing a monograph dissertation, submitting it for review, defending it, and ultimately do the work to transform it into a publishable form (articles), is not compatible with the fast pace of knowledge dissemination in my field.

While there were many advantages of doing an integrated-article thesis, one issue that emerged in this process was a relative lack of information about the format. Beyond main definitions and a general structure of the body of the thesis, Western University’s website does not provide the same amount of information as they do for the monograph format. I had questions about the content of the articles, copyright, and the examiners’ revision of already peer-reviewed work. Examples were few and hard to find in the library database, and there was no one who could speak about their experience. Throughout my studies I moved back and forth from the idea of developing an integrated-article thesis, and at one point (for most of my second year in the program) I committed time to write and develop elements of a monograph dissertation. At the beginning of my third year, I had the opportunity to attend an information session on the topic of developing an integrated-article thesis that motivated me in the direction of doing this dissertation format. The session reached a small audience, and it featured the experience of a recently graduated student who submitted an integrated-article thesis. However, my perception is that this session came late in my Ph.D. journey. Perhaps the articles that compose this submission would have been better planned if I had been thinking in their integration the entire time. Sessions like the one I attended should reach a larger audience and be intended for students in their first or second year, to help them make an informed decision about their thesis format.

Overall, I deemed my experience with the integrated-article dissertation a positive one. My firm understanding about this format is that it illustrates a candidate's "continuing journey as a researcher, demonstrating the strengths and weaknesses of [their] work from a range of evidence, whilst showing [their] intention to improve" (Peacock, 2017, p. 129). I am certain that this compendium of my work is a better evidence of my growth as an academic and of my abilities to produce original and relevant research.

7.3 Contributions of the research

From a theoretical point of view, this research is valuable to expand existing literature, especially concerning the use of visual tools for learning. Findings of this study (summarized in Table 10) contribute to a deeper understanding of collaboration through online mind mapping. Particular gaps in the literature that my research has addressed are: (1) mind maps affordances compared to those of threaded forums for online discussion, specifically for preservice teacher education (Chapters 2 and 3); (2) mind maps affordances for inclusive education (Chapter 4); (4) a theory for online interaction and knowledge construction during online collaborative mind mapping (Chapter 6).

Additionally, the practical contribution of this research is to inform the practice of interested audiences. A particularly relevant contribution is within the framework of the 21st Century Competencies for Ontario (Ontario Government, 2016) that recommends graphing tools and concept mapping tools as technologies that can foster, amongst other competencies, coordination, communication, metacognition, analysis, problem-solving, and reasoning. It is important to note that visual representation tools will help develop these competencies only if practitioners design appropriate collaborative tasks with them. My research (primarily Chapters 4 and 6) provides recommendations and suggestions for teachers and developers to implement mind mapping experiences in other courses and/or other education levels.

In addition to these theoretical and practical implications, there are methodological contributions in the process used to develop this research. First, on the intersection of qualitative and online research, which is still an incipient and promising field (Salmons, 2016). It must be noted that in the narrow field of online collaborative visual representations, qualitative studies are also underrepresented, since most of the available literature are effectiveness studies (Cendros Araujo, 2017). Hence, the methodological contribution of this research is that it illustrated how digital data that includes multimedia content can be collected, stored, and analyzed using qualitative methods. The strongest contribution in this area is presented on Chapter 5 where I outline the challenges of doing grounded theory with online multimodal data, but also Chapters 2, 3, and 4 contain valuable examples on how qualitative content analysis is conducted with online data.

7.4 Limitations of the research

The main limitation of this research is regarding the lack of participant feedback. Although end-of-course interviews were conducted with participants from Cases 2 and 3 (Set of participants B, as per Table 11), only seven teacher candidates attended. I refer to these interviews as anecdotal evidence in Chapter 3 since participation was not large enough to be representative of the whole group. Ideally, interviews or focus groups with at least a third of the total participants would provide a deeper understanding of students' perceptions about the activity. Also, participant feedback is a great source of validation for grounded theories, and this should be included in future research.

The second limitation was that the mind mapping software were stored outside the university's learning management system (LMS). This lack of LMS integration required participants to create accounts in the mind mapping tool's server. Accessing and retrieving participant data under these circumstances was difficult and greatly slowed down the process of selecting the mind maps to analyze (those where all participants gave consent) and analyzing them. It also makes instructor follow-up and support problematic and time consuming. A mind mapping software that participants can access directly with LMS credentials and provides significant metadata about access and participation would improve the implementation of the activity.

7.5 Suggestions for Future Research

There are several lines of research that can emerge from this study. The first one is in following the thread of the grounded theory of knowledge building through mind mapping. Future research in this area should focus on obtaining more evidence to support it or refine the theory. One way to do this is by gathering more data from future cohorts and search for variation on the patterns that the theory describes. This data should include participant interview and focus groups to gain a deeper understanding of perceptions, intentions and roles that participants take during mind mapping. Taking the theory back to participants to seek their validation is another desirable step.

When developing the topic of UDL and mind mapping, some opportunities for research emerged in exploring the impact that the activity could have in the performance of students with disabilities, as well as in the variations of learning styles. My study did not assess participants disabilities or learning styles of participants, and I acknowledge that these characteristics can make a great difference in the roles and behaviors that students exhibit during their interaction in mind maps.

Finally, in regard to method, there are many avenues to explore in online collaborative mind mapping. Social network analysis (SNA) is an approach that could gather meaningful results in terms of mind mapping interaction. However, this method is not exempt of the challenges of multimodal data. It would be an important contribution to determine how particular mind mapping actions (such as connecting or moving concepts around) can be interpreted and represented in a social network diagram.

7.6 Concluding Statements

This integrated-article dissertation has shown several possibilities for online collaborative mind mapping in mathematics teacher education that can be extended to other areas and levels. In answering the research questions, I conclude in a first instance that while the interaction and the roles of online mind maps and threaded forums are similar in nature, the first one provides more space to develop cognition and knowledge building, while the second one is a better space for social interaction and sharing. This translates into a higher social presence, open communication, shifts in participation, and transformation of identity achieved in threaded forums and a higher cognitive presence, organization, integration, and professional digital competence achieved in mind maps. As a consequence, online mind mapping is also a great activity to include UDL guidelines in the curriculum. Based on this case study, they can help vary demands and resources to optimize challenge; foster collaboration and community; optimize relevance, value, and authenticity; offer ways of customizing the display of information; illustrate through multiple media; and provide options for expression and communication.

In the use of mind maps as extant, multimodal documents for grounded theory, there were some challenges I had to overcome, being the most prominent ones related to informational richness, ethics, multimodal memo writing, and theoretical sampling. These realizations are important contributions that help make grounded theory more relevant in the field of online research. The theory that resulted from this process described the progression of knowledge building through mind mapping and asserts that preservice teachers follow a straight sequence of introducing topics, building concepts, and making sense of the whole picture. The two byproducts of this process are developing discourse and developing leadership, while using varied forms of expression.

Lessons learned from the implementation and research process allow me to conclude that good online collaborative practices include several technology tools in their environments, because research has shown that using a single tool is usually not sufficient to achieve all desired outcomes (Chen, Wang, Kirschner, & Tsai, 2018). For this reason, mind mapping implementations work best when done during a few weeks instead of using it through a full semester or year.

Previous exposure to mind mapping, concept mapping, or other visual representation techniques, whether they are paper-based or online, might also have a positive impact on knowledge building. In this research, I did not assess participants' prior knowledge of these techniques, but familiarity and dexterity with the mind mapping software did seem to increase in Case 3, which included the set of participants that used the activity for two terms in a row, especially by the third week of use (as discussed in Chapter 3). As an anecdotal note, participants in Case 3, who had the longest exposure to mind mapping, also requested less technical support when using the software. This might be attributed to familiarity with this particular technology, or it may be related to the characteristics and capabilities of the three different software (Popplet, Mindmeister, and Mindomo). In either case, the prior use of visual techniques and similar digital technologies will be helpful to develop the professional digital competence of teacher candidates.

The use of prompts for collaborative mind mapping should be aligned with instructional goals, using topics for more divergent constructions, and questions for more convergent ones. It is my expectation that researchers and practitioners can use the knowledge in this dissertation (as single papers, or as a whole) to implement better online experiences with their students, deciding on the most appropriate uses of threaded forums and mind maps, adequate prompts, and teacher scaffolding that ensure meaningful learning linked to curricular aims.

7.7 Chapter References

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Appendices

Appendix A: Letter of Permission to use data from the project Mathematics for Teachers

07 March 2018

Rosa Cendros has been working as my research assistant, collecting, organizing and analyzing data from online discussions and from interviews, of PJ teacher candidates in our teacher education program, 2015-2018. We have co-published several conference and journal papers based on this research. The research has ethics approval from Western University: Mathematics for Teachers, #108363

Rosa has my permission to use this data for her PhD thesis, which will focus on online interactions and knowledge construction of teacher candidates.

Sincerely,

[redacted]

George Gadanidis
Professor, Education
Western University

Appendix B: Letter of information and consent from the main study

Project Title: Mathematics for teachers
Principal Investigator: George Gadanidis, PhD, Faculty of Education, Western University

Western Education

Letter of Information - PJ/JI/IS Teacher Candidates

1. **Invitation to Participate.** You are being invited to participate in this research study on the effect of math-for-teachers online course resources on the development of teacher mathematical and pedagogical knowledge, and attitudes towards mathematics and its teaching, because you are in a course that uses these resources.
2. **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.
3. **Purpose of this Study.** This study will investigate the developing knowledge of teachers involved in math-for-teachers courses, using online course resources. The questions of the study are: (a) What do teachers learn about mathematics and mathematics pedagogy? (b) What attitudes and beliefs do teachers develop towards mathematics and mathematics teaching? (c) What role do the online course resources play in (a) and (b)? (d) What role do other course experiences play in (a) and (b)? (e) In what ways do (a) and (b) play a role in teacher candidates' classroom practice (in practicum settings)?
4. **Inclusion Criteria.** Individuals who are PJ or JI or IS teacher candidates enrolled in mathematics education oriented courses at the Faculty of Education, Western University are eligible to participate in this study.
5. **Exclusion Criteria.** None. All individuals who are PJ or JI or IS teacher candidates enrolled in mathematics education oriented courses at the Faculty of Education, Western University are eligible to participate in this study.
6. **Study Procedures.** If you agree to participate, your online discussion comments and reflection assignments will be analyzed anonymously as part of the study. If you do not agree to participate your online discussion comments and reflection assignments will not be read. You may also agree to for in-class observations of your work may be recorded. And, you may also agree to be interviewed at most twice (once after your course is completed and once in the second year of your program) about your course experiences and about your practicum experiences. The interviews will be conducted via an OWL worksite and you may respond to all, some or none of the questions asked. It is estimated that each interview will take up at most 15 minutes of your time.
7. **Possible Risks and Harms.** There are no known or anticipated risks or discomforts associated with participating in this study.
8. **Possible Benefits.** Early drafts of findings will be shared during interviews. The possible benefits to participants may be insights into teacher development. Information gathered may provide benefits to program design and to society as a whole which include a better understanding of the mathematics development of teachers.
9. **Compensation.** You will not be compensated for your participation in this research.
10. **Voluntary Participation.** Participation in this study is voluntary. You may refuse to participate, refuse to answer any questions or withdraw from the study at any time with no effect on your future academic status.
11. **Confidentiality.** All data collected will remain confidential and accessible only to the investigator and research assistant of this study. The data will be kept for five years in electronic form, and will then be deleted. If the results are published, your name will not be used. If you choose to withdraw from this study, your data will be removed and destroyed from our database. Representatives of The University of Western Ontario Non-Medical Research Ethics Board may contact you or require access to your study-related records to monitor the conduct of the research. You do not waive any legal rights by participating in this research.
12. **Contacts for Further Information.** If you require any further information regarding this research project or your participation in the study you may contact Dr. George Gadanidis, [redacted], [redacted]f you have any questions about your rights as a research participant or the conduct of this study, you may contact The Office of Research Ethics [redacted], email: [redacted]
13. **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 provide your name and contact number on a piece of paper separate from the Consent Form.

This letter is yours to keep for future reference.

Consent Form - PJ/JI/IS Teacher Candidates

Project Title: Mathematics for teachers **Study Investigator's Name:** George Gadanidis, PhD

I have read the Letter of Information, have had the nature of the study explained to me and I agree to participate. All questions have been answered to my satisfaction.

☐ I agree that my online discussions and reflection assignments will be analyzed anonymously as part of the study

☐ I agree to be contacted via an OWL worksite to be interviewed about your course experiences and about your practicum experiences. My email address is: ______________________

☐ I agree to have observations of my in-class work recorded anonymously.

Participant's Name (please print): ______________________________

Participant's Signature: ______________________________ Date: ____________

Person Obtaining Consent (please print): ______________________________

Person Obtaining Consent Signature: ______________________________ Date: ________

Appendix C: Letter of permission from IGI Global to republish the contents in Chapter 3

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By Jan Travers at 2:48 pm, Feb 05, 2019

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Organization: Faculty of Education, Western University

Address: [redacted]

E-mail: [redacted]

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Date: ____________

Please complete and email or fax this request form to:
Jan Travers • IGI Global, [redacted]

10/2017

Appendix D: Letter of permission from Taylor & Francis Group to republish the contents in Chapter 4

Taylor & Francis Group, LLC

GRATIS PERMISSION GRANT

May 7, 2019

Rosa Cendros Araujo
[redacted]

Dear Rosa Cendros Araujo:

Taylor & Francis hereby grants you permission to

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from Universal Access Through Inclusive Instructional Design: International Perspectives on UDL
ISBN: 9781138351073
In your Ph.D. thesis titled Collaborative mind mapping to support online discussion in teacher education
to be published by Western University in September of 2019.

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Appendix E. Questions List for Participant Interview

Below is a list of questions used as guides for interviewing teacher candidates Questions were open-ended and the interviewers followed the conversation with participants, trying to include all these topics, but not every participant responded all questions.

1. Which online math-for-teachers activities were most influential in your learning? And in what way were they influential?
2. What suggestions do you have for improving the online activities?
3. In the forums, what discussion is the most memorable for you? What topic were you discussing at that time? How did the conversation develop?
4. What topic or topics did you find the least interesting to discuss in the forums?
5. See the following activities related to participating in forums, in which one do you learn the most? The least? Explain
   a. Writing your own insights
   b. Reading others' insights
   c. Commenting/debating
6. How would you narrate your experience using mind maps? Tell me how you felt from the moment the tool was presented to you in class and how did the experience develop.
7. What did you learn from using mind maps? How did you learn this?
8. What did you like about using mindmaps? What didn't you like?
9. How was your experience in the forums different from your experience with the mind maps?
10. See the following activities related to participating in mind maps, in which one do you learn the most? The least? Explain
    a. Adding your own contributions
    b. Reading/interpreting others' contributions
    c. Commenting/debating
    d. Connecting concepts
    e. Organizing/moving concepts around

Appendix F. Initial Codes and Frequencies

Code Name	Total times coded	Total number of mind maps	Average of times coded per mind map	Percentage of mind maps with this code
Adding a comment to other's post	993	72	13.24	96.00%
Adding or building on topics	221	46	2.95	61.33%
Adding or building own's topic	565	72	7.53	96.00%
Agreeing	69	41	0.92	54.67%
Asking questions	22	15	0.29	20.00%
Asking Focused questions	8	7	0.11	9.33%
Polling or asking an open question	14	12	0.19	16.00%
Collaborating in real time	110	52	1.47	69.33%
Contributing on the deadline	272	70	3.63	93.33%
Developing leadership	373	70	4.97	93.33%
Building a skeleton	51	51	0.68	68.00%
Filling the blanks	62	46	0.83	61.33%
Giving directions	8	6	0.11	8.00%
Grouping topics	95	23	1.27	30.67%
Relocating a topic	62	15	0.83	20.00%
Highlighting	64	60	0.85	80.00%
Coding with colours	54	54	0.72	72.00%
Making aesthetics decisions	96	65	1.28	86.67%
Changing mind map colours	55	53	0.73	70.67%
Changing the Layout	41	41	0.55	54.67%
Resolving issues	13	12	0.17	16.00%
Disagreeing	9	7	0.12	9.33%
Ignoring initial plan	23	23	0.31	30.67%
Introducing a topic	560	72	7.47	96.00%
Leaving areas blank	58	33	0.77	44.00%
Making connections	571	72	7.61	96.00%
Referring to a class activity	123	57	1.64	76.00%
Referring to a class resource	97	66	1.29	88.00%
Quoting from a class resource	39	30	0.52	40.00%
Sharing life experiences	203	68	2.71	90.67%
Expressing emotions	89	52	1.19	69.33%
Sharing experiences from placement	50	32	0.67	42.67%
Sharing own's work	21	13	0.28	17.33%

Sharing past experiences with math or coding	43	20	0.57	26.67%
Using descriptions to expand a topic	568	70	7.57	93.33%
Using images	93	40	1.24	53.33%
Using the chat feature	5	5	0.07	6.67%
Using videos	33	30	0.44	40.00%

Notes:

- *Total Times Coded: Generated by Nvivo. Total times this code was used.*
- *Total number of mind maps: Generated by Nvivo. Total number of "sources" where this code appears.*
- *Average of times coded per mind map: Calculated dividing the total times coded (Column B) by 75, the total number of mind maps analyzed (Cases 1 and 2).*
- *Percentage of mind maps with this code: Calculated dividing the total number of mind maps (Column C) by 75, the total number of mind maps analyzed.*
- *It is important to remark that the numbers associated with codes did not determine their place or hierarchy in the emerging theory. Although in our research we looked at these numbers to grasp an idea of how often a behavior would appear in the mind maps, they are presented here only as a trail of evidence of the coding process.*

Appendix G. Codebook generated after the initial coding

Code Name	Description
Adding a comment to other's post	Participants add a comment or note to another's post. Used for every comment added
Adding or building on topics	Includes only when a participant adds or builds into another's topic (not their own)
Adding or building own's topic	A participant is generally assigned a topic. This code is used every time a participant builds on their own topic during a single session, regardless of how many topics or notes they add. This applies to previously existing topics, when a participant creates a new topic, it's labeled "introducing a topic"
Agreeing	Used when participants agree with other's opinion or comments, Includes comments of support such as "I liked your explanation"
Asking questions	Category created to group when participants ask questions either to start the interaction, or to continue it
Asking Focused questions	Participants as questions in reference to other's posts
Polling or asking an open question	Used when participants start a topic with a question for their group. e.g. "What is your previous experience coding?"
Collaborating in real time	A period of time in which two or more participants are working on the mind map at the same time
Contributing on the deadline	The code is used once for every participant in a group that starts their contribution on the day the mind map is due.
Developing leadership	Category created to group codes related to a participant showing initiative on mind map construction. It involves guidance and intervention in other participants' posts.
Building a skeleton	When a participant starts the mind map by creating the main topics. The initial structure may or may not change in the final product. The person starting the skeleton may or may not be the same person who creates the mind map.
Filling the blanks	When all topics in an initial skeleton are populated and a student contributes on the one topic not filled so far.
Giving directions	A participant specifies how contributions should be made. e.g. "Here's a start. Feel free to edit the look and design" or "pick a colour and start a legend."
Grouping topics	Making a broader topic or category from several topics
Relocating a topic	When participants move a topic, not just visually, but change it's connections and grouping.
Highlighting	Using different visual elements (font, colour, or shape) with the purpose of differentiating a topic or cluster.
Coding with colours	When participants intentionally use colours to highlight a topic
Making aesthetics decisions	* Category created to group changes participants make only for the sake of image (does not add, build, connect, group, or change meaning)
Changing mind map colours	Used when participants select different color schemes for the mind map
Changing the Layout	Used when a participant moves topics around without changing their connections, only for presentation.

Resolving issues	When a participant responds to a technical, content, or activity related inquiry made by another participant
Disagreeing	When participants disagree or do not support other's opinions or comments
Ignoring initial plan	When a participant does not follow an established rule. e.g. ignores colour legend, a skeleton, a question, or a style of participation that other members seem to be following.
Introducing a topic	When a participant starts a new topic in an already populated mind map
Leaving areas blank	When there is evidence of an intention to leave areas blank to be filled by other participants. Could happen in more instances, but this code only applies when there is evidence. e.g. a topic is "tagged" for another student, or a comment is left encouraging others to fill a topic.
Making connections	Includes only when participants make connections to other's posts (not their own). Sometimes, it includes a period of time which the participant spent only making (several) connections
Referring to a class activity	When participants mention and/or reflect on an activity done in face-to-face sessions
Referring to a class resource	When a participants mentions and/or reflects on a class resource
Quoting from a class resource	When a participant quotes directly from a class resource
Sharing life experiences	Category created to group all instances when participants share what they feel/felt or do/did in daily life that is related to class contents and discussion.
Expressing emotions	When participants express (positive or negative) feelings about the contents and class activities
Sharing experiences from placement	When a participant refers to what he or she did during placement or professional practice
Sharing own's work	Applies to every time TCs share their scratch program and/or work done in class or homework
Sharing past experiences with math or coding	Applies to past school experiences, but also to examples of math from everyday life
Using descriptions to expand a topic	When participants build a topic by adding a description or comment rather than new topics branching from it
Using images	When participants add or link an image in lieu of or to expand on text
Using the chat feature	When participants use the chat. Topics may vary, and may include personal messages not related to the course.
Using videos	When participants add or link a video in lieu of or to expand on text

Curriculum Vitae

Name:	Rosa Cendros Araujo
Post-secondary Education and Degrees:	Universidad Rafael Belloso Chacin Maracaibo, Zulia, Venezuela 2003-2008 B.Eng.
	Universidad del Zulia Maracaibo, Zulia, Venezuela 2004-2009 B.Ed.
	Universidad Rafael Belloso Chacin Maracaibo, Zulia, Venezuela 2009-2011 M.Sc.
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