Supporting Professional Learning and Research in a Collaborative Inquiry: A Case Study of a Technology in Mathematics Classroom Assessment Focused Collaboration

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Abstract

This thesis presents findings from a qualitative study of a collaborative inquiry into the use of technology in mathematics classroom assessment. The inquiry included five high school mathematics teachers, two instructional coaches, two technology coaches, and myself—a doctoral student researcher and part-time teacher. In this thesis I examine *what* was learned about using technology in assessment and *how* our learning was facilitated. This study was informed by the premise that our learning could be prompted by our interactions with one another and with different ideas for using technology in assessment (Davis & Simmt, 2003, 2006). For my study of our learning, I analyzed data that were collected from our face-to-face and online (synchronous and asynchronous) communications (e.g., meeting transcripts, my observation reflection notes), and from the materials that participants created and shared (e.g., sample assessment materials, participant-created meeting summaries). I use different lenses to examine this inquiry in three articles that are included in this *thesis by articles*. In the first article I focus on *what* was learned about using technology in assessment. This article shows that participants found that different tools could enrich formative assessment (*as* and *for* learning) by making it possible to improve the immediacy of feedback to teachers and students, to support student self-assessment, and to capture and share student thinking (e.g., video recordings of their solution strategies and/or their thinking about a problem, pictures of their work). Participants also found that technology could support summative assessment (assessment *of* learning) by changing the ways students can demonstrate their learning. In the second article I look at *how* our learning was supported. This article shows that teachers appreciated opportunities to share ideas and resources, and to hear what their colleagues were doing; that online communications helped to enable more frequent sharing between teachers at different schools; and that project leaders, particularly coaches who were in teacher support roles, supported professional learning and inquiry processes by sharing leadership responsibilities and by mediating technical demands on teachers. In the third article I examine my own experiences with navigating multimebership, as a teacher, project leader, and researcher in this collaborative inquiry. These findings show how I experienced internal tensions when it came to leading, learning, and conducting research in this inquiry with my colleagues.

Keywords: Mathematics Education, Educational Technologies, Classroom Assessment, Collaborative Inquiry, Distributed Leadership, Complexity Theory

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Contributions to the Articles

This thesis includes the following three articles. Contributions to these articles included feedback from my supervisor and thesis committee, and from participants who were asked at times to review our findings (e.g., in preparation for a conference presentation, conversations with Shelly, an Instructional Coach).

Lazarus, J. (2020a) *Using technology to enhance mathematics classroom assessment: Findings from a collaborative inquiry*. Unpublished manuscript.

Lazarus, J. (2020b). *Facilitating a technology-focused collaborative inquiry: A case study.* Unpublished manuscript.

Lazarus, J. (2020c). *Leading and learning in a collaborative inquiry: The narrative of my experiences as a researcher and project leader.* Unpublished manuscript.

CHAPTER 1: Introduction

This thesis presents findings from a qualitative case study (Stake, 1995; Yin, 2005) of a collaborative inquiry in which a team of ten educators, including five high school teachers, two instructional coaches, two technology coaches, and myself, as a doctoral student researcher and part-time teacher, explored the use of technology in mathematics classroom assessment. By drawing on the insights of this group of educators and by examining how our learning was supported, this study shows possibilities and considerations for using technology in assessment and for facilitating a technology-focused collaborative inquiry.

I examine a different aspect of this inquiry in each of the three articles that are included in this *thesis by articles*. In the first article I look at what was learned about using technology in assessment. In the second article I focus on the dynamics of the inquiry community, including how our learning was supported. In the third article I examine my own experiences with navigating tensions that arose from my multimembership in this inquiry, as I simultaneously took on the roles of teacher, project co-leader, and researcher. This study of *what* was learned and *how* our learning was facilitated is informed by the premise that practical ideas and creative insights into the use of technology in assessment can arise from participant contributions to a collaborative inquiry and that the emergence of these ideas and insights can be occasioned by supporting conditions for learning in a complex system (Davis & Simmt, 2003).

Goals

My personal goal for this study was to gain a deeper understanding of technology and assessment in mathematics by learning with a small group of educators. The significance of technology is widely accepted in mathematics education. The National Council of Teachers of Mathematics (NCTM, 2014, 2000), for instance, recognizes that technology is essential and that it can influence what and how mathematics is taught and learned.

National and international conference proceedings, large scale assessments, and research literature also reflect the significance of technology for mathematics education. Researchers from around the world, for instance, gathered at the 17th ICMI Study Conference to consider the potential for using technology in mathematics education (Hoyles & Lagrange, 2010). More locally, during a working group session at the 2012 annual meeting of the Canadian Mathematics Education Study Group (CMESG), researchers explored issues related to using technology in mathematics classroom assessment (Buteau & Sinclair, 2012). Participants attempted to create assessment items that are appropriate for a technology-rich classroom environment in which students have access to tools like *Wolfram Alpha,* a computational search engine that will provide full solutions to a range of mathematics questions. While participants acknowledged opportunities provided by such tools, including facilitating mathematics exploration and validation, designing appropriate exam questions was challenging for some people. A key issue reflected in this experience concerns creating items that emphasize mathematics understanding rather than technical skills.

This problem—designing assessment items that elicit mathematics rather than technical proficiency—is recognized by the Organisation for Economic Co-operation and Development (OECD) in a draft framework for the Programme for International Assessment (PISA) 2015. Promoting the use of technology in this assessment, the OECD argued that the need for technology reflects the demands of the 21st century and that technology can allow for assessment items that are more "interactive, authentic, and engaging" (OECD, 2013, p. 28). Like the CMESG working group, however, the OECD found that it can be challenging to distinguish between the mathematical and technical demands of a task. They noted that "a key challenge is to distinguish the mathematical demands of a PISA computer-based item from demands unrelated to mathematical proficiency, such as the information and communication (ICT) demands of the item, and the presentation format" (2013, p. 28).

Such issues with incorporating technology to support mathematics learning and assessment without overwhelming students with technical details emerged in my own practices. In the classroom, my intention is to establish an environment in which students actively contribute to learning and to incorporate technology and assessment activities that align with this intention. My thinking is heavily influenced by my research in the Master of Education program in which I explored how two teachers translated communication messages from curriculum statements into their classroom practices (Lazarus, 2008). This research influenced my intention to promote a math-talk learning when I became a teacher (Hufferd-Ackles, Fuson, & Sherin, 2004). In the classroom I encourage students to explain, ask questions, and take responsibility for their own and each other's learning. In collaboration with my master's thesis supervisor, I explored the possibility of integrating technology to create a blended math-talk learning community by using free online tools to facilitate student communication (see Lazarus & Roulet, 2013a, 2013b). Reflecting on our approach, we found that online tools provided various opportunities for assessment, including a platform for student and teacher feedback, a way to make student thinking visible in dynamic ways, and a place where students could self and peer assess. I was still curious, however, about the implications of technology for assessment. I wished to explore these implications further through graduate study and by collaborating with colleagues.

More attention to technology and assessment is needed in mathematics education research (Stacey & Wiliam, 2013; Trouche, Drijvers, Guedet, & Sacristá, 2013). Some studies highlight benefits of technology for assessment. In their extensive review of technology and assessment literature, for instance, Stacey and Wiliam (2012) highlighted studies that show opportunities for using technology to enable the assessment of more complex mathematical tasks and for developing more authentic, engaging, and interactive assessment tasks. Other research has shown that technology can have a positive impact on student success on mathematics assessments. Hargreaves, Shorrocks-Taylor, Swinnerton, Tait, and Threlfall (2004), for instance, found that when 10 year old students used a computer rather than paper-and-pencil in assessment, there was an overall positive effect on their mathematics performance. Similarly, results from the 2012 PISA computer-based assessments show that students in Canada are more likely (1.11 times) than students across OECD countries to succeed on tasks that require the use of computers to solve problems. In other research, Peltenburg, Heuvel-Panhuizen, and Robitzsch (2010) found that when 8-12 year old students in a special education mathematics program were allowed to use digital manipulatives, they showed more of their capabilities when solving subtraction problems. These students also achieved a higher percentage of correct answers than on standardized test items.

Pierce and Stacey (2010) summarize a variety of opportunities provided by technologies in a *pedagogical map* that highlights benefits for student tasks, for facilitating classroom interaction, and for mathematics. In addition to finding that technology—in this case networked technology (TI-Npire Navigator)—enables the development of innovative mathematical tasks, Clark-Wilson (2010) has shown how technology can help teachers develop and support new and existing assessment practices. More specifically, reports from teachers and classroom observations at seven secondary schools confirmed that technology helped expose students' mathematical thinking (e.g., problem solving processes) and supported peer and self-assessment. The value of technology for exposing student thinking is also demonstrated in Karadag's (2009) doctoral dissertation. Karadag used screen capturing software to record five secondary students' mathematical thinking and problem solving processes in an online dynamic learning environment. Such studies illustrate affordances of technology for designing mathematics tasks, enriching assessment items, and exposing student thinking and problem solving processes. Participants in the collaborative inquiry that is examined in this thesis explored such affordances as they planned, implemented, and reflected on their experiences with using technology in their own classrooms.

Research findings concerning issues that technologies pose in assessment are limited (Trouche et al., 2013). Some researchers have explored how to evaluate student work in a technology-rich environment (Hernandez-Sánchez, 2009 cited in Trouche et al., 2013). Other studies identify important implications for teaching practices in a technology-rich classroom. Clark-Wilson (2010) found that a networked classroom demands a new role for teachers, particularly with respect to managing increased amounts of student data. In addition to the new demands on teachers, Thomas and Palmer (2014) identify resources, training, and teacher confidence as major issues influencing the implementation of technology in mathematics teaching and learning. In agreement with Jaworski (2003), these researchers argued that to increase confidence, teachers need opportunities to collaborate in a “community of inquiry” in which they observe, practice, and reflect on the use of technology in classroom practice (Thomas & Palmer, 2014, p. 86). This position was foundational to my research design, with participants being encouraged to support one another as they grappled with the use of technology in assessment.

This study was designed to support the assumption that teachers are key stakeholders in educational research. Even though various stakeholders in mathematics education recognize the significance of technology, teachers are the key stakeholders who directly influence teaching and learning (Kieran, Krainer, & Shaughnessy, 2013). Their involvement was important because despite decades of research and curriculum emphasis, technologies have had little influence on classroom practice and, more specifically, on classroom assessment (Clark-Wilson, Robutti, & Sinclair, 2014; Stacey & Wiliam, 2014). The significance of the disconnect between technology-focused research and practice is reflected in an international focus on professional learning in the digital era (see Clark-Wilson et al., 2014). Teachers also bring valuable practical and scientific insights from the field to the study (Kieren, Krainer, Shaughnessy, 2013). With a collaborative inquiry, I aimed to draw on these insights in order to promote a study that would be more directly relevant to practice.

My interest in connecting research and practice in a collaborative inquiry stems from collaborative learning experiences that I encountered as a classroom teacher. By working with my master's thesis supervisor when I was teaching high school mathematics, I gained feedback and reflected more deeply on my practices. Participating in professional learning communities (PLCs) with my colleagues was also valuable for providing opportunities to reflect on experiences with people who worked in similar contexts. A PLC approach to teacher learning is important because unlike episodic forms of professional development, teachers look collaboratively at student and school data and to "....take collective responsibility for students' learning" (Cochran-Smith & Lytle, 2009, p. 49). My view of learning in a PLC is aligned with my view of learning in this inquiry. The theoretical assumptions that informed this study and the collaborative inquiry approach is outlined next.

Theoretical Framework

All researchers approach a study with ideas and foci that can come together to form a theoretical (or conceptual) framework (Miles & Huberman, 1984). In this section I highlight the underlying complexity theory perspective on learning in a complex system (Davis & Simmt, 2003, 2006) and I frame my thinking about the two overall foci in this study: (i) on conditions for learning in a collaborative inquiry, and (ii) on the collective knowledge of technology in mathematics classroom assessment in this inquiry community.

Complexity Theory

In the year 2000, Stephen Hawking deemed the upcoming century "the century of complexity." Complexity, a theory of adaptation and change, emphasizes emergence through distributed control, self-organization, and collective cognition (Davis & Simmt, 2006; Johnson, 2001; Morrison, 2006). There is no single complexity theory; all versions, however, emphasize that a complex system is "comprised of a large number of entities that display a high level of nonlinear interactivity" (Richardson & Cilliers, 2001, p. 8). Complex phenomena are adaptive (they can change their own structures) and emergent (they arise from interactions among their parts) (Davis & Simmt, 2003). Such qualities are illustrated in the emergent and adaptive nature of ant colonies, cities, our brains, and even the web (Johnson, 2001; Johnson, 2003).

The theory is relatively new to educational research, yet it has been used to describe different types of complex systems in mathematics education. Davis and his colleagues, for instance, argued that mathematics knowledge (Mowat & Davis, 2010), the knowledge that teachers require in order to teach mathematics (Davis & Simmt, 2006; Davis & Renert, 2014), and even mathematics communities (Davis & Simmt, 2003), can be considered complex systems. A key feature of the systems that are highlighted in these examples is the assumption that the whole is greater than the sum of its parts, whether the parts consist of people, ideas, or even ants (Davis & Simmt, 2003; Morrison, 2006). In a classroom that supports math-talk learning (Hufferd-Ackles, Fuson, & Sherin, 2004), for example, collective learning emerges as students ask each other questions, react to ideas, expand on each other's thinking, and share responsibility for learning. Mathematical ideas emerge and evolve through student contributions but are bounded by things like the teacher's goals, mathematics tasks, and time.

This study is informed by Davis and Simmt's (2003) research, which exemplifies how concepts and vocabulary from complexity science can be used to describe mathematical communities. More specifically, I considered the inquiry community to be a *learning system*; an "adaptive, self-organizing phenomenon" (Davis & Simmt, 2003, p. 138). In other words, this study is premised on the perspective that our learning would take shape as educators interact with one another and with different ideas for using technology in assessment.

Learning is understood "in terms of ongoing, recursively elaborative adaptations through which systems maintain their coherences within their dynamic circumstances" (Davis & Simmt, 2003, p. 138). Since there are multiple layers of learning in a complex system, including what is learned by individuals versus what is learned by the collective, Davis and Simmt emphasize the importance of clarifying the nature of a complex unity that is being considered. In their discussion of mathematical communities, for instance, "these complex unities [included] shared mathematical ideas, insights, concepts, and understandings that collectively constitute a body of mathematical knowledge in the classroom" (Davis & Simmt, 2003, p. 152). Extending this notion to the inquiry community, I consider the shared *ideas* for using technology in assessment, *insights* into problems that are posed by the use of technology, and *understandings* of technology and assessment, to constitute a body of knowledge of technology in assessment in this community.

In the first article that is included in this thesis (Chapter 3) I look at the body of knowledge with respect to technology in assessment that emerged from this collaborative inquiry. This focus has implications for the scope of my study. More specifically, this is a study of the ideas, insights, and understandings that evolved from participants' contributions to our face-to-face meetings and to our online communications. Even though this knowledge draws on the teachers' knowledge and on their descriptions of their practices, individual teacher knowledge and what actually happened in classrooms is beyond the scope of this study. Therefore, the description of *what* was learned from this inquiry focuses on the body of knowledge that emerged from participant contributions during this inquiry.

Conditions for Learning in a Collaborative Inquiry

It is widely accepted that a primary purpose of educational research is to inform practice yet there are different perspectives on how to do this (McMillan & Schumacher, 2006). Like Goos (2014) and Kieran, Krainer, and Shaughnessy (2013), I aimed to bridge the gap that is often seen between research and practice by supporting collaborative research relationships in which teachers contribute to theoretical and practical understandings of the phenomenon of interest (in this case of the use of technology in assessment).

My approach was informed by the work of others who have engaged in practitioner inquiries and collaborative action research projects in which teachers and researchers learn and grow together (e.g., Bruce, Flynn, & Stagg-Peterson, 2011; Bruce, Jarvis, Flynn, & Brock, 2011; Herbel-Eisenman & Cirillo, 2009; Lachance & Confrey, 2003). Teachers in such projects co-construct research questions, investigate solutions to classroom problems, collect and analyse data, and share responsibility for growth and critical reflection (Bruce, Flynn, & Stagg-Peterson, 2011, p. 434; Capobianco, 2007, p. 6). These studies connect researchers and teachers to contribute to research and practice. Likewise, through a collaborative inquiry, I aimed to connect my research with the professional learning in this collaborative inquiry. My research plans influenced our inquiry activities and our inquiry activities influenced my research plans.

One aspect of this thesis is to describe *how* our learning was supported. In this case, the inquiry was structured to promote participants' shared responsibility for our learning. Davis and Simmt (2003) have described how a teacher can aim to promote students' shared responsibility for learning in a mathematics learning system:

> The system itself "decides" what is and is not acceptable. Pragmatically speaking, with regard to the emergence of shared mathematical insight, this means that the teacher cannot position herself or himself (or a textbook or a curriculum document) as the final authority on matters of appropriateness or correctness. Structures can and should be in place to allow students to participate in these decisions. For us, then, a key element in effective teaching is not maintaining control over ideas and correctness, but the capacity to disperse control. (p. 153)

Likewise, the intention in this case was to provide structures that would enable participants' contributions to the emergence of shared insights into the use of technology in mathematics classroom assessment. In this case, particular conditions for learning in a complex system informed the inquiry design.

Connecting qualities of complex systems from other fields (e.g., Capra, 2002; Johnson, 2001; Waldrop, 1992) to mathematics education, Davis and Simmt (2003; 2006) described five interconnected conditions that are essential, but not necessarily sufficient, for prompting and bounding the emergence of activities in a learning system: internal diversity, redundancy, organized randomness, decentralized control, and neighbour interactions. *Internal diversity* is represented in the different attributes members bring to the system. This diversity, which may include for example, the different interests and expertise that people bring to a professional learning group, is important for stimulating new ideas and creative solutions. *Redundancy* is found in the common characteristics shared by members of a group, such as in a common language or shared experiences that everyone can relate to. While diversity is important for stimulating new ideas, redundancy is essential for enabling interactions. O*rganized randomness* is given by a common focus or goal that provides structure for activities and is at the same time open to the emergence of unanticipated directions. Individuals may focus on a particular topic in a teacher learning group, for instance, but by learning from each other about this topic, unanticipated directions will emerge. Organized randomness is necessary for balancing diversity and redundancy in a system. *Decentralized control* means that everyone shares responsibility for learning in a complex system and that no one person is in charge. In a teacher learning group, for example, this might mean that an administrator or teacher is not directing activities but that everyone participates equally. *Neighbour interactions* means that different ideas should "bump against each other" (Davis & Simmt, 2006, 156). For instance, one teacher may share something he or she does in the classroom and another teacher may build on this by contributing something relevant from his or her experiences. This study embraces the position that the emergence of new insights and creative solutions to problems encountered in practice are facilitated by these conditions of complex systems (Davis & Simmt, 2003).

These conditions have been applied in research and are referenced in teacher resources. Goos and her colleagues (2010) and Sinclair (2006), for example, used these conditions as a framework to analyse Sinclair's experiences with teaching with technology (Goos et al., 2010; Sinclair, 2006). They found that technology become an "element of a learning system" and the teacher's role in this system is to "organize conditions for emergence of a mathematical community" (2010, p. 321). In a monograph to help connect research and practice, Stanley (2009) explained how the classroom is a complex system. He suggested that in order to enhance student learning, teachers should support Davis and Simmt's (2003) conditions for complexity. I describe these conditions in more detail below, in connection with participant selection and relationships in this study. I also highlight connections between these conditions and my focus on what was learned about the use of technology in assessment (Chapter 3) and about how our learning was supported in this collaborative inquiry (Chapter 4).

Collective Knowledge of Technology in Mathematics Classroom Assessment

In this thesis I examine what was learned about using technology in mathematics classroom assessment (see Chapter 3). Effectively integrating technology in assessment requires particular professional knowledge of mathematics, pedagogy, technology and, in this case, of assessment. The complexity of the knowledge that is necessary for teaching has been recognized for some time. In 1986, Shulman acknowledged that content knowledge alone is not enough. He argued that teachers also need pedagogical content knowledge (PCK). Since then, different conceptualizations of teacher knowledge have been considered. In mathematics education, researchers offered theoretical discussions and research to examine the knowledge that is necessary for teaching mathematics (e.g., see Ball & Bass, 2003; Ball, Thames, & Phelps, 2008; Davis & Renert, 2014; Davis & Simmt, 2006). Davis and Simmt (2006) argued, in a theoretical discussion informed by complexity science, that "mathematics-for-teaching" is qualitatively different from the mathematics that students are expected to learn. These researchers propose that mathematics-for-teaching might even be considered a distinct branch of mathematics. The key point, however, is that the professional knowledge that is necessary for teaching mathematics is complex and includes more than content knowledge alone.

When it comes to using technology in mathematics classrooms, Thomas and Palmer (2014) have used the term *pedagogical technology knowledge* (PTK) to acknowledge the need for teacher proficiency with technology, and to understand the principles and techniques that are necessary for incorporating it in practice. Other researchers have used the terms *technological pedagogical content knowledge* (TCPK) or TPACK (Mishra & Koehler, 2006; Koehler & Mishra, 2009). Technical knowledge, including proficiency with different tools and techniques for incorporating them in mathematics classroom assessment, was an important aspect of professional knowledge in this inquiry. Thus, using *technology in mathematical assessment knowledge* (TMAK) to emphasize the assessment focus, might be appropriate for describing the teacher knowledge that is required to incorporate technology in mathematics classroom assessment. My point here is that the knowledge that is required for teaching mathematics and for incorporating technology in assessment is complex. It includes, for instance, pedagogical, content, technical, and assessment knowledge. My description of the participants in this study shows that there was a range in terms of the relevant knowledge and experiences that individuals brought to this inquiry.

In developing my own thinking about technology and assessment I encountered different perspectives in the literature and in practice. The importance of clarifying and bounding my focus became obvious. In this study, I leaned on a distinction offered by both Buteau and Sinclair (2012) and Stacey and Wiliam (2014). Buteau and Sinclair distinguish between using technology *to assess* and using technology *in assessment* (2012, p. 96). In the first case, the teacher uses technology *to assess* student learning. Automated scoring systems may be used, for example, to score student responses to mathematics questions. Technology in this case can improve item presentation, the type and immediacy of feedback, and how students interact with assessment items. On the other hand, students may use technology *in assessment*. With access to technology, students may explore concepts and use skills that are difficult or impossible to assess without it. Such affordances of using technology *in assessment* were considered in this inquiry.

In Ontario, Canada, the context for this study, policy documents draw on assessment literature (e.g. Assessment Reform Group, 2002; Harlen, 2006; Western and Northern Canadian

Protocol for Collaboration in Education, 2006) to recognize three approaches to classroom assessment: assessment *as* learning, assessment *for* learning, and assessment *of* learning (Ontario Ministry of Education, 2010, p. 29). Traditionally, assessment *of* learning has been emphasized but more attention should be given to assessment *as* and *for* learning (Earl, 2013; Ontario Ministry of Education, 2010). According to Earl, students are the primary assessors in assessment *as* learning as they self-monitor and self-correct in relation to personal goals and external standards. Assessment *for* learning is an interactive process carried out to support student learning. The teacher is the primary assessor who uses evidence of student learning in relation to a specific goal to inform instructional decisions. Assessment *of* learning is typically carried out by the teacher at the end of a unit, course, or grade. The purpose is to judge student learning and to place or promote students. While these three approaches are not necessarily independent, they were used to frame our thinking about the use of technology in assessment (see Chapter 3).

Research Questions

In order to gain a deeper understanding of the use of technology in mathematics classroom assessment and of how a technology-focused collaboration can be facilitated, the following research questions were addressed in this study:

- *What* was learned about the use of technology in assessment through a collaborative inquiry?
- *How* was our learning supported in this technology-focused collaborative inquiry?
- How did I, as a researcher and project leader, navigate tensions that emerged as I engaged in this professional learning and research collaboration with my colleagues?

Significance of the Study

This area of study is significant and findings from this particular study are valuable to members of the mathematics education community, including researchers, teachers, individuals in teacher support roles (e.g., instructional coaches), and curriculum consultants. First, there is a need for research that focuses on technology and assessment in mathematics (e.g., see Stacey & Wiliam, 2014) and on the conditions that can support teacher learning about the use of technology in mathematics classrooms (e.g., see Goos & Bennison, 2008). In addition to contributing to research, the collaborative nature of this study contributed to practice by presenting an opportunity for a group of educators to collectively grapple with using technology to support their assessment practices. The three articles in this thesis include both research insights and practical ideas for using technology to enhance and possibly even transform assessment practices, and for supporting a technology (in assessment) focused collaborative inquiry.

Research Design and Thesis Structure

Given the emergent nature of this study, I used an interactive research design (Maxwell, 2013). Unlike more linear and prescriptive approaches, this design "does not begin from a predetermined starting point or proceed through a fixed sequence of steps, but involves interconnection and interaction among the different components" (Maxwell, 2013, p. 3). The above research questions, which are at the heart of this design, are the main link between the conceptual components (goals and theoretical framework) and operational elements (methods and validity) of this study. Maxwell (2013) described the flexibility of this design in terms of stretching rubber bands:

> The connections among the different components of the model are not rigid rules or fixed implications; they allow for a certain amount of 'give' and elasticity in the design. I find it useful to think of them as rubber bands. They can stretch and bend to some extent, but they exert a definite tension on different parts of the design, and beyond a particular point or under certain stresses, they will break. The 'rubber band' in which there are constraints imposed by the different parts on one another, constraints which, if violated, make the design ineffective. (p. 5)

His description highlights the elastic nature of this design; it offers a structure that at the same time embraces emergence. Thus, the design is what Davis and Simmt (2003) might call "proscriptive" rather than prescriptive: it provides boundaries and is at the same time flexible to the emergence of unanticipated directions (Davis & Simmt, 2003). The components of my research design (and the articles in this study) are summarized in Appendix A.

There are six chapters in this thesis. The first two chapters address the research design. The more conceptual components of this design, which include the study goals and theoretical framework, were discussed in Chapter 1. The more operational components are presented in Chapter 2, which outlines the methods and identifies potential threats to the credibility of my conclusions. The next three chapters include articles in which I examine the collaborative inquiry from different lenses. In the first article (Chapter 3) I look at what was learned about using technology in mathematics classroom assessment. In the second article (Chapter 4) I examine the dynamics of this collaborative learning system and I describe how professional learning and inquiry processes were supported. In the third article (Chapter 5) I illuminate my own experiences as an insider/outsider navigating multiple roles (teacher, researcher, project leader, and learner). In the final chapter, I present a synthesis of the articles and a summary of the implications of this study for mathematics education research and practice.

CHAPTER 2: Methods

This chapter outlines the procedures and methods that were employed to address my research questions. First, I justify and describe the qualitative case study approach (Stake, 1995; Yin, 2009). Next, I discuss participant selection and relationships. In the third section I explain how data were collected and analysed. This chapter concludes with an account of the strategies that I used to enhance the credibility of my findings.

A Case Study

A case study approach (Stake, 1995; Yin, 2009) was used to gain an in-depth understanding of this collaborative inquiry. A qualitative case study seeks a rich understanding of a case (Stake, 1995). Through this case study, I wished to understand how a team of educators can grapple with using technology to support their mathematics classroom assessment practices. This case is instrumental since my interest in *what* was learned and *how* our learning was supported was more dominant than my interest in the specific case itself (an intrinsic case) (Stake, 1995). Through "thick descriptions" of our learning, my intention is to contribute "experiential understandings" (Stake, 1995, p. 43) that provide insight into the use of technology in assessment and into how similar inquiries can be supported.

A case study approach is valuable when research focuses on contemporary events and requires no control of behaviour events (Yin, 2009). The approach was used in this study to gain insight into the real life activities of a collaborative inquiry system. Given the collaborative nature of this inquiry and the underlying complexity theory perspective, I assumed that collective learning processes in this context might be prompted, bounded, and even nurtured, rather than caused, controlled, or directed (Davis & Simmt, 2003). A case study approach was important for examining the learning that emerged.

A case is defined by Stake (1995) to be "a specific, a complex, functioning thing"; it is a purposefully bounded system with working parts (p. 2). In this context, the case was a collaborative learning system and its purpose was to explore the use of technology in mathematics classroom assessment. A case study approach was important for allowing me to focus on the learning that emerged and to, at the same time, appreciate the uniqueness, complexity, and embedded and interactive nature of a case (Stake, 1995). Thus, the case study approach aligned with the complex and interactive nature of a collaborative learning system (Davis & Simmt, 2003).

A "somewhat indeterminate boundary defines the edge of the case: what will not be studied" (Miles & Huberman, 1994, p. 25). The boundary for this case included individual participant knowledge and experiences outside of the inquiry. More specifically, I focused on ideas and interactions that were shared at inquiry group meetings and subgroup meetings, or online between meetings. I did not study individual teacher knowledge or shifts in actual teaching practices. Also, since the focus was on collective professional knowledge, student experiences were beyond the scope of this study. At times, teachers shared evidence of classroom practices. This evidence was valuable for supporting professional learning but was not examined for my research purposes.

The following description of participants and relationships will show that this was a unique case, with diversity reflected in the range of institutional roles and participant attributes (e.g., comfort with technology, teaching experience). In this case, a somewhat heterogeneous group of educators worked together to learn about the use of technology in assessment.

Participants and Relationships

Ten educators from across one school district, including two instructional coaches, two technology coaches, five teachers, and myself, in a dual role as a teacher and doctoral student researcher, participated in this inquiry. As a part-time high school teacher during the 2014-2015 school year, I received a call for technology innovation project proposals. I, along with an instructional coach Patricia (all participant names in this thesis are pseudonyms), submitted a proposal that aligned with my research goal—to explore the use of technology in mathematics classroom assessment. The project was approved for the 2015-2016 school year and we invited Shelly, another instructional coach in this district, to participate. Two technology coaches were assigned by the technology department to support our activities. In the Fall of 2015, Patricia, Shelly, Brent, Sarah, and I met to discuss the project goals and possible teacher participants.

Purposeful sampling (Maxwell, 2013; Miles & Huberman, 1994) was used to identify possible teacher participants. We used the conditions for complexity (Davis & Simmt, 2003, 2006) as criteria to guide our selection. More specifically, we were looking for teachers who were teaching at least one high school mathematics course, who brought different backgrounds and experiences with technology to the project, who were willing to travel to a central location for face-to-face meetings, and who shared an interest in learning to use technology in mathematics classroom assessment. These conditions for complexity, in connection to the participant selection criteria, are summarized in Table 1.

***Table 1.* Participant Selection Criteria**

Condition	Criteria
Redundancy	Supporting the same Mathematics Curriculum (OME, 2005; 2007) in the same school district.
Internal Diversity	Offering different backgrounds and experiences with using technology, and supporting mathematics teaching and learning in different schools.
Neighbour Interactions	Willing to travel to a central location for full day face-to-face meetings and to participate in online (Google Hangouts) meetings
Decentralized Control	Working together to support our professional learning and the inquiry activities. No individual(s) in charge of directing activities.
Organized Randomness	Structuring activities by a shared focus on using technology to support mathematics classroom assessment. Participants chose individual foci that fit within this broad shared focus.

Network sampling (Creswell, 2013; Miles & Huberman, 1994), with participant referral (in this case from the coaches), was the basis for locating teacher participants. After discussing project goals and the conditions for complexity, coaches identified possible teacher participants. These teachers were invited by email. The first five teachers who expressed interest in participating, joined the inquiry. Once university ethics approval was received, all participants were invited to become part of the research. Everyone agreed. Data collection began once I received signed copies of the Consent Form (Appendix C).

Relationships between the participants are illustrated in Figure 1.

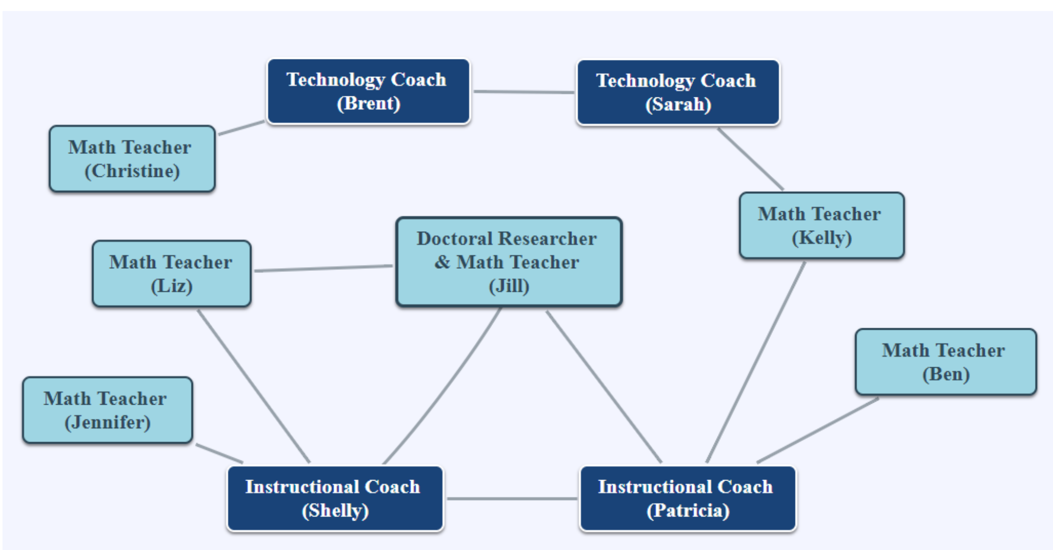


***Figure 1.* Participant relationships**

Patricia took the lead when it came to facilitating the inquiry group meetings. As an instructional coach responsible for supporting teachers, she worked in schools with Ben during the first semester and with Kelly during the second semester. Shelly was an instructional coach at the school that I was teaching at during this inquiry. I also worked closely with Shelly on other projects prior to this school year. For this project, Shelly was involved in co-planning for group meetings and she often met with me between meetings, to offer classroom support and to reflect on the project findings as they emerged. Shelly also worked closely with Jennifer and Liz as an instructional coach at their schools. During our inquiry group meetings, Shelly often recorded notes in a shared online document. She also asked questions, helped to summarize ideas, and elicited connections between ideas. Sarah was the primary contact from the technology department. She helped co-plan for some of our meetings, particularly early on, and she offered ideas and support during meetings. Sarah also worked with teachers in schools, particularly with Kelly. Brent, also a technology coach, attended some of the group meetings and offered technical support and advice. He also worked with teachers at their schools. During this project, he worked more regularly with Christine. Everyone except for Ben, who taught mathematics only during the first semester, participated in the project for the entire school year.

In order to support the emergence of a professional learning community, conditions for complexity informed the participant relationships. To support *neighbour interactions,* participants were encouraged to share and to explore different ideas, assessment policies, technologies, and classroom experiences. I aimed to have participants draw on one another as resources as they explored the use of technology in mathematics classroom assessment. *Internal diversity* was promoted by the different backgrounds and experiences that participants brought to the group. By involving teachers who were all teaching high school mathematics and instructional and technology coaches who were in teacher support roles in the same district, as well as the shared focus on using technology in mathematics classroom assessment, I aimed to promote *redundancy.* By supporting this condition, my intention was to facilitate interactions and to maintain a common focus.

To help *decentralize control*, we planned for opportunities to negotiate our collective focus and to offer opportunities for teachers to create individual goals (see Chapter 3). Teachers shared their classroom strategies and solutions to problems that they encountered when technology is used in practice. They were also involved in sharing our findings outside of the inquiry group (e.g., during informal conversations with other teachers, with other educators in the district, by presenting findings at a provincial conference for mathematics teachers). Involving teachers in various aspects of the inquiry is a strategy that I adapted from other collaborative inquiry and action research projects. For example, Herbel-Eisenmann and Cirillo's (2009) research involved teachers in observing lessons, participating in research group meetings, selecting and discussing literature, designing cycles of action research, keeping reflective journals, and presenting findings at conferences. More locally, in a large-scale collaborative action research project that was carried out with elementary teachers in Ontario, Canada, teachers engaged in cycles of action research in which they explored teacher-selected topics, and collected and analysed classroom-based evidence (Bruce, Flynn, & Stagg-Peterson, 2011; Bruce, Jarvis, Flynn, & Brock, 2011). Even more recently in Ontario, distributed control was reflected in a large scale project that involved 10 school-based professional learning communities from across the province to focus on Grade 9 Applied Mathematics (Suurtamm et al., 2017). The importance of distributed control is reflected in a report on how professional learning was supported in these professional learning communities (McKie, Suurtamm, and Lazarus, 2017). These research findings suggest that distributed leadership, rather than top-down leadership, was supported in the most successful professional learning communities. I aimed to support this view of leadership in the inquiry that is described in this thesis (see Chapter 4 for an analysis of the ways leadership was distributed).

The collaborative inquiry group provides a rich case for this thesis. Firstly, the group was formed to support the conditions for learning in a complex system (Davis & Simmt, 2003, 2006), which allowed me to examine the knowledge and learning processes that might emerge in a technology-focused collaborative inquiry system. The case was also unique, with diversity reflected in the range of institutional roles (teachers, researcher, coaches) and participant attributes (e.g., teaching experiences, comfort with technology, goals and interests), yet a common interest in developing assessment practices with technology. This diversity made it possible to examine interactions in a range of ideas (e.g., perspectives on the use of technology, classroom strategies) and insights (e.g., reflections on practices, possible solutions to problems that teachers encounter in practice) and to look at how a heterogeneous group of educators might work together in a technology-focused inquiry. This case offers insight into the ways teachers might use technology to support particular assessment purposes and how this kind of an inquiry might be supported. Since the project was funded, the group was able to meet several times over the course of almost an entire school year (approximately eight months). Therefore, I was able to collect and analyse data from our face-to-face and online communications for an extended period of time.

Data Collection and Analysis

Qualitative methods were valuable for gaining insight into the "real life" activities of this case (Eisner, 1991). Through a qualitative analysis of the learning that emerged in this collaborative learning system, I aimed to gain insight into how teachers can use technology in assessment and how a technology-focused collaborations can be supported. Creswell (2013) has explained that such insights are established only by talking with people directly, by listening, and by being open to their stories, even when these stories do not reflect what we expect to hear or what is found in the literature. In this case, qualitative data—including my observations of inquiry group meetings, my reflections on group meetings that were recorded in my research journal, audio records and transcriptions of group meetings, coaches' meeting notes that were shared with the group, artefacts created by participants and shared with the group, documents that were posted by participants in shared learning spaces (e.g. Google Drive folder, Google Site website, Padlet), and project-related emails between participants—were employed to examine the learning that emerged from this technology in assessment focused collaborative inquiry. These data were collected throughout the inquiry.

Data were collected and analysed simultaneously, beginning in November, 2015 and ending in June, 2016. These data were collected primarily from three audio recorded face-to-face meetings and from two online synchronous (Google Hangout) group meetings. Materials that participants shared online at and between the group meetings (e.g., meeting notes, sample assessment activities) were also analysed. At times, individual and smaller group meetings arose between the group meetings (e.g., with coaches to plan for meetings or with smaller groups of participants to prepare for presentations). Data were collected from these activities, only when the purpose of the meeting was relevant to this study and participant approval was received. See Appendix C for a more detailed summary of the data collection activities and data sources.

Layers of Inquiry

I engaged in multiple intertwined layers of inquiry simultaneously. One layer involved our collaborative inquiry activities and another layer involving my research activities. This project connected a district-level technology innovation inquiry project with my doctoral research. Firstly, there was a collective inquiry that involved 10 educators (including myself) in exploring strategies for using technology to support mathematics classroom assessment. Secondly, the same study was used as my doctoral research to examine the professional knowledge and inquiry processes that emerged. By participating in these simultaneous inquiries as a researcher and a teacher, I interacted with relevant ideas in different ways. As a teacher, I was able to try things out with students in a mathematics classroom. As a graduate student, I engaged with relevant theory and research. In the collaborative inquiry, the learning system that is at the heart of this study, I learned with participants while at the same time carried out a qualitative case study of our findings.

My Research. To support the premise that interactions are essential to prompting emergence in a learning system (Davis & Simmt, 2003), I aimed to design a study with a flexible structure to bound my research activities and simultaneously embrace the emergence of unanticipated directions. I adapted Simon's (1995) *Mathematics Teaching Cycle* (p. 136) to a *Research Cycle* (representing the interactive constitution of my research activities) with a *Collaborative Inquiry Cycle* (representing the interactive constitution of our inquiry activities). These cycles are illustrated in Figure 2.

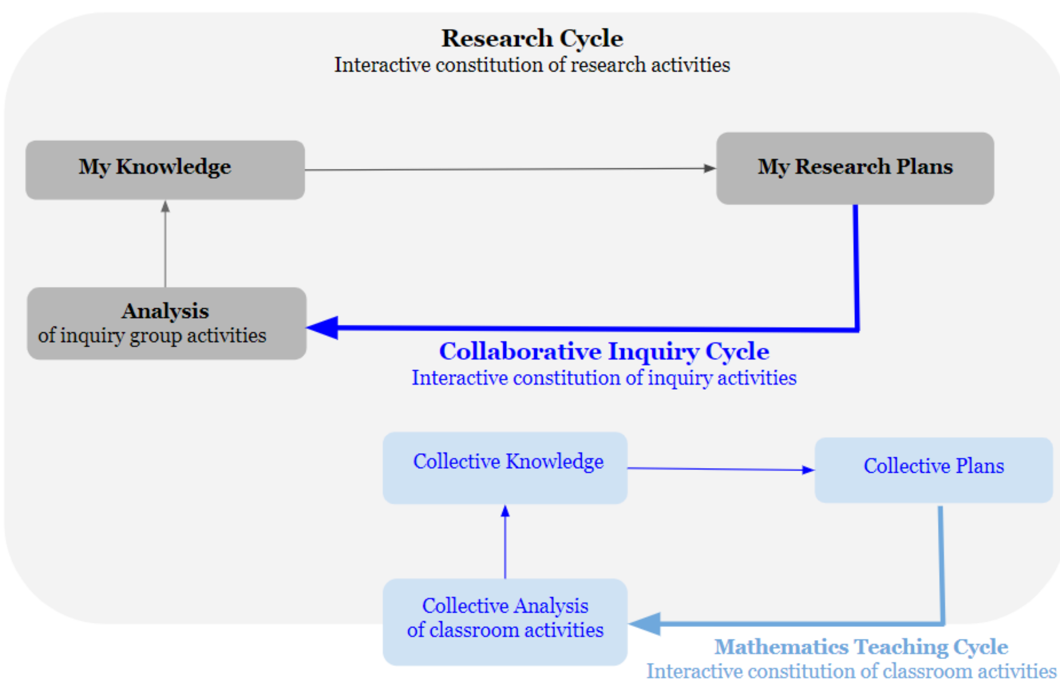


Figure 2. **Research Cycle: Interactive Constitution of Research Activities**
Adapted from Simon's (1995) "Mathematics Teaching Cycle."

Simon's *Mathematics Teaching Cycle* aligns with my view of what it means to grow and learn in a complex system. His cycle "emphasizes the important interplay between the teacher's plans and the teacher and students' collective constitution of classroom activities" (Simon, 1995, p. 141). Similarly, in my study design, the *Research Cycle* emphasizes the interplay of my research plans and participants' collective constitution of activities in the practitioner inquiry group.

The *Research Cycle* shows that my research plans were informed by my knowledge and that my knowledge (and therefore research plans) evolved as I analysed the interactions that arose in the field. My knowledge would include my knowledge of technology in assessment and of collaborative inquires (e.g., from my teaching experiences, from research literature). I gained new knowledge, however, as I analysed the interactions that emerged in the field. My ongoing analysis of the data that were collected (e.g., reflections in my research journal, meeting summaries and observations that I documented, transcriptions of the audio-recorded meetings) informed my knowledge of learning that had emerged in the inquiry group and therefore contributed to subsequent research process and, in the end, to the findings that are included in this dissertation. By using my analysis to inform data collection in this way, my intention was to expose any "blind spots" or unanticipated activities and to therefore improve the quality of my conclusions (Miles & Huberman, 1994, p. 49). This cycle of adapting my research plans (e.g., my goals, planned activities) as I gained new knowledge from my analysis of our interactions continued throughout this study.

Our Collaborative Inquiry. My research was carried out simultaneously with the collaborative inquiry project. Since our inquiry plans were also not knowable in advance, I adapted the *Collaborative Inquiry Cycle* (see Figure 3) to conceptualize the interplay of our collective professional knowledge of technology in assessment, our collective inquiry plans, and the analysis of our experiences that contributed to the emergence of new knowledge (e.g., new insights into the use of technology in assessment).

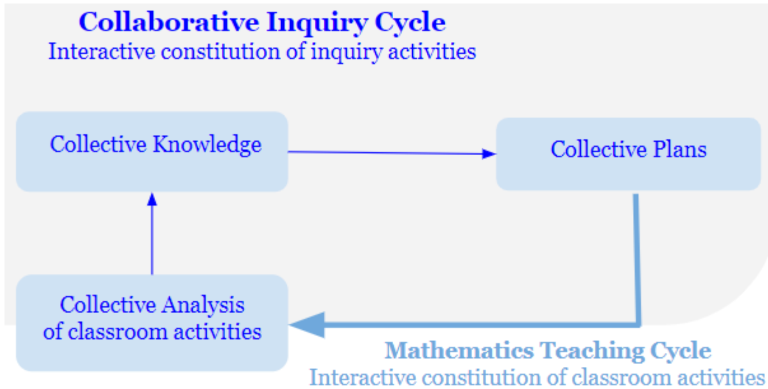


***Figure 3.* Collaborative Inquiry Cycle: Interactive Constitution of Inquiry Activities**
Adapted from Simon's (1995) "Mathematics Teaching Cycle."

This *Collaborative Inquiry Cycle* represents the interplay of the inquiry groups' classroom inquiry plans and the collective constitution of our classroom experiences. More specifically, it shows that this inquiry was designed so that our professional knowledge (e.g., of technology and assessment, of facilitating a collaborative inquiry) informed our inquiry plans (e.g., goals, planned classroom activities) and that the new knowledge we gained by reflecting on and assessing our experiences informed our subsequent plans. Participants were actively involved in contributing to our collective focus and overall plans, and in reflecting on classroom evidence (e.g., observations, assessment activities, photographs, or video recordings of students working with technology). The value of visual classroom evidence for promoting rich collaboration in the group is demonstrated by Bruce, Flynn, and Stagg-Peterson's (2011). These researchers found that when teachers shared visuals they were "more excited about their collaboration, had greater ownership over the process, and were willing to take more risks in trying new strategies in their teaching" (p. 446). Even though classroom evidence might be valuable for a collaborative inquiry, my research focused on our learning rather than on student learning. Therefore, I did not collect classroom evidence for my research. In this thesis, I refer to *our* collaborative inquiry as the district project activities. When I refer to *my* research, I am referring to my study of the learning that emerged in this inquiry.

Data Collection

Data were collected from the formal research activities (e.g., planned meetings) and informal activities (e.g., unplanned meetings with individual participants) that emerged over the course of the study. A summary of these activities and the data that were collected is provided in Appendix D. The inquiry activities were more complex than the *Collaborative Inquiry Cycle* illustrates and there was considerable overlap between the components of this model. The model was helpful, however, for structuring our activities and my data collection activities. I used the stages in this cycle to structure data collection. These stages included generating collective knowledge, planning for classroom activities, and examining (analysing) our experiences.

Stage 1: Generating Collective Knowledge. The purpose of this stage, which was the main focus of the first full-day audio-recorded face-to-face group meeting, was to establish rapport and to generate a collective knowledge of technology in mathematics classroom assessment. In order to start to develop a sense of community, it was important to include time (before the formal part of the meeting and during lunch time) for participants to talk informally about their lives outside of the project (Herbel-Eisenmann & Cirillo, 2009). To open up our conversation about technology in assessment, participants took turns introducing themselves and sharing their interests, questions, classroom experiences, and what they are noticing at their schools.

The first meeting also involved participants in negotiating a shared focus on using technology to support specific purposes of assessment: assessment *as, for,* and *of* learning (Ontario Ministry of Education, 2010). First, the group split up into three subgroups. Each subgroup analysed assessment policy statements and literature that connected to one of the purposes (Earl, 2013; Ontario Ministry of Education, 2010). They recorded key ideas in a shared online document (see Appendix D for a copy of this document) and then summarized these ideas for the group during a follow-up discussion. Next, the group considered different technologies that were accessible to all teachers in this context. They generated ideas for using each tool to support the purposes of assessment. Shelly and Sarah recorded the ideas that emerged in a shared document (see Figure 4).

	Technology					
	Plickers	**Desmos**	**MyScript Calculaor**	**Padlet**	**Kahoot**	**Nearpod**
As		- students can self check their work or peers (using comments)	- in some ways it's replacing the answer key (not higher order thinking)			
For	- beginning as a diagnostic - quick check on learning - more about group understanding vs individual understanding	- students are investing on their own (i.e. relationships) and use AirPlay to share				-beginning as a diagnostic -quick check on learning -to gather individual and group data (by student and by item)
Of		- can print screen and use graphs for assessments of learning				
			does not lend itself to assessment as much as it is an instructional tool			
Overview:	www.plickers.com	www.desmos.com		www.padlet.com	www.kahootit.com to play www.getkahoot.com to make	
	- app (information on website)	- app but also web based	- app	- web based & app		
	- simple tool to collect real-time assessment data	- free online graphing calculator	-handwriting calculator	- a collaborative space to share resources or thinking	-can highlight individual solutions	
		- does not need to be y=mx+b format				

Figure 4. **Co-Constructed Technology in Assessment Framework**

Even though the first meeting started by establishing a shared focus, the collective professional knowledge of technology in assessment continued to evolve over the course of the inquiry. My analysis of this knowledge is presented Chapter 4. The article in this chapter includes a review of relevant theory and research that informed the inquiry, an analysis of the collective knowledge that emerged, and vignettes that illustrate connections to my own classroom assessment practices, before and after I participated in this project.

Stage 2: Planning. The planning stage involved setting goals (collective and individual) and planning for classroom activities. During the face-to-face meetings, participants shared ideas, set goals, and planned for their classroom practice (e.g., to explore a certain tool, to help each other learn about a specific tool). After negotiating a shared focus during the first meeting, teachers identified classroom goals to focus on between meetings. Each teacher articulated his or her goal in a shared online document (see Table 2).

***Table 2*. Individual Teacher Goals**

Participant	Goal
Jill	To use technology (e.g., Nearpod, screencasting, Kahoot) to get students more involved in assessing their own learning.
Ben	Use technology on a more regular basis in class and become comfortable with using Kahoot and Nearpod for quizzes and review (assessment for and as). Use Airplay to share students' work with the class and explain/demonstrate their thinking.
Jennifer	To use technology (kahoot and/or nearpod) for diagnostic, minds-on, review, exit cards to inform students and myself regarding general comprehension. By doing so, I hope to increase student engagement and accountability, which will help them achieve to their potential by self-assessing and setting goals.
Liz	To use Desmos to discover the roles of "a", "h" and "k" in vertex form, to visually confirm our graphs.
Christine	Try padlet in conjunction with screen casting and flipped classroom as an interface for students to post questions and comments about explain everything video lessons.
Kelly	Make use of ipads on a regular basis with the specific use of Desmos and padlet (or nearpod).

Participants were also asked to identify support that they might need (e.g., technical support from coaches). For a more detailed summary of the first meeting, including the activities that involved generating collective knowledge (Stage 1 of Data Collection) and planning for the inquiry activities (Stage 2 of Data Collection), see Appendix E: Sample Inquiry Group Meeting Summary.

Stage 3: Reflecting on Our Experiences. During this stage, participants shared and analyzed their classroom experiences. After the first group meeting, time was dedicated at each meeting to having participants share what they were doing and what they were finding. Coaches facilitated these conversations (e.g., prompting conversation, eliciting connections among ideas, taking notes in a shared online document to record ideas as they emerged). The coaches' role is examined in Chapter 4 of this thesis. The article in this chapter connects to my goal of examining *how* our learning was supported.

At the beginning of the third group meeting, approximately three months into the project, participants contributed to analysing our experiences and to identifying key findings. This process involved considerable overlap between participants' analysis of the findings, and my analysis as a researcher. Before this meeting, I prepared meeting transcripts, summarized ideas and issues concerning the use of technology in assessment *as*, *for*, and *of* learning, and I met with Shelly to discuss the findings. Since we planned to present our findings at a provincial mathematics teacher conference, I recorded and shared the themes with participants at this face-to-face meeting and the group contributed ideas for the presentation. A copy of the presentation slides that were drafted at this meeting, and a copy of the final version of the slides that were created in collaboration with Kelly, who agreed to help facilitate the presentation, are included in Appendix F. This collective analysis of the inquiry findings represents one situation in which data analysis for my doctoral research purpose of examining what knowledge emerged, intersected with participants' analysis of their classroom experiences.

As the study unfolded, I began to notice that the three purposes of assessment occurred in more than just the classroom. I noticed, for example, that coaches engaged in assessment *for* learning by using feedback that they received from teachers at the meetings to inform subsequent plans for the inquiry group activities. As a researcher, I used assessment *for* learning to adapt my research plans in response to what was happening in the field. These are only a few examples of the connections that I was noticing in terms of assessment *as, for,* and *of* student learning, and assessment *as, for,* and *of* our professional learning and my research. I will unpack this observation in the article that is included in Chapter 6.

Data Analysis

Throughout this study I engaged in ongoing analysis of the data that I collected. I analysed the hard copies (i.e., my researcher journal, meeting transcripts) and electronic copies (i.e., audio recordings, electronic materials shared by participants, emails) of the data that I collected. Between each group meeting I looked for "blind spots" that could be addressed at subsequent meetings (Miles & Huberman, 1984, p. 49). For example, when someone suggested that technology can change summative assessment but this idea was lost, I made a note to try to pursue this idea at a subsequent meeting. My analysis was also focused on addressing my goals—to look at *what* was learned about the use of technology in assessment and at *how* our learning was supported—and was guided by my theoretical framework, which positioned my thinking about using technology to support particular assessment purposes and about facilitating learning in a collaborative learning system. I analysed my data in three concurrent flows of activity: *data condensation, data display,* and *conclusion drawing / verification* (Miles & Huberman, 1994; Miles, Huberman, & Saldaña, 2014).

Data Condensation. Data condensation involves "selecting, focusing, simplifying, abstracting, and/or transforming the data that appear in the full corpus (body) of written-up field notes, interview transcripts, documents, and other empirical materials" (Miles, Huberman, & Saldaña, 2014, p. 12). This flow began prior to data collection, with the choices involved in planning for the study. The data were condensed, for instance, by my decision to use a complexity theory framework, my goal to focus on our learning, and by my planned approach to collecting and analysing data. This flow continued as I transcribed audio recordings, coded data, prepared summaries, and generated categories, connections, and themes. It lasted until my final reports were complete.

After each group meeting, I transcribed the audio-recording. In order to minimize the influence of my own interpretations, I transcribed these recordings verbatim (Seidman, 2013). In some instances, however, I chose to summarize what was said and to note the time on the recording in case I needed to return to these instances later. I did this when conversations were off topic (e.g., talking about weekend plans or lunch) and/or when something was repeated, without adding to what was said already. At times, I highlighted segments of the transcripts and/or added my own preliminary questions, reflections, interpretations that struck me as being important (e.g., in connection to our learning or something to pursue at subsequent meetings).

I also kept a research journal in which I documented my observations and reflections at and between our meetings. As I transcribed the recordings for each meeting, I documented reflections in my journal. I noted what happened, my hunches, reflections, and patterns that I was noticing. I also reviewed the meeting transcripts and prepared summaries (see Appendix E for a sample meeting summary). In condensing the data in these ways, I was beginning to make connections. Keeping a research journal was important for documenting these connections and for reflecting on changes in my own and participants' understandings. By engaging in activities like transcribing audio recordings, noting my interpretations in a journal/memo, creating summaries, and meeting informally with coaches between meetings to reflect on these connections, I was able to keep ideas fresh in my mind and to look for the blind spots to pursue at subsequent meetings. In addition to being important for my analysis, regularly writing memos was important for reflecting on my research goals, methods, theory, experiences, and relationships with participants (Maxwell, 2013). I continued to condense data throughout this study by engaging in first and second cycle coding processes (Miles, Huberman, & Saldaña, 2014).

A *code* is a "researcher-generated construct that symbolizes or 'translates' the data" (p. 4) while *coding* is a transitional process between data collection and more extensive analysis (Saldaña, 2016). Portions of the data that are coded can range from a single word to a paragraph or even a full page (Saldaña, 2016). When I was looking at *what* knowledge was emerging, for instance, I used predetermined codes like "technology and assessment" to describe segments that fit within this overall focus. I also used more specific predetermined codes like "assessment *for* learning" and "technology in assessment *for* learning" to explore themes that connected to purposes of assessment and using technology for these purposes. Descriptive, in vivo, and process codes were also generated inductively and deductively, however (Miles, Huberman, & Saldaña , 2014).

First cycle coding involved reviewing transcripts and inquiry group materials, and coding segments of the data that included ideas that connected to my research questions (Miles, Huberman, & Saldaña, 2014). The initial codes that were assigned to data segments included words and short phrases that captured the essence of these segments (Saldaña, 2013). I generated a deductive "start list" of predetermined codes in advance. These codes were informed by my research questions and theoretical framework (Miles, Huberman, & Saldaña, 2014, p. 81).

In order to condense my data to focus on ideas and insights into the use of technology in assessment, these codes included, for example, "technology", "assessment *for* learning," "assessment *as* learning," and assessment *of* learning," for instance. Other descriptive codes, like "integrity of assessments," "changing assessments," and "choosing most appropriate tool," emerged inductively to describe segments that fit within my focus on ideas and insights that connected to the use of technology in assessment. In vivo codes (Charmaz, 2006, p. 55; Miles, Huberman, & Saldaña, 2014, p. 74), like "'technology to 'up the ante,'" also emerged in the field. In this first cycle of coding, I aimed to summarize data segments in connection to my study goals (see Appendix I for a more detailed summary of the codes).

For second cycle coding I organized my first cycle coded data according to the focus of each article and then used categorizing and connecting strategies (Maxwell & Miller, 2008; Maxwell, 2013). Categorizing strategies focus on "relationships of similarity" and involve defining categories based on comparisons. For example, for my analysis in the first article, which focuses on *what* was learned about using technology in assessment, I organized data with codes that fell under the umbrella of technology and assessment (e.g., "technology," "changing assessment") into an organizational category and compared the data within this category. Within this category, I compared data connected to "challenges/barriers" and "opportunities/enablers." Since the inquiry group considered particular purposes of assessment, I also compared ideas that connected to the use of technology in assessment *as, for,* and *of* learning. Maxwell described the function of these kinds of organizational categories as bins for sorting data:

> Organizational categories function primarily as bins for sorting the data for further analysis. They may be useful as chapter or section headings in presenting your results, but they don't directly help you make sense of what's going on [...] because they don't explicitly identify what the person actually said or did, only the category that what they said or did is relevant to. (Maxwell, 2013, p. 107)

His statement reflects that the categories are helpful for analysis but they do not directly help a researcher make sense of data. In other words, developing these categories was only a start. Further analysis was required to unpack themes. Some of my organizational categories were determined in advance and others emerged as I coded and analyzed the data. For example, my "start-list" of organizational categories included "issues with using technology in assessment" and "time" emerged as a subcategory when I noticed that this code had emerged within the initial category.

I used qualitative analysis software (ATLAS.ti) to facilitate the first and second cycle coding processes. With this software I was able to code data segments, to group multiple codes, and to retrieve quotations attached to individual or groups of codes. The image in Appendix G shows a portion of a transcript in ATLAS.ti from my first cycle of coding. This portion also shows some of my highlighting and reflections that I documented within the transcripts. With this software, I was also able to simultaneously apply multiple codes to a unit of text and use holistic coding when a single code applied to a large unit of text. For example, when I wanted to look at ideas that connected to specific assessment purposes, I was able to do a search for this purpose (e.g., "assessment *for* learning) and if I wanted to examine what was said about technology and assessment *for* learning, I could search for all data segments that had both of these codes attached to them. Being able to interact with my codes in these ways (i.e., to quickly gather all data segments attached to particular codes) facilitated second cycle coding.

For my second cycle of coding, I grouped categories of data (e.g., data with similar codes) into a smaller number of categories (Miles, Huberman, & Saldaña, 2014). I looked at the resulting first cycle codes for patterns: "threads that tie together bits of data" (Miles, Huberman, & Saldaña, 2014, p. 86). The difference between first and second cycle coding is summarized by Miles, Huberman, and Saldaña (2014), in their statement that "First Cycle coding is a way to initially summarize segments of data. As I mentioned above, ATLAS.ti facilitated this process. Pattern coding, as a Second Cycle method, is a way of grouping those summaries into a smaller number of categories, themes, or constructs" (p. 86). This second cycle of coding involved grouping codes into smaller number of categories and using connecting strategies to explore relationships between ideas.

Connecting strategies aim for a contextual understanding of the data by focusing on relationships among elements of the text. In this study, connecting strategies were important for analyzing how ideas emerged and evolved, and for analyzing the learning processes in the collaborative inquiry. When I examined *what* was learned in this context, for example, I created concept maps to organize ideas (e.g., assessment strategies, challenges and opportunities posed by technology for assessment) and to look for relationships. ATLAS.ti made it possible to all group codes that connected to one code (e.g., technology and assessment) (see image in

Appendix H for examples) but I wished to take a closer look at the relationships. Therefore, I used another concept mapping application (Mindomo) to represent and analyze connections (see Appendix H for an image of one of the maps that I created). The categorizing and connecting strategies are reflected in the matrix and network approaches that were used to display the data that I collected for this study.

Data Display. A display is "an organized, compressed assembly of information that permits conclusion drawing and action" (Miles & Huberman, 1994, p. 11). This flow of analysis began as I collected data and continued through writing the final reports on the findings. I used matrices to summarize categories of data (see Appendix H for a sample matrix representation). These matrices included codes, direct quotes, and summaries of data segments. Then, I created networks to illustrate relationships between ideas. Networks were created to illustrate and explore relationships between different categories (see Appendix H for a sample network representation). The network representation was important for emphasizing the distributed rather than discrete view of knowledge in this study (Mowat & Davis, 2010). Combining matrix and network strategies to categorize and connect information helped to provide a "well rounded account" of the data (Maxwell, 2014, p. 113). Throughout this process, I continued to engage in conclusion drawing and verification.

Conclusion Drawing and Verification. Conclusion drawing and verification begins with data collection and involves reflecting on patterns and themes, identifying possible connections and explanations, and determining what the data means (Miles & Huberman, 1994). In addition to drawing my own conclusions, participants played an active role in the process. Throughout all stages of collection, I verified my conclusions by analysing relationships and patterns in the data, and by discussing with participants. For example, after each inquiry group interview, I transcribed and analyzed the data to generate my own interpretations, and then I gave participants the opportunity to react to my interpretations at subsequent meetings. One example, illustrated above, was when participants responded to my initial analysis of the ides for using technology in assessment, in preparation for the annual conference presentation. I also had opportunities over the course of the inquiry to reflect on the findings with individual teachers (e.g., Liz who was teaching at the same school, Kelly who helped to prepare for and lead a presentation at a provincial conference) and coaches (e.g., Shelly to review my analysis of a meeting transcript and to consider next steps for meetings), and in subgroups (e.g., to plan for meetings with the coaches, to organize a final presentation for a district meeting). Thus, while I engaged in the processes of condensing and displaying data, and drawing conclusions based on my analysis of the data, participants played an active role in contributing to the findings.

I focus my analysis to address different (but related) research questions in the three articles that are included in this thesis. In these articles, I unpack the themes and conclusions that emerged in connection to my questions. More specifically, these articles highlight themes and conclusions that fit within three overall categories: (i) what this group learned about using technology in assessment, (ii) how this learning was supported, and (iii) how I navigated tensions that emerged from my efforts to facilitate a professional learning and research collaboration when I was also a colleague (see Appendix A for connections between research questions and data).

Validity

Validity is a controversial term in qualitative research. It tends to be associated with positivist assumptions about seeking more objective truths, often using quantitative methods (Maxwell, 2013). Even though some qualitative researchers avoid using this term, I am using it here in a way that is supported by the interactive qualitative research design (Maxwell, 2013). Validity is defined here, as it is by Maxwell (2013), to refer to “the correctness or credibility of a description, conclusion, explanation, or other sort of account” (Maxwell, 2013, p. 122). I draw on this definition to emphasize that I used particular strategies to enhance the credibility of my descriptions, interpretations, and conclusions. Often, qualitative researchers aim to do this by trying to participate as a "fly on the wall, observing a social setting as it develops independent of the researcher" (Herr & Anderson, 2005, p. 50). Given the interactive nature of this study, however, with my being both a participant and a researcher in this context, I was not a "fly on the wall" and I needed to use other strategies. Validity criteria continue to change and there are no clear-cut uniform approaches to enhancing the validity of research findings (Connelly & Clandinin, 1990; Herr & Anderson, 2005). There are, however, similarities among the approaches that align with the interactive qualitative research design. More specifically, in this study I used strategies to support researcher reflexivity.

Reflexivity is the effect that a researcher has on the setting or individuals studied. It is impossible to eliminate this influence, particularly with my being both a researcher and a participant in this case. Instead, I drew on Maxwell's (2013) strategies for enhancing validity by aiming to understand my own influence and considering how to use it productively (Maxwell, 2013). Since it was possible to influence participants' responses during meetings, for instance, I avoided leading questions and was mindful of the ways I used non-verbal cues. I systematically reflected on my interactions in the field and strived to listen and to support teachers' collaborative activities.

In addition to questioning my contributions, I constantly reflected on my own assumptions and how they might influence my interpretations of the findings. We all come to a study with ideas about what is being studied (Miles & Huberman, 1994). Since these assumptions influence research conclusions, it is important to be transparent about them and to question interpretations of the data. My own assumptions are reflected throughout this dissertation. My personal, practical, and intellectual goals, for example, reflected particular assumptions about professional learning, research, and the use of technology in mathematics classroom assessment. A complexity theory framework, which reflects particular ideas about collective knowledge and learning in a complex system, also informed this study. The underlying perspectives are outlined in the first chapter of this thesis.

Over the course of the study, I continued to reflect on my own and participant understandings. My research journal was important for monitoring and recording these reflections. I also triangulated multiple data sources (e.g., my reflections and observation notes, individual and group meeting transcripts, meeting notes that were created by coaches) and perspectives (e.g., by reviewing findings with the group, reflecting on my interpretations with participants). The importance of monitoring and reflecting on changes in understandings is articulated in Herr and Anderson's (2005) discussion of validity criteria for action research dissertations. Herr and Anderson point out that "the most powerful action research studies are those in which the researchers recount a spiraling change in their own and participants understandings" (p. 56). I describe some of the changes in my own understandings and in the group's understandings of technology in assessment in Chapter 3.

Since my research was linked to a district-level project, I risked one project taking precedence over the other. The potential for this risk has been shown in prior research, with Steele (2012), for instance, who found that when she conducted research with colleagues in a collaborative project, participants were happy to have her take the lead and she ended up directing the activities more than she would have liked. Like Steele, I wanted participants to share control for our activities. Unlike Steel, however, in this case instructional coaches and technology coaches shared project leadership responsibilities. In Chapter 5 I show how having the coaches share these responsibilities allowed me to listen, observe, and reflect on what was happening in the moment, without feeling the need to jump in. The analysis in Chapter 5 shows that I experienced inner tensions with navigating multiple roles in this inquiry (researcher, teacher, project leader, learner) and that I constantly questioned my influence on participants and on the inquiry activities.

In presenting findings from my analysis of my own experiences with navigating different forms of membership in this context as a narrative (this was not a narrative study), it is important to acknowledge that narrative is a "two-edged inquiry sword":

> Narrative and life go together and so the principal attraction of narrative as method is its capacity to render life experiences, both personal and social, in relevant and meaningful ways. However, this same capacity is a two-edged inquiry sword. Falsehood may be substituted for meaning and narrative truth by using the same criteria that give rise to significance, value, and intention. Not only may one 'fake the data' and write a fiction but one may also use the data to tell a deception as easily as the truth. (Connelly & Clandinin, 1990, p. 10)

Connelly and Clandinin caution that it is tempting to establish a "Hollywood plot" in which everything works out (p. 10). It was therefore important to be transparent about the choices that were made, to consider possible alternative stories, and to be critical of the limitations. One way I reflected critically on my influence and interpretations in this context was to analyse my experiences as an insider-outsider participant and researcher in this context. In this analysis and report on my findings (see Chapter 5), I aim to be transparent about the challenges that I encountered in this context.

In addition to reflecting on my influence and to being critical of my own assumptions, throughout this study I received feedback from my thesis supervisor and committee. This feedback prompted me to critically examine and clarify the purposes and limitations of my conclusions, including whether my conclusions were supported by my data. For instance, as I analyzed the data and wrote reports, I received feedback from my supervisor that prompted me to question my assumptions and to critically reflect on my interpretations. Likewise, feedback that I received from my committee contributed to the validity of my findings by bringing my attention to potential "blind spots." When I defended my research plans, for instance, the importance of documenting my decisions and my reflections was stressed, particularly because of the complexity of being both a researcher and at the same time a participant in a collaborative inquiry. This feedback prompted me to more critically examine my influence throughout the study. Reflecting on my experiences and influences in this context, and looking at studies that provide insight into the complexity of facilitating a collaborative research project (e.g., Avgitidou, 2009; Steele, 2012) and of navigating multiple forms of membership in a community of practice (e.g., Wenger, 1998; Wenger-Trayner, Fenton-O'Creevy, Hutchinson, Kubiak, & Wenger-Trayner, 2014), led me to better understand the complexity of being a researcher in a collaborative project. My focus on this aspect of the research process eventually led to the analysis of my experiences that is included in the third article in this thesis (Chapter 5).

On another occasion, when I described conclusions from my analysis of what was learned in this context, I discussed how technology can enhance (and possibly transform) mathematics classroom assessment. Since this study focused on the professional learning that emerged in this group and not on what actually happened in classrooms, however, I cannot claim that technology impacted student learning or the assessment of student learning. During a thesis committee meeting, questions about the scope of this conclusion prompted me to clarify the limitations. For instance, my analysis of our learning does show that teachers found ways to enhance, and possibly even transform, their mathematics classroom assessment practices. Further researcher is needed, however, to study the impact on student learning and student use of technology in assessment, in classrooms. These are only two examples that show how the feedback I received throughout this research brought my awareness to blind spots and continued to prompt me to critically reflect on my interpretations and to be more transparent about my research purposes and about limitations to my conclusions. Thus, in addition to the more internal processes of journaling and reflecting, ongoing feedback throughout the research process helped to further enhance the validity of my findings.

To summarize, I aimed to enhance the credibility of my findings from this qualitative case study by using strategies to support researcher reflexivity. I examined and documented my assumptions, my influence on participants and on the inquiry activities, and my conclusions and interpretations of the data. My reflections and the research that I encountered in my efforts to understand my role in this collaboration led me to analyze my own experiences in this context.

This deeper analysis (Chapter 5) provides insight into the internal tensions that I encountered as I engaged in this inquiry as a teacher, researcher, and project leader. Before presenting this analysis, the following two articles in this thesis examine the collective learning that emerged.

CHAPTER 3: Using Technology in Mathematics Classroom Assessment: Findings From a Collaborative Inquiry

Abstract. Technology can support mathematics teaching and learning. It also has implications for assessment. In order to explore the use of technology in mathematics classroom assessment, a small group of educators came together for a collaborative inquiry. This inquiry, which lasted approximately one school year, included two instructional coaches, two technology coaches, five high school mathematics teachers, and a doctoral student researcher (myself) who was also a part-time teacher. In this article I examine what was learned about using technology in mathematics classroom assessment. This qualitative study revealed that participants found opportunities to enrich assessment *as*, *for*, and *of* learning in mathematics. More specifically, participants found that technologies (e.g., open and closed student response systems, online collaborative spaces, dynamic mathematics applications) can support formative assessment (assessment *as* and *for* learning) by improving the immediacy of feedback to students and teachers, by promoting student self-assessment, and by making it possible to capture and share student solutions. Ideas for using technology in assessment *of* learning also emerged. More specifically, participants identified ways in which technologies (e.g., online sharing spaces, images and video recordings of student work) may be used by students to change the ways they demonstrate their learning in mathematics. In addition to discussing these findings, I describe how the inquiry group negotiated and refined a shared focus that was intended to bound our activities and at the same time embrace diversity in teaching experiences, comfort with technology, and interests with respect to using technology in assessment.

Keywords: Secondary Mathematics; Technology; Classroom Assessment; Collaborative Inquiry

The significance of technology for mathematics teaching and learning is acknowledged by the National Council for Teachers of Mathematics (NCTM, 2000, 2014). The NCTM (2014) suggests that technology should be both an indispensable feature of a mathematics classroom and an important part of assessment. Technology can, however, increase the complexity of teaching and have implications for assessment (e.g., see Clark-Wilson, 2010; Koehler & Mishra, 2008). As a teacher, I have experienced this complexity and I sought to deepen my understanding by engaging in a collaborative inquiry with colleagues and by carrying out research in this context. While I highlight some of my own learning in this paper, I focus here on the inquiry group's learning about the implications of technology for mathematics classroom assessment.

I have grappled with using technology to support teaching and learning in my high school mathematics classes. The following two vignettes illustrate the types of scenarios I encountered prior to this study.

> *Students in my Grade 10 class are solving quadratic equations when I see Mitch use an app on his phone to scan an equation and receive a full solution. At another table, Mary types a different equation into an online search engine using her personal electronic device. Like Mitch, she finds a step-by-step solution. I notice just how comfortable some of my students are with using their devices to find information. I wonder how else these tools might be used in the classroom.*
>
> ....
>
> *In another class, I am exploring the use of online collaborative tools to facilitate mathematics investigations and problem solving. I have posted a problem to an online platform (Padlet). Jane and Max respond by sharing a link to a dynamic mathematics representation of the algebraic, numeric, and graphical models that they created as they began to engage with this problem. At another table, Shannon and Brady open the link and interact with the different representations. They respond by posting a statement that the algebraic representation might be used to solve the problem. They show their approach but add that they are not sure if it will work. Another student, Haley, continues with Shannon and Brady's suggestion and shares a screencast video to explain what she did. This interaction continues, with students discussing the problem face-to-face in the classroom and sharing statements, dynamic sketches, images, and videos to show their thinking online. As I circulate around the classroom, listening to the conversations and watching the online contributions, I hear students say that they need to revisit their approaches. Some of the contributions are surprising and I decide to ask some groups questions about their responses. I also notice some common misconceptions and decide to address these the next day.*

These vignettes show some of the implications for assessment when technology is used in the classroom. The answer to a test question might be a mere swipe away. On the other hand, technology can change the ways students represent and interact with mathematics and with each other. In this sense, technology offers a number of affordances to the classroom. These affordances can prompt questions concerning assessment: What might assessment tasks and questions look like if students are allowed to use technology to demonstrate their learning? What might assessment look like if technology can change the way students interact with each other and with mathematics? These kinds of questions led to a collaborative inquiry in which I engaged with nine of my colleagues to work through issues of technology and assessment.

As a researcher, I also wanted to examine our collective learning. I was interested in the ways in which we grappled with developing our assessment practices, with learning new technologies, and with integrating technology and assessment. The need for technology and assessment focused research has been articulated by Stacey and Wiliam (2013). Based on their extensive review of technology and assessment research literature in mathematics education, Stacey and Wiliam called for further study in this area. This need has also been articulated in a more recent review of mathematics assessment literature (Suurtamm et al., 2016). Suurtamm and colleagues have expressed a need to consider some of the implications of technology for assessment: "How does the use of technology influence the design of assessment items? What are the affordances of technology? What are the constraints (p. 12)?" "What are some of the additional challenges in assessment when hand-held technologies are available (e.g., graphing calculators) or mobile technologies are easily accessible (e.g., smart phones with internet connections) (p. 19)?" These types of questions align with some of the issues and questions that prompted the collaborative inquiry that is described in this paper. In this study of our learning, I address the question, "*What* was learned about the use of technology in mathematics classroom assessment through a collaborative inquiry?"

Positioning this Research

This study is positioned at the intersection of literature that highlights what is already known about mathematics classroom assessment, opportunities for using technology to support assessment, and the complexity of practice. More specifically, in this section I highlight how research has shown both the opportunities that might arise when students have access to technology for assessments and the ways technology can increase the complexity of teaching and assessment. Since assessment is at the heart of this study, I begin by defining the view of assessment that is reflected in this paper.

Mathematics Classroom Assessment

Drawing on Earl's (2013) and Harlen's (2006) definitions, I assume that mathematics classroom assessment involves gathering evidence of student learning and using this information to inform decisions in relation to specific mathematics goals. The information that is gathered might be used, for example, to inform decisions about how to move forward to support student learning or to make judgements about the learning that has been demonstrated by students. Evidence of learning can be gathered by different stakeholders (e.g., students, teachers, external stakeholders) for different purposes (e.g., to support learning, to evaluate learning) in relation to different goals or purposes (e.g., to self-assess understandings, to inform teaching or judgments about student learning, to compare performance in different jurisdictions). So in this context, assessment is considered to be more than assigning grades; it is used to inform mathematics teaching and to support student learning.

In Ontario, Canada, the context of this study, the provincial assessment policy posits that decisions about student learning are made in relation to "how well a student is achieving the curriculum expectations in a subject or a course" and a primary purpose of assessment is to support student learning (Ontario Ministry of Education [OME], 2010, p. 28). The importance of this purpose is demonstrated in an extensive review of assessment literature that was carried out in 1998 by Black and Wiliam. The argument that stemmed from this review, and is supported here, is that formative assessment is the most powerful way to improve student learning.

Current perspectives on assessment tend to draw on cognitive, constructivist, and sociocultural perspectives to emphasize that learning is a more constructive social process, and that formative assessment is valuable for informing teaching and learning (Gipps, 1994; Shepard 2000, 2001; Suurtamm et al., 2016). The subjective nature of human judgement when it comes to classroom assessment is articulated in Ontario assessment policy documents:

> It is worth noting, right from the start, that assessment is a human process, conducted by and with human beings, and subject inevitably to the frailties of human judgement. However crisp and objective we might try to make it, and however neatly quantifiable may be our "results," assessment is closer to an art than a science. It is, after all, an exercise in human communication. (Sutton, 1991, p. 12; cited in OME, 2010, p. 29)

This statement reflects acceptance in the Ontario assessment policy that assessment is not necessarily a quantifiable measure of student learning. It is a human process.

The different purposes of assessment—to measure or evaluate learning versus to support learning—have been described using different types of language. In their review of the assessment literature, Black and Wiliam (1998) used *formative* and *summative* assessment to distinguish between using assessment to support student learning (formative) and using assessment to measure student learning (summative). In Ontario, the context for this study, policy documents draw on assessment literature (e.g. Assessment Reform Group, 2002; Harlen, 2006; Western and Northern Canadian Protocol for Collaboration in Education, 2006) to recognize three approaches to classroom assessment: assessment *as* learning, assessment *for* learning, and assessment *of* learning (OME, 2010, p. 29). Assessment *as* and *for* learning emphasize using assessment to support learning and might therefore be considered formative purposes of assessment. Assessment *of* learning, on the other hand, might be considered summative. In this study, participants' grappled with using technology to support assessment *as, for,* and *of* learning. These assessment purposes are defined more fully later, in my description of the framework used for the study of our learning about technology and assessment.

Opportunities for Using Technology to Support Assessment

Research has highlighted opportunities that might arise when technology is used by students for assessments. Hargreaves, Shorrocks-Taylor, Swinnerton, Tait, and Threlfall (2004), for example, compared 260 10-year old students' responses to paper-and-pencil assessments that, as closely as possible, matched computer versions of assessments. Hargreaves and colleagues found that there was an overall positive effect in the students' mathematics performance on the computer versions of the assessments. In other research, Peltenburg, Heuvel-Panhuizen, and Robitzsch (2010) found that when 8-12 year old students in special education were allowed to use digital manipulatives in assessments, these students showed more of their capabilities in solving subtraction problems. The students also achieved a higher percentage of correct answers than on standardized test items. The findings from these two studies suggest that technology can provide a useful medium for mathematics assessments.

Research also highlights opportunities for using technology to enhance assessments and to help make student thinking visible. Based on an extensive literature review and on their experiences with research and with teaching using "mathematics analysis software" (software that allows the user to perform algorithmic processes), Pierce and Stacey (2010, p. 2) created a *pedagogical map* to summarize the pedagogical opportunities that are provided by various types of software. This taxonomy highlights benefits of technology for student tasks, for facilitating classroom interaction, and for mathematics. In addition to finding that technology—in this case networked technology (TI-Nspire Navigator)—enables the development of innovative mathematical tasks, Clark-Wilson (2010) has shown how a connected classroom can help teachers develop and support new and existing assessment practices. More specifically, reports from teachers and classroom observations at the seven secondary schools confirmed that technology helped expose students' mathematical thinking (e.g., problem solving processes) and contributed strategies for student peer and self-assessment. The value of technology for exposing student thinking is also demonstrated in Karadag's (2009) doctoral dissertation. Karadag used screen capturing software to record five secondary students' thinking and problem solving processes in an online dynamic learning environment. He found that the ability to record these processes can enable more opportunities for process oriented assessments in mathematics classrooms (summative assessment). Karadag's findings also suggest that students can use videos of their solutions in discussions with their peers or in self reflection, which can support the improvement of their metacognitive skills and understandings (formative assessment).

Current research highlights some of the ways technology can change mathematics classroom assessment. Panero and Aldon's (2016) case study, for instance, describes how a Grade 9 teacher's formative assessment practices evolved with the use of digital tools. This case shows that the teacher's formative assessment practices were reinforced and augmented when he used technology (e.g., networked tablets, student response systems) to gather evidence of student learning and used this information to inform his teaching. Other researchers, Olsher, Yerushalmy, and Chazan (2016), also considered the use of technology for formative assessment purposes. These researchers examined how technological advances might support teaching by providing immediate access to large groups of student responses to open mathematics questions. In this case, technology helped to facilitate assessment by making it possible for the teacher to quickly categorize student responses and to then display a large number of student responses. Findings from Isabwe, Reichert, Carlsen, and Lian's (2014) research also suggest that technology may be valuable for formative assessment purposes. The university student participants in Isabwe and colleagues' study, from Rwanda and Norway, reported that opportunities to use technology to facilitate peer assessment was valuable for supporting their learning. Such studies show the potential for technology to support assessment, particularly formative assessment. It is important to note, however, the complexity of integrating technology in practice.

The Complexity of Practice

Research findings concerning issues that technologies pose in assessment are limited (Trouche et al., 2013). Some researchers have explored how to evaluate student work in a technology-rich environment (Hernandez-Sánchez, 2009 cited in Trouche et al., 2013). Other studies identify implications of technology for classroom practices. Clark-Wilson (2010), for instance, found that a networked classroom demands a new role for teachers, particularly with respect to managing increased amounts of student data. In addition to acknowledging the demands on teachers, Thomas and Palmer (2014) have identified resources, training, and teacher confidence as major issues influencing the implementation of technology in mathematics teaching and learning. In agreement with Jaworski (2003), these researchers argue that collaboration in a "community of inquiry" in which teachers observe, practice, and reflect on the use of technology in classroom practice is important for helping teachers gain confidence with using technology in assessment (Thomas & Palmer, 2014, p. 86). This position is foundational to the collaborative inquiry that is described in this paper. In an effort to support professional growth, and to contribute to research in this area, participants came together for a collaborative inquiry to explore the use of technology in mathematics classroom assessment. I examined the findings that emerged, including ideas (e.g., classroom strategies) and insights (e.g., possible solutions to problems of practice) that connected to the use of technology in mathematics classroom assessment. More specifically, in the findings that are presented below, I illuminate what this group learned about using technology to enhance and transform their assessment practices.

To summarize, this study is positioned within classroom assessment literature, with a specific focus on using technology in assessment. Prior research illuminates some of the opportunities for using technology to support classroom assessment and points to the complexities of integrating technology in practice. My research examined what a team of high school educators learned as they collectively grappled with different ideas for using technology to support their assessment practices. In the following section, I clarify my perspective on the use of technology in assessment.

A Framework for Examining Our Learning About Using Technology *in* Assessment

In this paper I report on one aspect of a larger study of the learning that emerged in a collaborative inquiry. This study reflects a particular perspective on what it means to grow and learn in a complex system (Davis & Simmt, 2003). I work from the premise that our learning about technology in assessment is an emergent and adaptive phenomenon; it arises and changes in structure as people contribute new ideas and insights (Davis & Simmt, 2003). Extending Davis and Simmt's (2003) definition of a body of mathematical knowledge, I consider the collective knowledge about technology in assessment in this community to include the shared ideas (e.g., for using technology in assessment), insights (e.g., possible solutions to problems that are posed by the use of technology), and understandings (e.g., of purposes of classroom assessment, of the purpose of using technology in assessment) that constitute a complex unity. In this study of the ideas, insights, and understandings that took shape in this inquiry, I look for themes that emerged with respect to the use of technology in assessment. To help frame my focus in this section, I first explain what is meant by using technology *in* assessment rather than *to* assess (Buteau & Sinclair, 2012; Stacey & Wiliam, 2014). Then, I clarify the focus on using technology *in* assessment *as, for,* and *of* learning in mathematics.

In developing my own thinking about technology and assessment, I encountered different perspectives in the literature and in practice. The importance of clarifying and bounding my focus became obvious. In this study, I lean on a distinction offered by both Buteau and Sinclair (2012) and Stacey and Wiliam (2014). Buteau and Sinclair distinguish between using technology *to assess* and using technology *in assessment* (2012, p. 96). In the first case, technology is used to assess student learning. Automated scoring systems may be used, for example, to quickly score student responses to mathematics questions. Technology in this case may improve item presentation, the type and immediacy of feedback, and how students interact with assessment items. On the other hand, when technology is used *in* assessment, "students can use the mathematical capabilities of technology [e.g., to interact with dynamic mathematics representations, to access answers using calculators, to access information online] in the mathematical performance that is being assessed" (Stacey & Wiliam, 2013, p. 724). With the vignettes in the introduction to this paper, I aimed to show some of the possibilities and implications of using technology capabilities *in* assessment. In the first scenario, for instance, technology made mathematics information and solutions to various assessment items more easily accessible. Whereas in the second scenario, technology made it possible for students interact with different mathematical representations and for teachers to record and display student thinking and problem solving processes in more dynamic ways. In the collaborative inquiry that is described in this paper, participants explored how these kinds of technology capabilities could be used *in* assessment.

Using Technology in assessment *as, for* and *of* learning in Mathematics

Both the inquiry focus and my analysis of the findings reflect particular assumptions about the ways in which technology can be used in assessment. More specifically, the themes in my analysis connect to the use of technology *in* assessment *as, for,* and *of* learning in mathematics. Since the Ontario Ministry of Education (2010) assessment policy helped to inform this inquiry, this section summarizes perspectives on the purposes of assessment in the policy and weaves in relevant research (Assessment Reform Group, 2002; Black & Wiliam, 1998; Earl, 2013).

The messages concerning assessment *as, for,* and *of* learning that appear in the Ontario assessment policy (OME, 2010) are informed by research and by other organizations such as the Assessment Reform Group (2002) and the Western and Northern Canadian Protocol (2006). In 1996, Paul Black and Dylan Wiliam were funded by the Assessment Reform Group (a group of researchers brought together by the British Educational Research Association in 1989) to carry out an extensive review of assessment literature. This review provided evidence that formative assessment can improve student learning (Black & Wiliam, 1998). The Assessment Reform Group has continued to emphasize the importance of formative assessment (more recently using the term assessment *for* learning). Their 2002 publication titled *Assessment for Learning: 10 Principles,* which highlights principles of assessment *for* learning, is referenced in the Ontario assessment policy. Drawing on the Assessment Reform Group definition, the Ontario Ministry of Education defines assessment *for* learning as “the process of seeking and interpreting evidence for use by learners and their teachers to decide where the learners are in their learning, where they need to go, and how best to get there” (Assessment Reform Group, 2002, p. 2; cited in OME, 2010, p. 4). This definition informed a technology in assessment framework that was created by the inquiry group. This framework was developed from the inquiry group's reflections on the assessment policy (OME, 2010) and relevant literature (Earl, 2013). To support assessment *for* learning, a teacher might use information that is gathered by different means (e.g., conversations, observations, quizzes) to get a sense of where students are at in their learning and to inform next steps for supporting learning. A teacher can use assessment *for* learning in the above technology-rich classroom scenario, for instance, by examining student contributions and then offering feedback to individual students. Or, the teacher might use the same information *for* learning by highlighting different ideas and solutions strategies during a follow-up whole class discussion. Based on the solutions that students share, the teacher might even decide that a subsequent lesson to address common misconceptions is a necessary next step. In each of these scenarios, information is used by the teacher to support student learning, either directly or indirectly by informing teaching.

The definitions of assessment *as* and *of* learning in the assessment policy (OME, 2010) refer to a document titled *Rethinking Classroom Assessment with Purpose in Mind* (Western and Northern Canadian Protocol for Collaboration in Education [WNCP], 2006). The WNCP document was prepared by Dr. Lorna Earl, a researcher in assessment, and Dr. Steven Katz (Aporia Consulting) in collaboration with the WNCP and included partners from different provinces and territories. According to both the WNCP and the Ontario assessment policy, assessment *of* learning involves the teacher in summarizing student learning at a given point in time, and in making judgements for grading and reporting purposes. Assessment *of* learning might be exemplified in the technology-rich classroom scenarios that are illustrated in the introductory vignette above, for instance, if the teacher chooses to assign a grade to student solutions or to have students write a test or quiz to demonstrate their understandings.

With assessment *as* learning, students are the primary assessors. They begin to self-assess and to engage in setting individual goals, self-monitoring, and determining their next steps in relation to their goals (Earl, 2013, Earl, 2003). Informed by the WNCP publication and research at the time, the Ontario Ministry of Education defines assessment *as* learning as focusing on “explicit fostering of students’ capacity over time to be their own best assessors” (WNCP, 2006, p. 42; cited in OME, 2010, p. 4). Referring again to the above classroom scenario, for example, a student may engage in assessment *as* learning by reflecting on the different solutions that are shared by other students and using this information to improve his or her own strategy. Since assessment *for* and *as* learning are directly linked to improving student learning, Ontario policy statements emphasize that these purposes are to be "integrated seamlessly with instruction" (OME, 2010, p. 28).

The three purposes of assessment are not necessarily mutually exclusive. Brookhart (2001), for instance, found from her analysis of interviews with 50 students in high school English and Anatomy courses, that students who saw learning as a lifelong process, tended to view formative (*as* and *for* learning) and summative (*of* learning) assessment in integrated ways. In other words, these students did not make "neat distinctions" between formative and summative assessment; instead they engaged in ongoing self-assessment and realized that the information from summative assessments could be used in formative ways (e.g., to approach future learning). Even though the formative and summative purposes of assessment might not be distinct, the three purposes were used to frame our thinking about classroom assessment. More specifically, our technology in assessment focus was framed by a focus on using technology in assessment *as, for,* and *of* learning in mathematics.

To summarize, the inquiry focus and my analysis of our findings was bounded by an overall focus on using technology *in* assessment. The analysis that follows is organized by themes that emerged in connection to the use of technology *in* assessment *as, for,* and *of* learning in mathematics. Before presenting my findings, I outline the methods that were used in this study.

Methods

I used a qualitative case study approach to examine what was learned about using technology in assessment. In this section I explain the value of a case study approach. I also describe the collaborative inquiry project and participants. Then, I outline participant selection and describe how the data were collected and analysed.

Case Study of a Collaborative Inquiry

A qualitative case study seeks a rich understanding of a case (Stake, 1995). A case is defined by Stake (1995) to be "a specific, a complex, functioning thing"; it is a purposeful bounded system with working parts (p. 2). In this context, the case was a collaborative inquiry professional learning system and its purpose was to explore the use of technology in mathematics classroom assessment. This case was instrumental since my interest in understanding what was learned about technology and assessment was more dominant than my interest in this specific case itself (an intrinsic case) (Stake, 1995). A case study approach allowed me to focus on the learning that emerged and to, at the same time, appreciate the uniqueness, complexity, embeddedness, and interactive nature of a case (Stake, 1995), in this case a complex professional learning system (Davis & Simmt, 2003). In this context, I refer to the professional learning system as a collaborative inquiry.

The collaborative inquiry in this case study was designed to support Cochran-Smith and Lytle's (2009) conceptualization of a practitioner inquiry. More specifically, participants in this inquiry were co-producers of the practical ideas and research knowledge that emerged. Thus, my research aimed to connect research and practice by involving educators as "key stakeholders" (Kieren et al., 2013). This vision is reflected in similar inquiries and collaborative action research projects in which participants have been involved in co-constructing inquiry questions and research goals, in investigating solutions to classroom problems, in collecting and analysing classroom evidence, and in sharing responsibility for collective growth and reflection (e.g., see Bruce, Flynn, & Stagg-Peterson, 2011, Herbel-Eisenmann & Cirillo, 2009; Lachance & Confrey, 2003). Likewise, participants played an active role in the collaborative inquiry that is described below.

Participants

The key criterion for selecting a case is to maximize what we can learn (Stake, 1995). Stake (1995) has acknowledged that we can learn from both typical and unusual cases. In this context, the case might be considered typical in the sense that it involved a team of educators with a range of interests, comfort with technology, and experiences that might be reflected in practice; from a new teacher who was working through the curriculum for the first time, to more seasoned teachers who were comfortable with the curriculum but less so with technology, to teachers who were more comfortable with technology and the curriculum but wanted to further develop their practices. This case might also be considered unique since it involved teachers from different schools across a school district, two instructional coaches and two technology coaches supported the professional learning and inquiry processes, and myself, in a dual role as a teacher participant and a doctoral student researcher. The project was also funded, which made it possible for participants to come together for three full day face-to-face meetings and two online (synchronous) meetings over the course of almost one full school year (eight months). The range in participant attributes, and the funding, however, allowed me to examine the interaction of different perspectives on technology and assessment that emerged for an extended period of time.

Instructional Coaches and Technology Coaches. Two technology coaches (Brent and Sarah) and two instructional coaches (Patricia and Sarah) participated in this study. During the school year prior to carrying out this study, I was a part-time mathematics teacher and I was also in the process of completing a proposal for this study. At that time, I responded to a district level call for technology innovation project proposals with Patricia (all participant names are pseudonyms), an instructional coach at the same school in which I was teaching. Our proposal aligned with my doctoral research plans. Once our proposal was approved for the 2015-2016 school year, two technology coaches, Sarah and Brent, were assigned to support us in our learning (Sarah was our primary contact). Then Shelly, another instructional coach, joined the team. Early in the Fall of 2015 I met with Patricia, Shelly, Sarah, and Brent to discuss the project goals, including the district project expectations and my research goals. We also considered potential teacher participants. Since the school district project plans aligned with my research plans, participant selection was informed by the underlying complexity theory perspective (Davis & Simmt, 2003; Davis & Simmt, 2006).

Teachers. Six high school teachers, including myself, participated in this collaborative inquiry. Teacher participation was voluntary and purposeful sampling was used to generate a list of potential participants (Maxwell, 2013; Miles & Huberman, 1994). Given the complexity theory underpinnings and the proposed collaborative nature of the inquiry, I aimed to support the five conditions for learning as outlined by complexity theory: distributed control, neighbour interactions, redundancy, internal diversity, and organized randomness (Davis & Simmt, 2003, 2006). Distributed control was supported by the teacher-directed nature of this project. Leadership responsibilities were distributed across participants so that no individual was in charge. To promote neighbour interactions, we were looking for teachers who were willing to travel to a central location for up to three face-to-face meetings and up to two 75-150 minute virtual meetings (Google Hangouts) over the course of the school year.

To promote internal diversity and redundancy, we were looking for teachers who were teaching at least one high school mathematics course in this district, and who shared an interest in exploring the use of technology in mathematics classroom assessment. We were also hoping to bring together teachers from different schools, and who had different teaching experiences and comfort with technology. After discussing the inquiry and these selection criteria, coaches identified teachers who they thought might be interested. The coaches' perspectives were valuable as they were already working with teachers at different schools across the district and they therefore had a sense of what teachers were working on and who might be interested. The first five teachers who agreed to participate joined this inquiry. Once university ethics approval was received, project participants were invited to become part of my research. Everyone agreed and therefore became research participants. Five teachers participated in this inquiry: Ben, Liz, Kelly, Christine, and Jennifer. Participant backgrounds are summarized in Appendix J).

Data Collection and Analysis

Participants came together for three face-to-face meetings and two virtual (Google Hangouts) meetings over the course of the school year. The first meeting was face-to-face and lasted approximately one school day, including breaks (e.g., for lunch). A month later, everyone met again for a 75-minute (one class period) virtual meeting using Google Hangouts. A second full-day face-to-face meeting took place in February, at the beginning of the second semester of the school year. Approximately two months after that, the team came together for another 75 minute virtual meeting. The final meeting was a more informal face-to-face meeting that lasted approximately one hour and took place after a presentation of findings at a provincial conference. The meeting dates, codes that I use in the findings, and participant attendance for each meeting is included in Table 3.

Table 3. **Summary of Group Meeting Dates, Attendance, and Codes**

Meeting	**Attendance**
Meeting 1 Full School Day Oct. 28 Face-to-Face	All participants attended, including: Jill (Researcher/Teacher/Project Co-Lead) Patricia (Instructional Coach/Project Co-Lead) Shelly (Instructional Coach) Brent and Sarah (Technology Coaches) Ben, Christine, Jennifer, Kelly, & Liz (Teachers)
Meeting 2 ~75 minutes Nov. 25 Virtual (Google Hangouts)	All participants attended. Coaches paired up with teachers at their schools: Brent with Christine Jill with Liz Patricia with Ben Sarah with Kelly Shelly with Jennifer
Meeting 3 Full School Day Feb. 12 Face-to-Face	All were present except for Ben, who was no longer teaching math. Brent and Sarah left at lunch.
Meeting 4 ~75 minutes Apr. 8 Virtual (Google Hangouts)	Jill, Patricia, Shelly, Christine, Jennifer, and Kelly attended this meeting.
Meeting 5 ~ 1 hour May 5 Face-to-Face	This was informal meeting after a conference presentation that not all participants attended. Jill, Patricia, Shelly, Christine, Kelly, and Liz attended.

Over the course of the inquiry, participants also communicated with each other asynchronously (e.g., by email, Google Drive). These correspondences were included as data for this study.

In order to study what was learned about technology and assessment, I analysed the qualitative data collected from our face-to-face and online activities. Data included meeting transcripts, field notes, summaries, and materials (e.g., sample assessment activities, slides prepared for district and conference presentations) gathered from the group meetings, and from the smaller group and individual meetings that took place over the course of the school year. Since data for a qualitative study can include "virtually anything you see, hear, or that is otherwise communicated to you while conducting the study," (Maxwell, 3013, p. 87), I also kept a research journal to record observations and reflections. Individual and smaller group meetings (e.g., meetings with coaches to plan and reflect) that arose between the full team meetings were only audio-recorded when participant approval was received. During all of these meetings, some of which were not audio-recorded, I took notes in my research journal.

The data were collected and analysed simultaneously, in three concurrent flows of activity: data condensation, data display, and conclusion drawing / verification (Miles & Huberman, 1994; Miles, Huberman, & Saldaña, 2014). Data condensation involved "selecting, focusing, simplifying, abstracting, and/or transforming the data that appear in the full corpus (body) of written-up field notes, interview transcripts, documents, and other empirical materials" (Miles, Huberman, & Saldaña, 2014, p. 12). This flow began prior to data collection, with the decisions that were made in planning for this study. Such decisions included the choice of a complexity theory framework, the specific focus on technology in assessment, and the planned approach to the study. Condensation continued as I organized, transcribed, summarized, and coded the data; and then generated categories, examined connections between different ideas that emerged, analysed themes that arose from my analysis of the categories and connections, and as final reports on the findings were prepared. Such reports included presenting our findings at a provincial conference, developing a website to share our learning with other teachers in the district, presenting our findings to other educators who carried out technology innovation projects in the district, and writing this doctoral thesis. Thus, data condensation was a process that flowed from the initial conceptualization of the study and continued until final reports were complete.

I used matrices to summarize categories of data and networks to illustrate and explore relationships between categories. Throughout this process of representing my data, I continued to explore relationships in the categories of ideas, insights, and understandings that emerged. I also engaged in conclusion drawing and verification by reflecting on patterns, identifying possible connections and explanations, and working to determine what the data meant (Miles & Huberman, 1994). This was an interactive process. Participants responded to my interpretations of the data and contributed to reports on the findings (e.g., to a provincial conference presentation, to developing a webpage that would summarize our learning for the district project, to district level presentations). Thus, participants played an active role in contributing to the findings that follow.

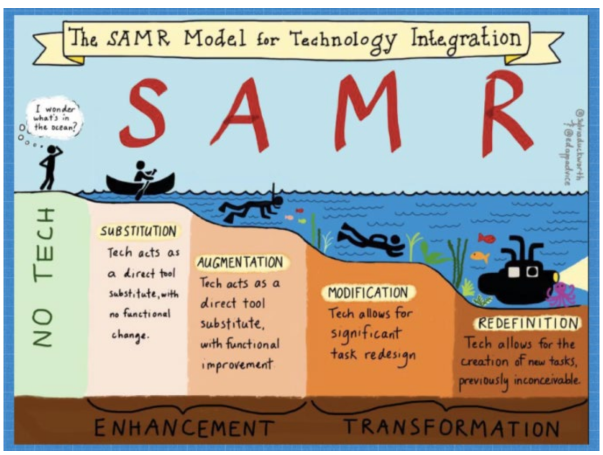
Findings

These findings are structured in a way that reflects my focus on what was learned about using technology *in* assessment. More specifically, in this section I look at what the group learned about using technology *in* assessment *as, for,* and *of* learning in mathematics. A central theme for this group concerned the importance of considering the purpose for using technology—in this case, to support classroom assessment. I elaborate on this theme below. Then, I present findings that connect to assessment *as* and *for* learning. In this case, participants stressed the importance of focusing on these more formative assessment purposes. I highlight themes that connect to these purposes and then conclude with ideas that emerged for using technology in ways that make it possible for students to demonstrate more complex understandings and problem solving processes (assessment *of* learning).

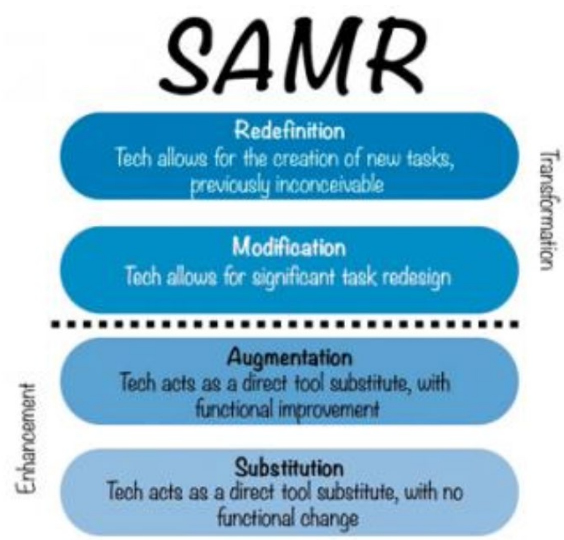
Using Technology to Enrich Assessment Practices

The analysis of participants' contributions to this inquiry shows that teachers agreed that technology should not be used for the sake of it. They stressed the importance of first considering the purpose of the technology and how it might support assessment. During our first meeting, for instance, teachers expressed that there is little value in using technology for tasks that could just as easily be accomplished without it. Kelly and Ben, for instance, questioned the use of virtual manipulatives when actual manipulatives are just as accessible (Trans, GRP_{OCT}, p. 4). During a subsequent meeting in which Shelly (Instructional Coach) and I reflected on the inquiry group findings, Shelly also questioned the value of using tools like virtual tiles in comparison to other technologies that can change the ways students interact with mathematics (e.g., dynamic mathematics software) (Trans, IND_{JAN}, p. 13). During this preliminary analysis of the first two group meetings, Shelly and I noticed that a framework might be useful and we considered some possibilities. Since the SAMR Model (Puentedura, 2013) was being used in the district at that time, we asked Sarah (Technology Coach) to share this framework with the group.

The SAMR Model (Puentedura, 2013) was introduced as a framework for thinking about moving beyond using technology for the sake of it to instead using technology to enrich assessment practices. The SAMR Model represents a shift from using technology in ways that offer little or no functional change in practice, to using technology to enhance and possibly even transform practices through ***S****ubstitution,* ***A****ugmentation,* ***M****odification, and/or* ***R****edefinition* (Puentedura, 2013). Sarah introduced the SAMR Model in connection to our focus on assessment at the third group meeting (GRP_{FEB}, p. 14-19). She included two images in her presentation to summarize this model (see Figure 5).



Sylvia Duckworth's sketchnote of the SAMR Model on Twitter (April 2, 2015)



Ruben Puentedura's (2013) summary of the SAMR Model.

Figure 5. **Images of the SAMR Technology Framework that were shared with the inquiry group.**

The image on the right in Figure 5 was created by Puentedura (2013) and the image on the left in Figure 5 shows a sketchnote diagram that Sylvia Duckworth created to summarize this model and shared on Twitter on April 2, 2015. Participants considered both of these images, which show that technology can be used to *enhance* practices when it is used as a substitute or to augment what is possible without technology. Or, it is possible to 'go deeper' by using technology to *transform* practices when it is used to modify or redefine what is possible without it.

Sarah described possibilities for using technology in each of these four ways (see Appendix K for slides from Sarah's presentation). For substitution, for instance, technology provides little or no functional improvement. Sarah suggested that a SMART Board might act as a substitute for a chalkboard when it is used to project information to students. In this case, technology offers no functional change to a task. This seemed to be the way that Kelly and Ben were thinking about virtual manipulatives during our first meeting. Augmentation, on the other hand, enhances what can be accomplished without technology (Puentedura, 2013). Sarah exemplified augmentation by explaining that students might use screencasting tools (e.g., Explain Everything) to record their voices as they explain their solutions to mathematics problems.

According to the SAMR Model, transformation happens when technology is used to modify or redefine practices (Puentedura, 2013). Modification involves using technology to change practices (Puentedura, 2013). Sarah exemplified this use by describing how a SMART Board in combination with screencasting can be used to make videos of student solution strategies visible to other students in a class. In addition to modifying current practices, technology can enable redefinition of practices. Using technology to redefine practices might be considered transformative in the sense that it is possible to do things that are impossible to do without technology (Puentedura, 2013). Sarah exemplified redefinition with the idea to combine screencasting (e.g., student-created Explain Everything videos) and other applications and having students share their learning (see Figure 6).

Figure 6. **Ideas for Using Technology to Redefine Assessment**

She explained, for instance, that students could demonstrate their understandings, or mastery of course content, by creating tutorial videos and using other applications to share their work, and having students view and respond to others' thinking. Or, students could select evidence of their "best solutions" and demonstrate their achievement of course expectations by sharing these solutions using an online collaborative platform (e.g., Padlet). This kind of interaction is more difficult to achieve without technology.

The SAMR model (Puentedura, 2013) helped to frame the ways we saw opportunities for enhancing and possibly even transforming our assessment practices. Sarah explained, for example, that this framework is useful for thinking about how technology is used:

> But I think for me what's of value is just, when I'm thinking about how I'm using technology, with SAMR I now have a context to talk about, I'm just substituting because it's making my life easier, right? Or I'm using technology in a different way to actually transform what I'm doing with my students (Sarah, Technology Coach, Trans, GRP_{FEB}, p. 17, 718-723).

The data makes a strong case for using technology to enrich assessment practices. When participants considered the various ways that technology can be used, they started to shift their views to consider how technology might help them enhance, or possibly even transform, their current practices. These transformations could be seen in the purposes of assessment, including assessment *as, for,* and *of* learning, which are highlighted next.

Technology in Assessment *as* and *for* Learning

My analysis of data that were categorized by the focus on using technology in assessment *as* and *for* learning revealed that it was important for this group of educators to focus on these assessment purposes. The importance was stressed during our second face-to-face meeting when instructional coaches, Shelly and Patricia, explained that they have noticed that it is easy to get caught up with final marks and public reporting (Trans, GRP_{FEB}, p. 2). Participants added that there has always been more of a focus on assessment *of* learning, and they wanted to more fully explore assessment *as* and *for* learning. Shelly and Kelly, for instance, described how they felt that it would be important for teachers to develop their "schema" for these purposes:

> **Shelly (Instructional Coach):** But I think the importance of focusing our learning on the assessment *for* and *as* [...] trying to keep at least reflecting on the *for* and *as* because it's

so easy to go to the *of*. So just kind of being deliberate in our thinking around that would be valuable.

Jill (Teacher/Researcher): Yeah.

Kelly (Teacher): I think we all have an *of* so that's kind of a, you know, but work on the other two.

Shelly (Instructional Coach): A schema for *of* but not a schema for *for* and *as*. Yeah.

(Trans, GRP_{FEB}, p. 4)

This segment highlights the coaches' position but also shows that teachers might feel that they have a better understanding of assessment *of* learning and that they might therefore need to delve into the more formative purposes of assessment.

The emphasis on formative assessment (*as* and *for* learning) as opposed to summative assessment (*of* learning) was evident in my coding of the data, with 27 segments coded "assessment *as* learning" and 19 segments as "assessment *for* learning," compared to only 9 coded "assessment *of* learning." This focus is understandable given that the teachers seemed to feel a need to develop their practices in these areas. In addition, while it was not stated in the data, focusing on the more formative purposes of assessment might be more important given that they can more directly support mathematics teaching and learning (Black & Wiliam, 1998). Three themes emerged with respect to the use of technology to enhance assessment *as* and *for* learning: technology can (i) improve the immediacy of feedback, (ii) support student self-assessment, and (iii) make it possible to capture and share student solutions and problem solving processes. These themes are discussed next.

Improving the Immediacy of Feedback. Teachers stressed the importance of opportunities for using technology to provide the teacher and students with more immediate feedback. Jennifer, for instance, talked about using student response systems (e.g., Kahoot!, Nearpod) with her students. She found that the instant feedback that she received helped her to quickly gauge where her students were at (assessment *for* learning) (Trans, GRP_{NOV}, p. 1). Ben also reported that the feedback his students received when they used student response systems helped them to gauge their own understandings (assessment *as* learning) and to determine whether they were ready for an upcoming summative assessment (Ben, Teacher, Trans, GRP_{NOV}, p. 5). These examples are included here to show how teachers saw technology as helping to improve the immediacy of feedback for both teachers and students.

Teachers reported that the opportunities for using technology to improve the immediacy of feedback was the “biggest piece” when it came to using technology to support their assessment practices. This sentiment was articulated at our final meeting when Shelly asked the group about the value of technology. Liz pointed out that both the teacher and students can get feedback more immediately than they would with another form of an assessment (e.g., a quiz):

> **Liz (Teacher):** Instead of waiting days because you know, sometimes you give a quiz out and you have a few people away [...] so you want to wait until they show up maybe two days later and then, but you want to give it back to them right away so you can discuss these things. At least you can discuss it with the kids who are there that day if you give them something with technology and you put it on the board and you look at it.
>
> **Patricia (Instructional Coach):** It's instant feedback, there you go. Summed it up. Two words. Good job.
>
> **Liz:** Just like anything. If they were to write a pencil and paper test, right? You want to give it back to them immediately too.
>
> **Shelly (Instructional Coach):** So it's immediate feedback for you and it's immediate feedback for them.
>
> **Liz:** Exactly. So you know where your next day's lesson's going to go.
>
> (Trans GRP_{MAY}, p. 15)

This discussion reflects the significance of instant feedback for "us" (teachers) and for "them" (students). In the sections that follow I show that teachers also found opportunities for using technology to support student self-assessment and to make it possible to capture and share student thinking. Some of the data in these sections will further exemplify the ways participants noticed technology improving the immediacy of feedback.

Supporting Student Self-Assessment. My analysis of the data revealed that teachers found opportunities for using technology to support student self-assessment, particularly when students used tools that allowed them to verify their thinking and to investigate mathematical ideas. There appeared to be a shift in thinking about the value of technology for supporting student self-assessment during our first group meeting. This conversation started with teachers expressing their frustration with students relying on technology for answers and not thinking about the reasonableness of the answers:

> **Kelly (Teacher):** That it's nice that technology can do everything for them so that they can go ahead to a more advanced problem but at what....
>
> **Liz (Teacher):** But it's not just the mental math for me. When I look at the kids and we do stuff, I'm like, "Really? Look at that answer. Does that even make sense? Is that even reasonable? Did you even stop to think about it?"
>
> **Christine (Teacher):** Yes. "But my calculator told me."

(Trans, GRP_{OCT}, p. 8)

This segment of the transcript illustrates the idea that students might use technology without thinking about the reasonableness of the information that they access.

Nonetheless, the group continued this discussion to consider how technology might be part of the solution, particularly when it is used by students to make connections and self-assess the reasonableness of their solutions. Patricia suggested that when students have access to information with technology, teaching might involve having students make estimations and judge the reasonableness of their answers. Teachers expressed their agreement (Liz, Jennifer) with this position and Christine suggested that technology might assist with that:

> **Christine (Teacher):** But even technology can help us with that, right? Because if you're having a kid say, solve a quadratic equation and hey you've got to be able to solve it by factoring and use the quadratic formula. Well if they mess up their calculations there but they could check it using graphing technology and go, "Hey wait a minute, my answer's not jiving." Like there's one way to check that it's reasonable from your graph on your technology.
>
> **Patricia (Instructional Coach):** And making all those connections.
>
> **Christine (Teacher):** Yeah exactly.

(Trans, GRP_{OCT}, p. 8)

These segments illustrate a shift from seeing technologies that provide access to mathematics information and solutions as a barrier to seeing them as part of the solution. More specifically, this segment exemplifies how participants identified opportunities for using technology to support self-assessment, or assessment *as* learning, when students are expected to consider the reasonableness of information and to verify their thinking by making mathematical connections. The importance of these skills has been emphasized recently by Dylan Wiliam on Twitter, with a statement that "maybe there are some generic 21st century skills after all, such as learning how to initially evaluate the trustworthiness of online sources" (Wiliam, 2017).

My analysis of data that were categorized according to a focus on using technology in assessment *as* learning provided evidence that teachers found opportunities having students use applications on their personal electronic devices to support assessment *as* learning. Liz, for instance, found that after she used dynamic mathematics software (Desmos) for an investigation with her students, they started to use this tool to self-assess their answers, without her prompting them:

> So they [students] were using Desmos to try to figure out what the parameters *a*, *h*, and *k* do to your base graph. And the kids really enjoyed it. They picked it up really quickly. I was using the iPads that we have at school and after a while they... I didn't have to bring the iPads in because all the kids have phones and then they would just pull out their phone while we were working and they would pull out Desmos and they would use it to check their work or look something up. (Liz, Teacher, Trans, GRP_{NOV}, p. 2)

Thus, in addition to using tools like Desmos to receive instant feedback as students investigated connections between mathematics representations, Liz found that her students continued to use these tools to verify their answers. Therefore, with this technology, Liz found that her students were engaging in assessment *as* learning.

To summarize, the data from this study, including the examples above, shows that the teachers found ways to support student self-assessment with technology. With calculators and dynamic software, or perhaps with online search engines, they found that students can verify their thinking and solutions. Participants cautioned that with technologies that make answers easily accessible, however, it is important to expect students to judge the reasonableness of mathematics information and solutions. In addition, by making connections through mathematics investigations, teachers identified opportunities for students to self-assess their understandings of different mathematical representations. Some teachers in the group also found that as students gained experience with applications that are available on their personal devices, they continued to self-assess by using these tools in the same ways without being prompted. More research is needed, however, to examine how students can become more self-regulated learners through the use of technology for self-assessment.

Capturing and Sharing Student Solutions and Problem Solving Processes. My analysis of participants' contributions with respect to the focus on using technology in assessment *as* and *for* learning showed that teachers found opportunities for using technology to help capture and share student work and problem solving processes. Some of the applications that were considered in this inquiry included closed student response systems (e.g., Kahoot!, Polleverywhere, eqaoquizzer, KnowledgeHook, Plickers), open text response applications (e.g., Polleverywhere), and other technologies that make it possible for students to share drawings, videos, and pictures of their work (e.g., Nearpod, Padlet, AirPlay). With these kinds of tools, it is possible for the teacher and students to receive immediate feedback. The form of this feedback varies, however, with the closed response systems indicating whether a multiple choice answer is correct or incorrect. Open response applications, however, make it possible to capture and share more detailed responses. With some of these applications, students can even share images or videos of their solution strategies. Teachers shared some of the ways these systems helped to support their assessment practices.

A student response program, Nearpod, made it possible for students to submit text, images, or drawing responses. Nearpod is an interactive mobile presentation application that can be used for polls, closed response items (e.g., multiple choice), short answer questions, and drawing responses. Students can use this application to "draw" using a whiteboard interface or they can take a picture of their work to share with the class. When teachers discussed their experiences with using Nearpod, they recognized that this type of technology is particularly valuable for making students accountable for their contributions. Jennifer explained, for instance, "for accountability I thought it was great because you can just click on and see what everybody's working on. And for comparison purposes. So used it for assessment *for* learning mostly I guess" (Trans, GRP_{NOV}, p. 1). Christine also described how this technology made it possible for her to see what her students were doing and she was able to use her observations to inform her next steps in a lesson:

> I can see my computer screen what they're doing on Nearpod so I mean I kind of try to keep an eye on that to know, "Oh you know, here's a good one to show." Or "Here's, you know, I can see a few of them are making this common mistake." So I kind of know as they're doing it what I kind of want to pull up and then I'm able to pull it up pretty easily. (Christine, Teacher, Trans, GRP_{FEB}, p. 7)

Christine's description of her use of Nearpod to "keep an eye on" misconceptions provides insight into the possibility for using technology to facilitate assessment *for* learning.

Online sharing and collaborative spaces were also found to be valuable for making student thinking visible. Some teachers chose to use an online collaborative platform in their classrooms. Christine, for example, described how she had her students use Padlet as a place to "check in" by prompting them to ask or answer questions, and/or to share examples:

> Right on that Padlet I would have, here's the topic, here's the success criteria, the learning goal, whatever that was, and here's the link to the video. And then I would have things where they could post something like if they had a question or, you know, give me an example of this. Or what's the difference between this and this? And I basically told them, in the unit you have to post, I don't know I gave them some number, like at least three times or five times. In the unit you have to post somewhere, just as kind of a check-in. (Christine, Teacher, Trans, GRP_{FEB}, p. 17)

In this way, Christine found that she could get a sense of their thinking (e.g., student understandings of specific topics, questions that students had) and students could receive feedback on their ideas. Again, this example illustrates a possible opportunity for supporting assessment *as* and *for* learning. By using Padlet to capture student questions and ideas, Christine was implementing technology in a way that provided students with opportunities to reflect on their own thinking (assessment *as* learning), and she (the teacher) used this information to plan her next steps (assessment *for* learning).

To summarize, this analysis of what was learned about using technology in assessment *as* and *for* learning revealed that the opportunity to receive more immediate feedback was important to this group. Of course it is possible for teachers and students to receive feedback without technology. Students can use whiteboards or chalkboards to display their thinking or they can write paper-and-pencil quizzes, for example. In this case, however, teachers appeared to find that technology presented opportunities to enhance their practices by making it possible for them and their students to more immediately access evidence of student learning than without technology. With student response systems, for example, teachers reported that they could quickly gauge student understandings. Or with dynamic mathematics software, they found that students could self-assess their understandings by making connections between algebraic and graphical representations of mathematical relationships. Further research is needed, however, to better understand how formative assessment can be transformed in technology-rich mathematics learning environments.

Technology in Assessment *of* Learning

Participants identified opportunities for using technology in assessment *of* learning. Summative assessment was not a central focus yet participants found that technology can help students demonstrate more complex understandings and problem solving processes. Participants, particularly the coaches, considered possibilities for transforming assessment *of* learning by having students demonstrate their achievement of curriculum expectations in a new way. More specifically, they envisioned an online portfolio approach in which students use technology to curate content (e.g., sample of best work) over the duration of a mathematics course. These two opportunities for using technology to support assessment *of* learning are highlighted next.

Demonstrating conceptual understandings and problem solving processes. My analysis of participant contributions that were categorized by the focus on using technology in assessment *of* learning provided evidence that participants found that technology can make it possible for students to demonstrate more complex understandings and problem solving processes. Kelly's description of how she incorporated technology in a summative assessment, for instance, exemplifies her finding that technology can help students move beyond technical skills like graphing when the purpose of an assessment is to have students demonstrate more complex processes like their ability to interpret graphs of linear systems:

> My grade 10's, so we've been using Desmos just to show like linear systems and that kind of stuff and one boy asked, "Well do we get this on the test?" And I said, "The test, I need to see that you can graph by hand, that you can solve by substitution, elimination, do the word problems and all that stuff." And then I have a task that uses all of that but that's not the important part. [...] I'd seen that they can do elimination, substitution, now I need to see, can you, you know, pick the right one, get the number, and then use that number to go on and get something else. I said, when that big task comes, then you can use the technology to get the answers. Then use the answers to continue. So there's two parts of it where I've already had a look at [...] do [you] have [the] knowledge to do the basics but now use the technology because I've just up'd the ante on this task you're going to get.
>
> (Kelly, Teacher, Trans, $GRP_{FEB,}$ p. 6).

Her description shows that with technology she found that it can be possible to separate the assessment *of* more basic skills, like graphing and solving systems algebraically, to focus on more conceptual understandings. She also emphasized, however, that she was 'upping the ante' of the task by expecting students to do more than "the basics." Kelly shared examples of specific questions that lend themselves to the use of technology. These examples are included in Appendix H.

Participants stressed the need to consider the purpose of a summative assessment (e.g., for students to demonstrate mathematics skills versus problem solving processes) and then how technology can support this purpose. The importance was emphasized during the first group meeting when Jennifer pointed out that given technology capabilities, we need to consider how to preserve the integrity of formal assessments by thinking carefully about the questions that we are asking. Following a discussion of some of these capabilities (e.g., accessing full mathematics solutions), Shelly challenged the group to consider whether it is actually “cheating” to use technology for assessment:

> **Shelly (Instructional Coach):** Is it cheating if they leave school and they're going to use that in their life? I'm just throwing that out there. I'm not saying that it is. I'm asking the question.
>
> **Jennifer (Teacher):** Well it depends what you're asking them to do. Like we were also talking about like, in the curriculum, they have to be able to graph without technology.
>
> **Christine (Teacher):** That's right. Exactly.
>
> **Jennifer (Teacher):** So if they're using it to check their answer while they're supposed to be doing it out of their heads then yes that's cheating. Right? It's like what's the [curriculum] expectation that you're evaluating?
>
> (Trans, GRP_{OCT}, p. 6-7).

This conversation reflects the perspective that whether or not it is “cheating” when students use technology for formal assessments depends on the purpose of that assessment. If the purpose is to capture more complex understandings and problem solving process then technology might be valuable (see Kelly's description above). Or, technology might enhance a paper-and-pencil task by making it possible to capture student thinking with video recordings of their explanations. On the other hand, if the purpose of a summative assessment is to assess procedural skills, perhaps technology (e.g., calculators, dynamic software) is not appropriate. The data from this study suggests that this group found that it is important to first consider the mathematics expectations that are being evaluated before deciding if technology is appropriate for a formal summative assessment.

Curating Samples of Student Work to Demonstrate Learning. Participants, particularly the coaches, described how they envisioned using technology to transform assessment *of* learning with online portfolios. They reflected on how students can use technology over the span of a mathematics course to curate evidence (e.g., images or videos of their work) or their learning. This idea was presented by technology coaches at the second face-to-face meeting. Sarah described what a summative assessment might look like if students were to use technology to demonstrate their mastery of curriculum expectations:

> So what we were thinking of is if you're thinking about Explain Everything [screencasting software], right? Where they can capture their thinking. What a neat opportunity for students to be able to show their mastery in a different way. Because we all know our students are engaged in technology so why could they not create videos, right? That show their understanding of a concept and explaining it, and then post it somewhere the others can see it, either within the class or outside the class. So the whole idea that they could actually, with a concept, literally make their own course to show their mastery of an idea. (Sarah, Technology Coach, Trans, GRP_{FEB}, p. 15)

Students could create hard-copy portfolios. With technology, however, they can record and share more dynamic representations of their work (e.g., student-created video explanations, student-created dynamic mathematics sketches to illustrate their thinking); thus presenting an opportunity to transform assessment *of* learning.

The possibility of using technology to support a more integrated approach to assessing student understandings in mathematics was considered in this inquiry. Some of the teachers were exploring an approach to spiralling curriculum expectations in cycles rather than teaching expectations in discrete units. The following discussion shows how an idea for aligning assessment *of* learning with this approach by having students choose how to demonstrate their learning throughout a course emerged:

> **Brent (Technology Coach):** I was thinking just now. If you're spiralling [...] now you're pulling stuff from different cycles to address that understanding of those expectations. So

> now maybe it will help the students say, "Oh, I see what you've done here. I see what you're doing to me."
>
> [...]
>
> **Brent (Technology Coach):** And they can continually add to it, keep coming back and saying, "Okay now I have either a deeper understanding or a different example of whatever. And maybe that would help them piece it together, I'm sure.
>
> [...]
>
> **Sarah (Technology Coach):** And when you talk about student voice, right? And allowing them to choose how they show their work. Like it could be a picture of something they've done. Kind of thing [...] it could be an Explain Everything file so it just gives them that autonomy to decide, you know, what's the best example of... here's where I mastered this skill or this idea.
>
> **Jennifer (Teacher):** [...] so it's exactly what you were talking about before, how they're choosing what goes in.... like they're building their own assessment in a way but it has to have all of these things in it. Like they have to demonstrate all of these things but they're choosing how to demonstrate it, which is very different from normal math exams.
>
> **Sarah (Technology Coach):** Yeah. And I think when you talk about the challenges, right, that technology presents and yeah, there's now apps that you take a picture and there's the answer, right? Like you can't do this with these sorts of situations. (Trans, GRP_{FEB}, p. 16)

Sarah's comment provides insight into a possible solution to a problem, identified at the first group meeting, with students having access to answers at their fingertips. Connecting the online portfolio idea that is considered here to this "challenge," her comment suggests that the problem might be minimized (or even nonexistent) if students are collecting evidence of their work (e.g., pictures or videos of their work) throughout a course. This possibility was not considered further by the group, however.

As may be evident in the above transcript excerpts, it was mainly the coaches (Sarah, Brent, and Shelly) contributing to this idea for transforming assessment. Even though different possibilities evolved from this conversation, it is unclear from the data whether any of the teachers incorporated this idea in practice. In terms of my own teaching practices at the time, I incorporated some of ideas that emerged from this inquiry. I chose to explore the use of screencasting with students creating videos to demonstrate their learning with respect to specific curriculum expectations. I chose not to pursue the idea of having students create an online portfolio to curate evidence of their learning, however. At the time, I did not feel that I, or my students, were ready for this. Perhaps other teachers were not ready or not interested in pursuing this idea at the time. Or, with the collective decision to focus on assessment *as* and *for* learning, perhaps it was an idea that did not directly align with their goals. Regardless, this approach reflects one possibility for using technology to transform assessment *of* learning in mathematics.

The Boundaries of Our Technology in Assessment Focus

The inquiry was designed to offer multiple entry points, to embrace the emergence of unanticipated participant contributions, and to, at the same time, bound our learning by focusing on using technology in assessment. Thus, the intention was to establish a "proscriptive" rather than prescriptive inquiry focus (Davis & Simmt, 2003, p. 155). The risk with a focus that is too narrow and prescriptive is that there can be little room for new ideas and creative insights to emerge (Davis & Simmt, 2003). If, on the other hand, the inquiry was unfocused, then there would have been little room for participants to grow and learn together. In this case, the inquiry was designed to bound our activities and to at the same time embrace diversity in teaching experiences, comfort with technology, and interests with respect to the use of technology in assessment. Since boundaries that promote emergence and at the same time enable interactions are impossible to establish in advance, they must be "refined and negotiated" in practice (Davis & Simmt, 2003, p. 154). In this section I describe how a shared inquiry focus took shape in this context.

Coming to a Shared Understanding of the Purposes of Assessment. The first step in establishing a collective focus was to come to a shared understanding of assessment. In this case, we chose to focus on particular purposes of classroom assessment: assessment *as, for,* and *of* learning (Earl, 2013; OME, 2010). During our first meeting, the inquiry team divided into three subgroups and each subgroup focused on one purpose. This process involved examining assessment policy statements and literature, and summarising the ideas in a shared online Google Document (see Appendix D). Then, the entire group discussed each purpose.

During the assessment conversation at our first meeting, participants highlighted that assessment *for* and *as* learning are ongoing processes, and that regular feedback is essential for supporting student learning. One statement that was included in the shared document, for example, indicated that "teachers make judgment about students' understanding/skills related to the overall expectations after having offered several opportunities to improve their learning" (Doc, GRP_{OCT}, p. 2). This statement reflects the need for students to have regular feedback on their learning. As already highlighted in the findings, the group found opportunities for using technology to improve the immediacy of feedback, and to perhaps support ongoing feedback. For instance, teachers found that student response systems (e.g., Kahoot!, Nearpod, Plickers) helped students gauge their understandings. Additionally, tools like calculators and dynamic mathematics software helped students to receive instant feedback as they made connections through mathematics investigations. Students also continued to use apps like Desmos, which was available on their personal electronic devices; thus supporting ongoing self-assessment without the teacher prompting. Thus, the importance of regular feedback was stressed by participants, and for this group of educators, the "biggest piece" when it came to using technology was the opportunity to improve the immediacy of this feedback.

When it came to assessment *as* learning, participants stressed that teachers should model self-reflection and provide opportunities for students to set goals, to monitor their own progress, to reflect on their learning, and to determine their next steps (Shelly, Instructional Coach, GRP_{OCT}, p. 12). Sarah added that "as a *lead learner* in the classroom," the teacher should model self-reflection, and eventually students would become more self reflective (Sarah, Technology Coach, Trans, GRP_{OCT}, p. 12). The findings above suggest that technology might support some of these activities. Participants also emphasized, however, that students should be expected to consider the reasonableness of the information that they access with these tools. Thus, for this group, self-reflection was an important part of assessment *as* learning and technology offered opportunities to support this assessment purpose.

When assessment *for* learning was discussed at our first meeting, participants emphasized that this purpose is ongoing, interactive, and important for informing next steps for mathematics instruction and to support student learning. Patricia summarized the ideas that emerged during our subgroup discussion of this process:

> Very much this two-way involvement [...]. The *for* is very much student with teacher. Teacher with student and a little bit of student to student as well. So it's very two-way [...]. It's to inform instruction, our instruction, in many different ways and that also means that it gives you your next steps. It helps you with differentiating the instruction for different kids

> [...]. It's gathered through a variety of different ways so it's not just paper and pencil testing. We need to look at that big T word down there, Triangulation [...] it doesn't have to be formal assessment. It could be, you're having a conversation with a student. You notice something that they're doing while they're explaining something to you. And you think, "Oh, that kid doesn't get this bit. I need to do this with them." So it doesn't have to be a formal assessment. It can be sort of ongoing casual type of assessment. (Patricia, Instructional Coach, Trans, GRP_{OCT}, p. 13).

This segment highlights the importance of gathering information to inform next steps, and of using triangulation (e.g., information from conversations, observations, student created products) to get a sense of where students are at and to determine appropriate next steps.

When it came to considering assessment *of* learning, a statement that Jennifer (Teacher) noted in the shared Google Document became the primary focus of our conversation. Jennifer disagreed with her interpretation of a Earl's (2013) statement that in assessment *of* learning, other students are the "reference point". She explained that assessment *of* learning should be criterion-referenced (e.g., based on criteria outlined in mathematics curriculum), and that teachers should make judgements about student learning that are based on curriculum expectations rather than by comparing with other students:

> It [statement in Earl, 2013] said 'other students' and I thought that seemed contradictory to me because we're supposed to be doing criterion-referenced assessment which means we're always referring back to the achievement chart and how, where they fit in that with the expectations. But saying that the reference point is other students means like we're back in the... 'How many Level 4's do I have?' And 'Oh I thought yours was good until I saw his.' (Jennifer, Teacher, Trans, GRP_{OCT}, p. 13)

In the end, participants agreed that this statement is "completely opposite" to the assessment policy in the context of this study, and so this note in the shared document was revised to state, "reference point - criterion-referenced NOT norm-referenced." Brent summarized that it is acceptable to disagree with the literature: "if we come to a common understanding outside of that [literature] then let's roll with that" (Brent, Technology Coach, Trans, GRP_{OCT}, p. 14). After reflecting on the three purposes of assessment, the next step in refining our inquiry focus involved considering how different tools might be used to support these purposes.

Negotiating and Refining a Technology in Assessment Framework. We co-constructed a technology in assessment framework during the first inquiry group meeting. This process involved considering one tool at a time and discussing how each tool might support the assessment purposes. During this conversation, Shelly (Instructional Coach) and Sarah (Technology Coach) recorded the ideas that emerged in a shared document (see Figure 5).

	Technology					
	Plickers	Desmos	MyScript Calculaor	Padlet	Kahoot	Nearpod
As		- students can self check their work or peers (using comments)	- in some ways it's replacing the answer key (not higher order thinking)			
For	- beginning as a diagnostic - quick check on learning - more about group understanding vs individual understanding	- students are investing on their own (i.e. relationships) and use AirPlay to share				-beginning as a diagnostic -quick check on learning -to gather individual and group data (by student and by item)
Of		- can print screen and use graphs for assessments of learning				
			does not lend itself to assessment as much as it is an instructional tool			
Overview:	www.plickers.com	www.desmos.com		www.padlet.com	www.kahootit.com to play www.getkahoot.com to make	
	- app (information on website)	- app but also web based	- app	- web based & app		
	- simple tool to collect real-time assessment data	- free online graphing calculator	-handwriting calculator	- a collaborative space to share resources or thinking	-can highlight individual solutions	
		- does not need to be y=mx+b format				

Figure 5. Ideas for using Technology in Mathematics Classroom Assessment

Since teachers had different experiences and comfort with the technologies, this process involved a brief introduction to each tool (e.g., demonstrating some of the functionalities, sharing how it might be used in practice), an opportunity to try it out, and a discussion of possibilities for using it in assessment.

This technology in assessment framework was only a starting point as we started to organize our ideas for using technology in assessment. Over the course of the project, teachers were encouraged to choose (and adapt) these ideas and/or to come up with different strategies that would support their practices. During the second meeting, for instance Patricia, an Instructional Coach, emphasized that there was no pressure to try everything. She stated that "just because we learn about some software here, that doesn't mean to say you have to go out and use that straight away. So it's kind of like that permission amongst ourselves not to" (Patricia, Trans, GRP_{FEB}, p. 21). The need for teacher choice was most evident during the second inquiry group meeting, when one participant expressed that she felt overwhelmed by all of the different technologies:

> I don't know, not necessarily fear, but the coaches are exposed more to what is out there than we are and so I find that in the last meeting and this meeting that apps and whatnot are brought to us but it's really the coaches who have the expertise in the apps so it would be nice to, as [Sarah] said, try one or two things and figure that out rather than a whole pile of stuff. (Kelly, Teacher, Trans, GRP_{NOV}, p. 6)

Patricia responded by saying that this was a good point and that it would be important to choose a smaller number of tools (or perhaps one tool) and to become more comfortable with the technology.

The coaches continued to encourage teachers to slow down and to choose tools that were relevant to them. At our final team meeting, Shelly explained that in a technology-focused project like this, there is "always this fear of overwhelming people." Everyone agreed that in the end, they did not find the inquiry overwhelming because of the flexibility to choose what worked for them. Christine, for instance, articulated the importance of allowing teachers to choose according to their comfort:

> It was never a, "You have to do this" though, right? It was "Here are some things that you might want to try." And there's not a lot of scariness that goes along with that. You're either going to try them or you're not. Or you're going to say, "Hey, I think I can try this one thing. Or I think I can try these four things but you pick it at your comfort level. (Christine, Teacher, Trans, GRP_{FEB}, p. 10)

This statement reflects the importance of teacher choice, particularly when teachers in this technology-focused inquiry had different comfort and experiences with using technology.

Under the umbrella of our collective focus on technology in assessment, teachers chose their goals. These goals were articulated at our first meeting, for instance in a shared online document (Google Document) (see Table 2 on page 23). The range of teacher goals in this context (e.g., from integrating different technologies in order to develop a blended learning environment through the use of a flipped classroom to gaining confidence with one or two tools) all fit under the umbrella of our overall focus on technology in mathematics classroom assessment. The process of identifying goals and reporting on experiences became more informal during subsequent meetings and typically involved each participant in sharing the ideas that he or she was exploring, observations and reflections, and next steps.

To briefly summarize, the inquiry group negotiated and refined a shared focus on using technology in assessment. This process involved first reflecting on the purposes of assessment and then considering how technologies can be used to support these purposes. From my analysis of teachers' contributions to this inquiry, it is evident that teachers can be overwhelmed by the possibilities, however. It was therefore important for teachers to explore a manageable number of tools and/or ideas in order to gain confidence with using technology in practice.

Discussion and Conclusions

This study of what a small group of educators learned about using technology in mathematics classroom assessment has drawn on the insights of educators who, as key stakeholders in educational research, bring valuable insights from the field to research (Kieren, Krainer, Shaughnessy, 2013). This study revealed themes in the opportunities that participants found for using technology to enrich their formative assessment practices. These themes included the potential to:

- improve the immediacy of feedback to students and teachers,
- promote student self-assessment, and
- capture and share student work.

Even though this group chose to focus primarily on formative assessment, ideas for using technology in assessment *of* learning emerged. In this case, participants identified opportunities for using technology to change the way students can demonstrate their learning in mathematics. These findings contribute to prior research and to professional literature that highlights implications of technology for assessment in mathematics (e.g., Stacey & Wiliam, 2013; Webel & Otten, 2015). In this section I discuss contributions of this study of a technology-focused inquiry, including: (i) structuring a shared inquiry focus, and (ii) using technology to enhance and/or transform assessment *as, for,* and *of* learning in mathematics.

Structuring a Shared Inquiry Focus

Technology is always changing and despite decades of research and curriculum emphasis, it can have little impact on classroom practice (Clark-Wilson, Robutti, & Sinclair, 2014). Studies have pointed to a need to support teachers' professional learning about the ways in which technology can be integrated in practice (Goos & Bennison, 2008; Johnson, Riel, & Froese-Germain, 2016). The above findings show that a diverse group of educators, with a range of teaching and technical experiences and interests, can work together to grapple with using technology to support their mathematics classroom assessment practices. In order to embrace the diversity in this group, and to at the same time bound a collective focus, participants contributed to a shared inquiry focus.

This focus reflects a "proscriptive" structure (Davis & Simmt, 2003, p. 155); in this case, for the knowledge of technology and assessment that took shape. Davis and Simmt have described proscriptive structures as being flexibly organized:

> The structures that define complex systems [...] maintain a delicate balance between sufficient organization to orient agents' [participants'] actions and sufficient randomness to allow for flexible and varied response. Such situations are matters of neither 'everyone does the same thing' or 'everyone does their own thing' but of everyone participating in a joint project. (Davis & Simmt, 2003, p. 155)

In this case, the inquiry was structured to offer multiple entry points and to allow for the emergence of new ideas and creative insights.

It is impossible to decide in advance how a proscriptive focus will take shape (Davis & Simmt, 2003). The above findings show that an inquiry focus was negotiated and refined through the processes of working towards a shared understanding of the purposes of assessment and then considering how different technologies can support these purposes. Further research is needed to better understand how a technology-focused inquiry can be supported. Since this inquiry included educators who represented a range of roles (e.g., instructional coaches, technology coaches, teachers, researcher) and participant attributes (e.g., teaching experiences, comfort with technology, curricular goals), this is a valuable context for this analysis. Therefore, in an analysis focused on the dynamics of this inquiry community, I examine how our learning was supported and I aim to provide insight into how a similar inquiry might be supported (see Lazarus, 2020b).

Using Technology to Enhance and/or Transform Assessment *as, for,* and *of* Learning

A common theme in this inquiry concerned the need to move beyond using technology "for the sake of it." This need has been identified in prior research. In their review of the ways in which technology is changing assessment in mathematics, for instance, Stacey and Wiliam (2013) argued for a principled approach to integrating technology and assessment. They advocated for applying the National Research Council Mathematical Science Education Board's (1993) principles: by focusing on mathematics that is important for students to learn (mathematics principle), enhancing student learning (learning principle), and supporting all students in demonstrating their understanding (equity principle). Likewise, the data in this study makes a strong case for carefully considering the purpose of technology for assessment. In this case, the group considered possibilities for enriching their practices by incorporating technology in assessment *as, for,* and *of* learning in mathematics.

Extending Ruben Puentedura's (2013) SAMR Model, my analysis of what was learned in this inquiry shows that teachers found opportunities for using technology to enhance and possibly even transform their practices. In this case, there was diversity in the ways participants thought about using technology in assessment. After our first meeting, for instance, one teacher expressed her need to focus on particular tools before considering their use in assessment, while another teacher identified her goal to incorporate dynamic mathematics software into investigations that students previously used paper-and-pencil for. Another teacher aimed to integrate tools to support assessment in a "flipped classroom." Thus, these kinds of approaches show that there appeared to be a range in what teachers were working towards: gaining comfort with the technology, to potentially *enhancing* and/or *transforming* their practices. This diversity is reasonable given the range in teaching experiences, comfort with technology, and interests in the group. Despite the different participant needs, however, common themes emerged in the ideas for using technology in assessment *as, for,* and *of* learning.

In this case, participants expressed the importance of focusing on formative assessment (*as* and *for* learning). Teachers stressed that with technology they and their students received more immediate feedback. Thus, technology seemed to improve the efficiency of their current practices. Prior research that describes technology-rich formative assessment practices shows similar opportunities and provides insight into some of the challenges. Panero and Aldon's (2016) findings, for instance, echo the theme in the inquiry group's finding—that technology can support formative assessment practices. Panero and Aldon observed a Grade 9 mathematics class to understand how a teacher processed information that he received from student use of technology (e.g., tablets, student response systems) and how he used this information to inform his teaching. Their case study shows how this teacher evolved his assessment practices with technology. More specifically, they found that technology helped to facilitate formative assessment processes by improving the efficiency of ways in which a teacher can collect, interpret, and use evidence of student learning. Likewise, Clark-Wilson's (2010) classroom-based study of a group of seven mathematics teachers revealed that with technology (a networked handheld system) teachers were able to develop new, and support existing, formative assessment practices by gaining more insight into students' sense making processes and by increasing opportunities for student self- and peer assessment. Clark-Wilson's study also shows, however, that teachers may need to develop strategies to respond to increased amounts of classroom evidence. Even though this issue did not emerge in this collaborative inquiry, Clark-Wilson's findings point to an important consideration when it comes to using technology to more efficiently gather and use evidence of student learning.

Panero and Aldon's (2016) study also shows "that the formative assessment strategies present in the teacher's intentions were reinforced and augmented by the use of technology" (p. 84). Likewise, while teachers in this collaborative inquiry emphasized the importance of "upping the ante" of their assessments, and the SAMR Model seemed to provide a framework that aligned with this intention, it is unclear whether the teachers in this group actually moved beyond using technology to reinforce or augment their current practices. The group generated some ideas to enhance (to **S**ubstitute or **A**ugment what is possible without technology) and to possibly even transform (**M**odify or **R**edefine) their assessment practices (Puentedura, 2013) but further research is needed to describe specific classroom practices that fit within this framework. For instance, teachers in this inquiry group stressed that technology can be part of the solution when it comes to having access to mathematics information and to new ways to interact with mathematics representations. Teachers emphasized that there needs to be more emphasis on having students make connections and judge the reasonableness of this information. But what does this look like in practice? How can using technology in assessment *as* learning impact student learning? What are the opportunities for students? What are the challenges? How can teachers support students in making these connections? These kinds of questions might be considered by teachers and researchers.

This group focused primarily on developing their formative assessment practices with technology. Other professional inquiries and/or research might explore more specific ideas for using technology in assessment *of* learning. In this case, some participants found that technology made it possible for students engage with more complex problems in summative assessments, and to demonstrate more complex understandings and problem solving processes. Participants emphasized that in order to preserve the integrity of a summative assessment, teachers need to carefully consider the purpose of an assessment. For example, if the purpose is to have students demonstrate their ability to solve quadratic equations algebraically then allowing access to technology can be problematic. On the other hand, if the purpose is to have students demonstrate their ability to interpret solutions to linear systems then a teacher might allow students to use dynamic mathematics software (e.g., Desmos) to determine solutions graphically. Kelly shared this idea and a task that she created for a class that she was teaching (See Appendix M). Further research is needed to describe what this looks like in practice, however. How can students use technology to demonstrate their learning in mathematics? What are the affordances of technology? And what are the challenges?

As a teacher in this context, I was able to explore ideas that emerged in connection to my own practices and I incorporated some of these ideas into my own practices. The following vignette illustrates how I adapted some of these ideas to design a summative assessment task (a copy of this task is included in Appendix M):

> *I wished to design an assessment task that would allow students in my Grade 10 mathematics class to demonstrate their ability to "manipulate algebraic expressions (factor & expand), as needed to understand quadratic relations," and to "identify characteristics of quadratic relations (graph, table of values, equations)." Students had access to their personal electronic devices, and to applications that were available on school devices. They could use calculators to verify calculations and/or graphing software to explore connections between the different representations. Since several participants in the inquiry group were using Explain Everything, screencasting software, I decided to try this application. I designed a task that required students to explain connections between characteristics and connections between the algebraic, numerical, and graphical representations of quadratic relations. To "preserve the integrity" of the assessment, each student received a different quadratic equation and was expected to convert between different forms of the equation, to describe what each form told him/her about the graph, to sketch the graph and identify key features, and to show the table of values and justify using the pattern in the table of values, that the relation was quadratic. Some student thrived with the use of technology. I experienced some technical issues, and challenges with students who were uncomfortable with recording their voices, but also found that the*

> *visual and voice representations exposed more of their thinking processes and the connections that they were making.*

Even though assessment *of* learning was a personal interest and other participants tended to be more interested in developing their practices with technology in assessment *as* and *for* learning, I learned alongside my colleagues in this inquiry and found ways to integrate different ideas to develop my own practices. Thus, while our individual goals and practices might have differed, this study revealed practical ideas and insights into the use of technology in mathematics classroom assessment.

CHAPTER 4: Supporting a Technology-Focused Collaborative Inquiry: A Case Study

Abstract. With the ever-changing technological landscape comes a need to reflect on how technology might support mathematics teaching and learning (NCTM, 2014). In an effort to explore the use of technology in mathematics classroom assessment, a small team of educators came together for a collaborative inquiry. This article highlights the dynamics of this inquiry community, with specific attention to the ways our learning was supported. Participants included six high school teachers with diverse experiences and comfort with technology (including a doctoral student researcher), two instructional coaches, and two technology coaches. This collaboration was blended, with both face-to-face meetings and online communications. Informed by the perspective that particular conditions can help prompt and bound leaning in a complex system (Davis & Simmt, 2003), the findings suggest that a technology-focused inquiry can be supported by decentralizing control and enabling interactions so that teachers have opportunities to "bump ideas." In this case, technology helped to enable interactions and project leaders, particularly instructional coaches and technology coaches, helped to facilitate the activities by sharing leadership roles and responsibilities (Bruce, Jarvis, Flynn, & Brock, 2011). More specifically, coaches helped to: (i) *manage* the inquiry activities (e.g., organizing meetings) and classroom evidence (e.g., helping teachers collect and share classroom evidence), (ii) *mediate* between the inquiry group and external groups, (iii) *model* technologies and technology rich assessment practices, (iv) *mediate* to help mitigate technical demands, (v) *motivate* the use of technology in assessment, and to (vi) *mediate* and *motivate* by providing in school technical and instructional support. This article concludes with recommendations for supporting a technology-focused collaborative inquiry.

Keywords: Mathematics Education, Collaborative Inquiry, Technology-Focused Inquiry, Distributed Leadership

With the ever-changing technological landscape comes a need for ongoing reflection on the ways technology might be integrated into the mathematics curriculum (National Council for Teachers of Mathematics [NCTM], 2014). But how might professional learning be supported when technologies are constantly changing and when teachers are at different places in terms of their curricular goals, their teaching experience, and their comfort with technology? Consider the following scenario, for instance:

> *Students in Mr. Jones's class are solving proportions. John pulls out his personal electronic device and uses a digital handwriting calculator to find a solution. In another classroom, Ms. Miller, an instructional coach, is working with Ms. Highsted, whose students are solving quadratic equations. Jane uses an app on her tablet to scan an equation and she receives a full algebraic solution. Jane then uses a dynamic mathematics app to graph the function and determine the reasonableness of the algebraic solution. She records her screen and shares a video of her solution with Matthew,*

another student in this class. Next week, Ms. Smith, a math consultant, overhears the teachers talking about their experiences. Mr. Jones is uncomfortable with technology and is feeling overwhelmed by what he is seeing students doing. Ms. Highsted is excited by the possibilities but wants to learn more. After hearing these teachers' dilemmas, Ms. Smith agrees to support a group of teachers and coaches in the district to explore the ways technology might be integrated in practice. She puts out a call for teacher-directed technology-focused project proposals. Ms. Miller and Ms. Highsted respond with a proposal to bring a group of educators together to explore the ways technology might support mathematics classroom assessment. The project is approved. Ms. Miller and Ms. Highsted wonder, however, how will they facilitate this inquiry? How can they lead without directing the activities? And how can a group of educators work together to grapple with using technology in assessment?

The first part of this scenario offers only a snapshot of some of the ways technology might be integrated in mathematics classrooms. As a teacher, these are the kinds of experiences that led me to plan a collaborative inquiry in which a team of teachers and coaches would explore the ways technology might support mathematics classroom assessment. At the same time, as a graduate student, I wished to better understand the dynamics of this inquiry community. As a project leader, I wanted this to be a collaborative project and while I had a plan to support this goal, it was impossible to know in advance how our activities would play out. In this paper, I analyse the dynamics that emerged, focusing on how our learning was supported The specific research question addressed in this article is, "How can learning be supported in a technology-focused collaborative inquiry?"

The Need to Better Understand How to Support a Technology-Focused Collaboration

Prior research suggests that there is a need to better understand how a technology-focused collaboration can be supported. First of all, despite decades of research and curriculum emphasis, studies have shown that technology has had little influence on classroom practice—a disconnect that prompted an international focus on professional learning in the digital era (Clark-Wilson, Robutti, & Sinclair, 2014). Studies have also shown that poor access, lack of professional learning opportunities, limited time for teachers to learn about technology and classroom time for students to learn, and inadequate support from colleagues and those who support technology are factors that influence teachers' implementation (Forgasz, 2006; Goos, 2005; Thomas & Chinnappan, 2008; Thomas & Palmer, 2014). Goos and Bennison (2008), researchers who surveyed teachers' use of technology in secondary mathematics classrooms in Australia, found that professional development was the most "pressing need" identified by teachers when it came to incorporating technology in practice (p. 126). Similarly, responses to a survey of 4,043 K to 12 teachers from across Canada have indicated that there is a "lack of proper training in how to use networked devices to meet curricular goals" (Johnson, Riel, & Froese-Germain, 2016, p. 5). These kinds of studies point to the need to support teachers' use of technology and to better understand how to support professional learning in using technology to meet curricular goals.

Research suggests that the ways teachers learn about technology can influence their confidence and their attitudes towards using technology in mathematics (Thomas & Palmer, 2014). The 22 teachers from Auckland New Zealand who participated in Thomas and Palmer's (2014) research responded to a Likert-scale attitude survey, and participated in classroom observations and individual interviews. When asked about the ways they learned to use technology, teachers who had low confidence with integrating technology in mathematics reported that they learned mainly from manuals, websites, workshops, workbooks/textbooks, and their students. When asked about the kinds of professional learning they would benefit from, they reported that they wanted more time to "fiddle around" with technology (p. 84). Teachers with moderate confidence, however, learned from other people, sometimes formally but often informally through their interactions with colleagues. The teachers who had moderate confidence described "incidental informal learning" to be most valuable. They wanted more time to learn from their colleagues. Like the teachers with moderate confidence, teachers who were highly confident with using technology learned primarily from their colleagues, mainly in their departments. These findings suggest that teachers benefit from learning by interacting, formally and informally, with their colleagues. But how can these kinds of interactions be supported? What conditions might facilitate professional learning about the use of technology in mathematics classrooms? Researchers point to a need for further study in order to better understand the conditions that support this learning (Goos & Bennison, 2008).

Based on their finding that teachers valued opportunities to learn about technology by interacting with colleagues, Thomas and Palmer contended that professional learning is "best constructed around such a supportive community of inquiry in a manner that gives teachers the opportunity to observe, practice and reflect on the use of digital technology in a classroom environment" (p. 86). Thomas and Palmer hypothesized that the last factor is typically missing from professional learning opportunities and that an inquiry community would be best supported by bringing together a small heterogeneous group of teachers to create a "classroom audience" in which teachers can discuss and reflect on their practices. Thomas and Palmer believe that these conversations, in the presence of teachers who have high pedagogical technology knowledge (PTK), are important, particularly since they have proven valuable in university (Paterson, Thomas, & Taylor, 2011). I believe in the importance of a supportive community in which a heterogeneous group of educators comes together to explore the use of technology in mathematics. This position, which is informed by a particular perspective on supporting learning in a complex system (Davis & Simmt, 2003), is reflected in the collaborative inquiry that is described in this paper.

Collaborative approaches to supporting professional learning and to conducting research are promoted by mathematics associations (NCTM, 2014) and are encouraged by researchers (e.g. Kieran, Krainer, & Shaughnessy, 2013). Establishing a collaborative inquiry is not straightforward, however. Westheimer (1999), for instance, found that even in schools with a reputation for strong teacher communities, there can be significant differences in goals, structures, processes, and beliefs. In other research, Steele (2012) reflected on strengths and weaknesses of a collaborative action research project and she found that even when a facilitator aims to support a teacher-directed collaboration, participant expectations about power and leadership can influence their participation. As a researcher and facilitator aiming to support teacher autonomy in this project, Steele found that teachers "seemed quite happy to consider [her] 'in charge'" (p. 25). Her findings suggest that even when a project leader aims to support collaboration, the activities might play out differently. This finding points to the complexity of facilitating a collaborative inquiry. In this paper I take a closer look at the collective learning processes that emerged in a collaborative inquiry that involved a diverse team of educations in exploring the use of technology in mathematics classroom assessment. Through this analysis I aim to examine how a technology-focused inquiry can be supported.

Conditions for Learning

From its inception, the inquiry community was considered a complex system. In a complex system, *learning* is considered an interactive and adaptive process: different ideas must interact for new ideas and creative insights to emerge (Davis & Simmt, 2003). The learning process might be prompted, bounded, and nurtured but it is not necessarily caused, controlled, or directed (Davis & Simmt, 2003). Davis and his colleagues have stressed that emergent events cannot be caused but might be occasioned (Davis, Sumara, & Kieren, 1996; Simmt & Kieren, 1999). So there is a shift from what "must" or "should" happen to what "might" or could" happen (Davis & Simmt, 2003, p. 147). From this perspective, five interconnected conditions are essential but not necessarily sufficient to facilitate learning in a complex system: organized randomness, decentralized control, neighbour interactions, and internal diversity, and redundancy (Davis & Simmt, 2003). According to Davis and Simmt (2003), these conditions are "proscriptive" (as opposed to prescriptive) in the sense that they set boundaries for the activities but do not state what must be done. These conditions informed the approach to supporting the professional learning and inquiry processes in this study.

Organized Randomness

A complex learning system is "rule-bound, but those rules determine only the boundary of activity, not the limits of possibility" (Davis & Simmt, 2003, p. 154). On the one hand, boundaries help to enable interactions by providing common ground for collaboration. Without boundaries, it would be difficult or impossible for participants to work towards a common goal (Davis & Simmt, 2003). So, a complex system is *organized.* On the other hand, there is space for *randomness*, in terms of an openness to the emergence of unanticipated ideas and directions that might arise (Davis & Simmt, 2003).

The inquiry that is described in this paper was *organized* by the common focus on exploring how technology can support mathematics classroom assessment. At the same time, *randomness* was facilitated by the opportunity for teachers to pursue different individual goals that fit within our collective focus. The kinds of goals that fit within our focus could include, for example, taking the time to explore new technology and/or learning strategies for using particular tools in assessment. From a case study analysis of what we learned about using technology to support assessment, I found that *organized randomness*, in terms of our flexibly bounded focus, allowed teachers with different experiences and interests to pursue their individual interests and to at the same time contribute to our shared focus (Lazarus, 2020a).

Decentralized Control

Control is decentralized in a complex system, which means that rather than having one or more individuals in charge, participants share responsibility for the activities (Davis & Simmt, 2003, 2006). The intention in this project was for all participants to share responsibility for our learning. It is important to acknowledge that even when control is decentralized, leadership roles and responsibilities are important. Findings from Bruce, Jarvis, Flynn, and Brock's (2011) study of teacher teams across Ontario, for instance, show that leadership, in the form of leader teachers in their study, was essential to collaborative action research processes. Their research also suggests, however, that when it comes to facilitating collective learning, more traditional perceptions of leadership that emphasize formal leadership positions (e.g., of power) might need to be challenged. Bruce, Jarvis, Flynn, and Brock found that participants expressed contradictory statements about the need for leadership in teacher teams. One participant, for instance, said that there "really isn't a need" for a leader but that it would be "really crazy without one" (p. 44). Bruce and colleagues hypothesized that this kind of contradictory statement might be a consequence of more traditional perceptions of leadership. Instead, a collaboration might be supported by a more distributed perspective (e.g., Spillane, 2005) that emphasizes leadership as a shared practice.

The inquiry that is described in this paper was designed to support this perspective—that leadership should be distributed in a collaborative inquiry. In a theoretical discussion of a distributed leadership perspective, Spillane, Halverson, and Diamond (2004) suggested that we need to move beyond considering the roles, strategies and traits of people in formal leadership positions, and to instead consider leadership as a practice. To offer insight into the improvement of school leadership, Spillane and colleagues called for more empirical studies with a distributed leadership perspective. More specifically, these researchers argued that "cases of how leadership is stretched over individuals in a variety of ways that vary depending on the particular leadership tasks and situations might help leaders to think about the enactment of leadership tasks in new ways" (p. 29). In a narrative of my experiences, I illuminate the complexity of my efforts to "stretch" leadership across participants in this collaborative inquiry group (Lazarus, 2020c). This insider account shows some of the internal tensions that I encountered as a project leader, researcher, and teacher aiming to decentralize control for our activities (Lazarus, 2020c). With the findings that are presented below in this paper, I will show how project leadership responsibilities were “stretched” across individuals in this collaborative inquiry.

Neighbour Interactions

Given the interactive and adaptive nature of the learning process in a complex system, neighbour interactions are essential. Neighbour interactions implies that different ideas must "bump" against one another for new ideas to emerge (Davis & Simmt, 2006, p. 156). More specifically, my assumption in this study was that in order for new learning to emerge, it would be important for people to have opportunities to interact with one another and with different ideas for using technology in assessment. To enable these interactions, this inquiry was designed so that the group of educators would come together as much as possible to discuss and reflect on their goals, plans, and experiences with using technology in assessment. Given my focus on the dynamics of this inquiry community and the learning processes that emerged, in the findings that are presented below I will offer a more in-depth description of how our interactions were supported.

Internal Diversity

Internal diversity is reflected in the different attributes that are necessary for generating new ideas and creative solutions to the problems that arise in practice (Davis & Simmt, 2003). The intention in this project was to generate ideas for using technology for assessment and to explore solutions to problems that teachers encounter when technology is integrated in practice. To promote internal diversity, this inquiry included participants with a range of experiences (e.g., with teaching mathematics, with using technology in mathematics), institutional roles (teachers, instructional coaches, technology coaches, a researcher), and interests in using technology in assessment. The diversity of this group is described in more detail in the case description below. From a complexity perspective, this diversity was important for generating new ideas for using technology in assessment and for coming up with solutions to problems that teachers encounter in practice. With the diversity in this group, I was able to examine how a heterogeneous group of educators can work together to learn about using technology in assessment and how people in teacher-support roles (district-level instructional coaches and technology coaches) might ‘lead’ without directing activities.

Redundancy

Redundancy, in terms of common characteristics that enable interactions, is important for facilitating learning in a complex system (Davis & Simmt, 2003). This inquiry was designed to foster redundancy by bringing together a team of educators who had common experiences with supporting high school mathematics teaching and learning in the same school district, with working to implement the same provincial mathematics curriculum, and with using the same provincial assessment guidelines. Therefore, when this group came together to learn about using technology in assessment, they were drawing on common language. The inquiry design also incorporated redundancy by having a shared focus, in this case with everyone focusing on using technology to support mathematics classroom assessment. In this case, teacher participation was voluntary; teachers chose to join this project because of their shared interest in using technology in assessment. This redundancy, in terms of the shared interests and experiences in the group, was supported to help enable interactions.

Research Design

Given the emergent nature of this study I decided to incorporate an interactive qualitative research design. This design offers a flexible structure, with components that form "an integrated and interacting whole" (Maxwell, 2013, p. 4). One component of this design was my *goal* to examine how our learning about the use of technology in assessment was supported. Another component of this design is the *methods* that I used to help address my goal. The complexity theory proposition—that learning in a complex system might be prompted, bounded, and nurtured by the five conditions outlined above (Davis & Simmt, 2003)—helped to guide the specific approach and methods that were used in this study. For the purpose of this study, I used qualitative methods and a case study approach (Stake, 1995; Yin, 2009).

A Case Study

A case study approach was important for this research. Firstly, Yin (2009) suggests that case study research helps to address "how" and "why" questions. Through a case study, I was able to examine *how* professional learning and inquiry processes were supported in a technology-focused collaboration. I aimed to observe rather than to try to control our learning about the use of technology in assessment. A case study approach was valuable given that it is a preferred method when a researcher is focusing on real-life events and when behaviours cannot be manipulated (Yin, 2009). I also intended to gain an in-depth understanding of a more general problem rather than of the case itself. Therefore, this was an *instrumental case study* (Stake, 1995). In other words, this study is instrumental in the sense that it responds to the need to better understand how teacher learning about the use of technology in classrooms (in this case classroom assessment) can be supported (Goos & Bennison, 2008). Connecting to Yin's (2009) definition, this case study can be considered "an empirical inquiry" that investigates a "real-life" collaboration in-depth by triangulating evidence from multiple sources (Yin, 2009, p. 17).

A case can be considered a "a complex, functioning thing" that is purposefully bounded (Stake, 1995, p. 2). The complex functioning thing in this context was a technology-focused collaborative inquiry system. In this case, I assumed that our collective learning would emerge from our interactions around ideas for using technology in assessment (Davis & Simmt, 2003). While the boundaries between this case and our context (e.g., our learning outside of these interactions) might not be clear (Yin, 2009), my focus on the dynamics of this community and our learning was at the heart of this study. Therefore, the case was purposefully bounded by our interactions at face-to-face meetings, our online communications, and by the focus on ideas for using technology in assessment.

The following case description will show that this is a unique case, with diversity reflected in the range of institutional roles and participant attributes (e.g., comfort with technology, teaching experience). This case is also representative of a heterogeneous group of educators working together to learn about the use of technology in assessment. Through a "thick description" of this case and my analysis of how our learning was supported, my intention is to contribute "experiential understandings" (Stake, 1995, p. 43) that can help guide similar technology-focused inquiries.

A Description of the Case

This case was a combination of serendipity and researcher design. In one sense, the case was a coming together of people who were interested in focusing on assessment and technology in mathematics classrooms. In another sense, I, as a researcher, was conscious of the conditions that can support collective learning (Davis & Simmt, 2003). These assumptions about learning influenced some of the choices involved in selecting participants and in setting up the dynamics of the case.

In selecting participants, I kept internal diversity in mind, particularly in the range of institutional roles and individual attributes that the ten educators brought to the group (see

Appendix J). Two instructional coaches, two technology coaches, five teachers, and myself, in a dual role as a teacher and a graduate student researcher studying our learning, participated in the inquiry. Teachers came from different schools across the district and they had different teaching backgrounds, curricular goals, and comfort with using technology. Coaches brought unique experiences with providing instructional and technology support. These coaches acted as mentors and resources. They provided in-school support and offered complementary knowledge of relevant instructional practices and initiatives. Technology coaches brought current knowledge of relevant tools and of technology-related initiatives. As a teacher and researcher, I brought my own understandings of the use of technology and of related research to the project.

At the beginning of the school year I met with the coaches to discuss the project goals, my research goals, and potential teacher participants. After considering the goals, coaches identified teachers from the different schools they were working at who they felt might offer different perspectives and be interested in learning more about using technology in assessment (e.g., these teachers were already exploring the use of technology). Even though the coaches supported teachers at different schools, they had worked with teachers from across the district (e.g., at district-level professional learning activities) so they were familiar with most mathematics teachers in our district. The names of several potential participants emerged from this conversation and five teachers agreed to participate. Therefore, ten educators, including four people in teacher support roles (technology coaches and instructional coaches) and five high school mathematics teachers, participated in this inquiry.

Participant Roles and Relationships

Patricia (Instructional Coach) and I were the formal project leaders. We initiated the project and were responsible for ensuring that the project expectations were met. As the project began we invited Shelly (Instructional Coach) to join. Then, Sarah and Brent (technology coaches) were assigned by the technology department to support our activities. Even though Patricia and I were the official project leaders, the findings below show how leadership responsibilities were shared by myself, Patricia, and the other coaches. I therefore refer to myself and all of the coaches as project leaders in this context.

Figure 1 (also on p. 16 in this thesis) illustrates the relationships between the coaches and teachers.

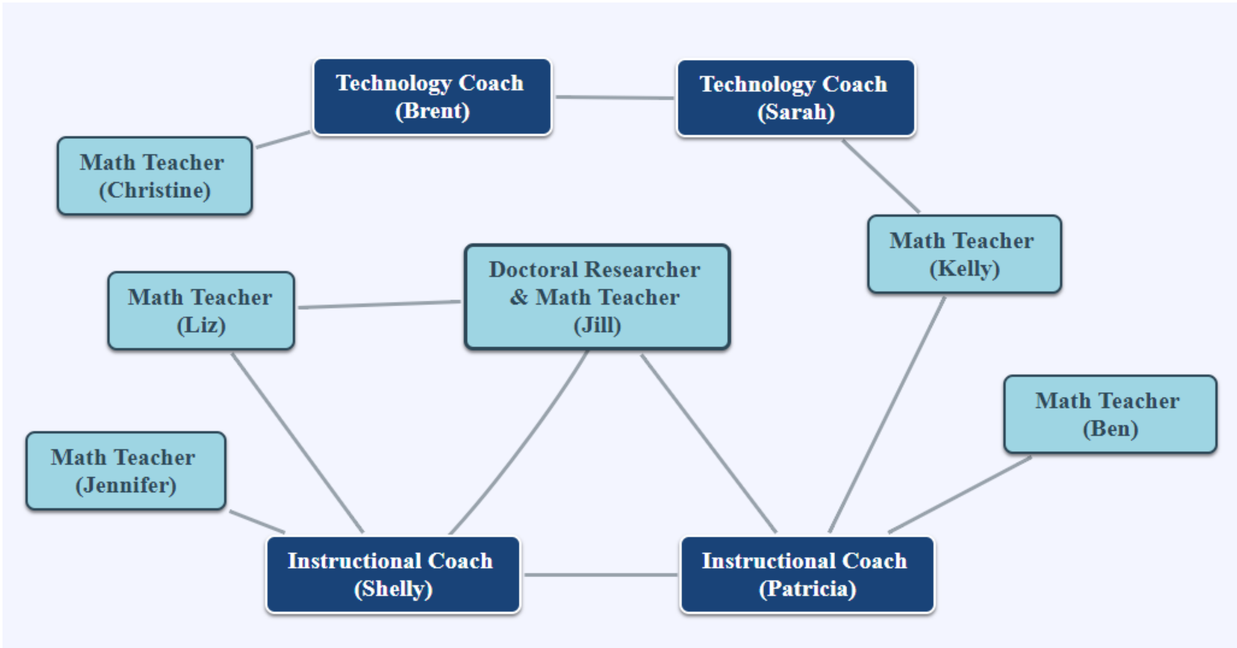


Figure 1. **Participant relationships**

This figure shows that there were many different ways that people worked together. The coaches worked with each other and with different teachers. I worked with Liz at one school where Shelly was an instructional coach. Technology coaches, Brent and Sarah, were available to support all teachers but they worked more closely with Christine and Kelly. Brent worked with Christine. Christine was experienced with using technology and was looking for support with using technology in more complex ways (e.g., integrating tools to create a flipped classroom environment). Sarah worked more closely with Kelly who was an experienced mathematics teacher but was uncomfortable with technology. During our second meeting, for example, Kelly expressed concern about feeling overwhelmed by different tools. Figure 1 also shows that Patricia worked with Ben and that Shelly worked with Jennifer. So, each teacher was connected to a project leader who was available to provide in-school support.

This collaboration was blended in the sense that we participated in both face-to-face and online meetings. We met five times over the course of the school year. Two of our gatherings were full-day face-to-face meetings, with one happening near the beginning of the school year and the other happening halfway through the school year, at the beginning of the second semester. We also participated in two online meetings (Google Hangouts) between the face-to-face meetings. These meetings lasted approximately one-hour each. The group met one last time for approximately one hour after a conference presentation. A more detailed summary of our inquiry activities and the research data that were collected is included in Appendix C.

Data Collection and Analysis

A case study relies on multiple sources of evidence and data collection and analysis are guided by prior developments of theoretical propositions (Yin, 2009). In this case, data collection and analysis were guided by the complexity theory proposition that learning is an interactive and adaptive process and that this process might be supported by particular conditions for learning (Davis & Simmt, 2003). I aimed to support these conditions in the inquiry design by including educators with different attributes yet common experiences with supporting high school mathematics teaching and learning (*internal diversity* and *redundancy*), establishing a flexibly bound focus on using technology in assessment (*organized randomness*), providing opportunities for participants to meet and share ideas (*neighbour interactions*), and by supporting teacher-directed activities (*decentralized control*). I examined how our focus took shape to enable this heterogeneous group of educators to work together towards a common goal (see Lazarus, 2020a) and in this paper, the findings show how online communication and distributed leadership helped to enable our interactions.

I looked at multiple sources of evidence from our inquiry activities to examine how our professional learning and inquiry processes were supported. Data sources included my observations of the group meetings, my reflections on group meetings that were recorded in my research journal, audio records and transcriptions of group meetings, coaches' meeting notes, artefacts created by participants and shared with the group, documents that were posted by participants in shared learning spaces (e.g. Google Drive folder, Google Site website, Padlet), and project-related emails between participants. These data were collected throughout the inquiry (see Appendix C for a summary of the data that were collected).

In focusing my analysis on what supported our learning, I first looked at what participants saw as important to their learning. So, my first step was to review the meeting transcripts and to organize segments of dialogue in which participants shared their perspectives on how their learning was supported (coded "perspectives on how to support professional learning/collaboration"). As I attempted to group these segments into common themes, one theme emerged overwhelmingly. Teachers appeared to see their greatest learning as coming from interacting with colleagues. My analysis of this data also revealed evidence that teachers saw time pressures as constraints to both incorporating technology into their classroom practices and to participating in our inquiry activities. Online communication seemed to help facilitate our interactions, however. I will discuss these themes below.

In addition to looking at participants' perspectives, I wanted to see how decentralized control (through the lens of distributed leadership) might have contributed to our learning. For this purpose, I used leadership roles and responsibilities identified by Bruce, Jarvis, Flynn, and Brock (2011) to guide my analysis. From their cross-case analysis of Lead Teacher perceptions of their roles and responsibilities, Bruce and colleagues (2011) found that leaders helped to *manage, model*, *mediate*, and *motivate* collaborative action research activities. In this technology-focused inquiry, I wanted to see how project leaders, particularly participants who were in teacher-support roles (instructional coaches, technology coaches), shared these kinds of responsibilities. I grouped evidence from the meeting transcripts, reflections in my journal, my observations notes, and my summaries of the meetings, into these four categories to examine how these leadership roles and responsibilities took shape in this technology-focused inquiry. My intention was to build on prior research (Bruce et al., 2011) in order to better understand how people in teacher-support roles might help to support professional learning and collaborative inquiry processes in a technology-focused inquiry.

Findings

Three overall themes emerged from my analysis of teachers' perspectives and of how leadership roles and responsibilities helped to support our learning: (i) teachers valued opportunities to bounce ideas (neighbour interactions), (ii) online communication helped to enable interactions, and (iii) instructional coaches and technology coaches shared project leadership roles and responsibilities. I will discuss each of these themes in more detail.

Teachers Valued Opportunities to Share and Hear What Other Teachers Were Doing

One thing that I wanted to look at was what teachers saw as important to supporting their learning. I coded segments in the meeting transcripts that described their perspectives on their learning and this analysis demonstrated a common theme—that teachers valued opportunities to share ideas. At our second face-to-face meeting, for instance, Patricia asked the group to think about how we could support each other, "Like what are some things that you think we can do, all of us, to support each other in this endeavor that we're in together?" (Patricia, Instructional

Coach, GRP_{NOV}, p. 20). Jennifer and Kelly responded by emphasizing the importance of opportunities to share both positive and negative experiences:

> **Jennifer (Teacher):** I just think the sharing [...] just sharing of experiences and resources and being willing to share like, "I did this and it was like, it did not work." Or like, "I thought this was great and then it just..." Like sharing your, not mistakes because they're not like, but just, yeah, successes but also....
>
> [...]
>
> **Kelly (Teacher):** It's nice to hear what other people are doing so like, you know, Padlet and Explain Everything. So those are the two things that I will note this semester and that's pretty much all I can get. (GRP_{NOV}, p. 20)

This theme reoccurred and even at our final meeting, when the coaches asked teachers for their feedback, Christine articulated that this sharing was the "biggest bonus" of this inquiry:

> **Christine (Teacher):** I think the biggest bonus of something like this is just chat with people, right? Like to bounce ideas. And when you have an opportunity to talk to people about things, you try things that otherwise you wouldn't even come up with because those ideas get generated from that. [...] And as hard as it is to take that day or to take that afternoon, or whatever it is, it forces you to do those things and it changes, perhaps the way that you would do things. (GRP_{MAY}, p. 12)

These kinds of statements are representative of the theme that was evident within teachers' perspectives on their learning. Teachers valued opportunities to bounce ideas with their colleagues.

As Christine's comments suggest, finding time to meet was challenging, particularly later in the school year after there were a number of interruptions for bus cancellations due to weather. This theme was very prevalent in the data. Teachers reported at our final meeting, for instance, that because of several "snow days" that year, they felt that they had not progressed as much as they would have liked. Shelly acknowledged the impact of these interruptions and teachers expressed that time constraints can lead to reverting to their "tested and true" practices:

> **Shelly (Instructional Coach):** [...] because we just had all these snow days too before that last Google Hangout so there's so much context I think that impacts on everything we're doing, right? If we hadn't had those snow days do you think that we'd be in a different place when it comes to our using technology?

Kelly (Teacher): I know I would be.

Shelly (Instructional Coach): Okay.

Kelly (Teacher): Only from the standpoint of, more time for me to become more comfortable with the technology and then more time to allow... not that it's not valid but, you know right now I'm feeling like every second that they're in front of me it's so precious that I can't afford 15 minutes to...

Christine (Teacher): Right. So rather than just trying something. You're going with the tested and true because you can't afford the time. (GRP_{MAY}, p. 4)

The above segment exemplifies the pressure that teachers felt when it came to developing their own comfort and trying new things in their classrooms. They felt that they needed time to try out new ideas. Time was also a constraint when it came to organizing our meetings. Class time was "precious" and teachers felt that they could not afford to miss any more time with their students, as snow days had already eaten into their class time. As a teacher, I could relate to this feeling. As a researcher, I decided that given the importance of interactions for our learning—both from a complexity theory perspective (Davis & Simmt, 2003) and from what teachers were saying about supporting their learning—I needed to examine how our interactions could be best facilitated if we could not meet face-to-face as regularly as we would have liked. My ongoing analysis of the teachers' perspectives on our learning revealed that the "pros" of online communication can "outweigh" the cons when it came to finding opportunities to share. I will discuss this theme next.

The "Pros" of Online Communication Can "Outweigh the Cons"

This collaboration was blended, with the inquiry group using both synchronous and asynchronous tools to communicate and share ideas. We used online folders (Google Drive), shared documents (Google Docs, Sheets, and Slides), and a collaborative platform (see Appendix L for an image of our Padlet page) to record ideas (e.g., in meeting notes) and to share materials (e.g., assessment activities, videos of students using technology in assessment). We also used an online platform (Google Hangouts) to check in between face-to-face meetings. These virtual meetings lasted approximately one hour each and were facilitated primarily in a roundtable format, with teachers taking turns sharing and reflecting on their experiences (see Appendix C for a summary of the meeting details).

Looking at the meeting transcripts for what teachers said about their learning in connection to time pressures and using online tools, there is evidence that online communication might help to enable interactions and therefore support collective learning. Teachers' comments also suggest, however, that online tools should be used carefully, to avoid overwhelming teachers. At our final meeting, for instance, Christine explained that the "pros" of synchronous meetings (Google Hangouts) can outweigh the "cons":

> You know what, they [virtual group meetings] were fine. Like they were a little awkward, you've got a bit of a time delay and they're a little awkward but honestly I think the pros outweigh the cons in that you don't have to take an entire day and everybody drive and the time and the cost and everything that's associated with that. (Christine, Teacher, Trans, GRP_{MAY}, p. 4)

There was no further discussion about the value of these meetings so it is unclear how the rest of the group felt. This kind of statement and my own observations of our activities, however, lead me to believe that there is value to blending collaborative activities, particularly when participants come from different schools. In this case, the virtual meetings allowed us to interact more frequently than would have been possible with strictly face-to-face meetings. Even though they might have been "awkward" at times, virtual meetings allowed us to share and reflect on our experiences (primarily in a roundtable format). By enabling our interactions, it appears that synchronous tools might help to support learning in a collaborative inquiry.

It is important to note the "cons" of online communication, however. This position was articulated more explicitly earlier in the inquiry when the team was considering what our sharing might look like, beyond face-to-face. We reflected on asynchronous tools, including the online folder (Google Drive) that we were already using, and the possibility of incorporating an online collaborative platform (Padlet) as "a more on the spot immediate way of communicating with people" (Patricia, Instructional Coach, GRP_{FEB}, p. 20). Teachers' responses during this conversation suggest that overall the group was open to using this platform. The need to be mindful of the demands on teacher time was articulated, however, when Jennifer acknowledged that teachers are busy:

> We're all busy, right? You want to make it so that it's really easy to do it and we don't kind of go like, "Oh, like that's the last thing on my list because I have to just be ready for

> tomorrow and whatever" because I know that's how my day feels. (Jennifer, Teacher, GRP_{FEB}, p. 20)

Other teachers expressed their agreement with this position. From these kinds of statements, it appears that when it comes to using online tools to facilitate a collaborative inquiry, it is important to keep in mind the purpose of the technology and to avoid overwhelming teachers.

To summarize, the pros of using online communication to help facilitate interactions in a collaborative inquiry can outweigh the cons. Looking back at my observations of the meetings (my meeting notes and meeting summaries) and at the meeting transcripts, there is evidence that online synchronous tools (Google Hangouts) made it possible to share and reflect on our experiences more frequently and asynchronous tools (Google Drive, Padlet) allowed us to share resources and ideas between face-to-face meetings. Coaches made themselves available to support teachers with these technologies. Thus, it seems that coaches helped to make it less onerous for teachers to collaborate by being on-site with teachers for the synchronous online meetings, and by posting resources (e.g., sharing links to relevant resources) and classroom evidence (e.g., videos of students using technology in assessment) to the online platforms. I wonder if teachers might have contributed to (and perhaps referred) to these platforms more frequently if they had been involved in creating the Padlet page and/or if we contributed to and used these platforms more frequently during the meetings. Regardless, from my analysis of the teachers' perspectives on the ways their learning was supported and on my observations of the inquiry activities, it appears that online communication might not be perfect but that it can help to facilitate opportunities for teachers (and coaches) to enable more frequent interactions.

Coaches Shared Leadership Roles and Responsibilities

My intention for this project was for teachers, coaches, and myself to learn alongside one another. This intention aligned with the position that no individual is 'in charge' of collective learning in a complex system (Davis & Simmt, 2006). In examining this case through my research, I wished to better understand how this intention played out; in other words, how might project leaders, particularly coaches who are in teacher-support roles, help to support a technology-focused collaborative inquiry? I wondered, for instance, how did the coaches 'lead' without directing? To help address these kinds of questions, I decided to look at leadership roles and responsibilities that seemed to support distributed leadership, or a "'first among equals' approach to shared leadership within a group dynamic" (Bruce, Jarvis, Flynn, & Brock, 2011, p. 45). To help frame my thinking about distributed leadership, I focused my analysis on the four elements that emerged from Bruce and her colleagues' (2011) analysis of lead teachers' perceptions of their roles and responsibilities in collaborative action research. These four elements were found to be the roles that leaders took on to support learning in collaborative action research teams. Therefore, I categorized evidence from my observation notes, meeting summaries, and meeting transcripts to look at how the coaches shared responsibility for *managing*, *mediating*, *modelling*, and *motivating* (Bruce et al., 2011) our activities. Contributing to Bruce and her colleagues findings, themes in this analysis show that coaches in this technology-focused inquiry took on a variety of leadership roles as they helped with: (i) *managing* inquiry activities and classroom evidence, (ii) *modelling* technologies and technology-rich practices (at group meetings and in classrooms), (iii) *mediating* between the inquiry group and external groups, (iv) *mediate* the technical demands on teachers, (v) *motivating* the use of technology in assessment, and (vi) *mediating* and *motivating* in schools.

Managing inquiry activities and classroom evidence. Managing involves taking on organizational responsibilities, including, for example, organizing meeting dates and content, planning for the activities, and tracking (e.g., inquiry questions, classroom evidence) (Bruce, Jarvis, Flynn, & Brock, 2011). In this case, project leaders, primarily myself and Patricia (Instructional Coach), often with Shelly's (Instructional Coach) help, organized meeting dates and checked in with participants with relevant meeting information (e.g., goals, agenda). During our group meetings, Sarah (Technology Coach) and Shelly often recorded notes to track ideas that emerged (e.g., meeting notes in Google Drive). As our meeting facilitator, Patricia managed our interactions during the meetings by ensuring that we were on track with respect to our meeting goals. Between meetings, I met with coaches to reflect on the inquiry goals and our observations, and to plan for subsequent meetings.

From this analysis, it appears that coaches also helped to manage classroom evidence. Like in Steele's collaborative action research project (2012), teachers in this case tended to rely on their classroom observations. More specifically, teachers shared and reflected on their observations at all of our meetings but the first visual forms of classroom evidence (e.g., videos of students using technology) were shared (in our Google Drive folder) after our third group meeting. I wonder if the lack of classroom evidence resulted from the time constraints teachers experienced. Or perhaps, as prior research has shown (Avgitidou, 2009), the group needed time to build collaboration and to support teacher empowerment. Coaches facilitated this sharing after our third meeting, however, by helping to collect visual evidence (e.g., pictures, videos of students using technology in assessment) from the teachers' classrooms. The coaches also uploaded files to our team folder (Google Drive) and posted to the collaborative platform (Padlet). Shelly (Instructional Coach), for instance, recorded short video clips and took pictures of students using a specific tool (Airplay) in Liz's (Teacher) class. Likewise, Patricia shared video clips and images of students using different tools (Quizlet, Knowledgehook) in Kelly's class. The coaches also summarized some of the ways teachers used these tools and their experiences (e.g., what worked and what didn't work) on the collaborative platform (Padlet). Unfortunately, with more of this sharing happening closer to the end of the project, we had little opportunity to delve into it as a group. I would argue, however, that considering the demands on teachers' time, coaches contributed by helping teachers manage classroom evidence. This is similar to a statement made by a lead teacher in Bruce and her colleagues (2011) study, that her role involved "staying on top of things" and helping to take the "burden" off teachers (Bruce et al., 2011, p. 44). The above evidence shows how, in addition to helping manage the inquiry activities, coaches in this case helped take the burden off teachers' by helping to manage classroom evidence.

Modelling technologies and technology-rich practices. Bruce, Jarvis, Flynn, and Brock (2011) found that teacher leaders in their collaborative action research projects modelled action research processes and instructional practices. In my study, project leaders modelled technologies and some of the ways technology might be used in assessment. At the first group meeting, for instance, the team considered different tools and the ways they support particular purposes of assessment. Shelly (Instructional Coach) and I modelled some of the ways we used or had seen different technologies incorporated in practice. Since I wanted input from teachers, without pressuring them to share at our first meeting, I began by acknowledging that we would share some possibilities and that we were inviting input:

> So if you have used anything and you want to share [...] my name's up there a lot, only because I didn't want to put anybody on the spot. I'm happy not to share. Like I'll share some of the things that I'm doing and obviously, I always think of things that I could improve. So it's not perfect but it's, I thought, something that I could at least show you what it can do. (Jill, Researcher/Teacher/Project Leader, Trans, GRP_{OCT}, p. 15)

At this meeting, I showed some possibilities, Shelly (Instructional Coach) shared others, and Liz (Teacher) showed us a tool that we invited her to share because of her experience with it. In this case, our modelling was a springboard to facilitate discussion about different possibilities. We took turns showing each tool and participants shared their experiences with it and/or contributed ideas for using it to support assessment.

The coaches, particularly technology coaches, brought unique experiences with technology and with supporting teacher learning in the use of technology. They therefore modelled different technologies and technology-related practices. For instance, after teachers asked to learn more about screencasting (Explain Everything) at our November meeting, Sarah (Technology Coach) prepared a workshop to model this tool. In addition, after Shelly (Instructional Coach) and I reflected on findings that emerged at the first two inquiry meetings, we felt that it would be helpful for the team to consider a technology framework that connected to the ideas that were shared. Therefore, Sarah (Technology Coach) created a short presentation to model ideas for using technology to support mathematics classroom assessment (see Appendix K). This framework connected to an idea that was emphasized by participants, that technology should be used for more than "the sake of it" (e.g., Patricia, Trans, GRP_{OCT}, p. 5). Again, Sarah only presented possibilities rather than how technologies and this framework should be used. However, with their unique training and experiences, in addition to providing in school support, the coaches supported our learning about the technologies by modelling these different possibilities.

Mediating between the inquiry group and external groups. From my analysis of participants' contributions to this inquiry it was evident that project leaders helped to mediate between the inquiry group and external groups. Looking at lead teachers perceptions of their roles, Bruce, Jarvis, Flynn, and Brock (2011) found that these leaders helped to mediate activities by intervening between participants and external groups/individuals. In my study, the project leaders (myself and the coaches), helped to mediate between external groups, particularly when it came to meeting the technology project expectations.

Since this project was funded by the school district technology department, we needed to ensure that the project requirements were met (e.g., working towards the goals that were outlined in our proposal, organizing meetings, presenting findings). Sarah and Brent, district-level technology coaches, were assigned by the Instructional Technology Leader to support our activities. They described their role in an email early in the school year:

> Hi Jill and Patricia,
>
> Happy Back to School! Last year when innovation projects were selected, [Instructional Technology Leader] assigned coaches to assist and support groups as needed. He did the same this year and Brent and I are lucky enough to be connected to your group!
>
> [...]
>
> If you have any meetings that we can come and be co-learners at that would be awesome or if there's anything we can help with please don't hesitate to send us an email.
>
> Have a great day,
>
> Sarah and Brent (Sarah, Technology Coach, EMA_{SEPT})

This email reflects that the technology coaches saw their position as co-learners and supporters of our activities. Given their connection to the technology department, they also helped to mediate between the team and this department, an external group.

Sarah and Brent helped to ensure that the technology project requirements were being met. Sarah, for instance, helped to track teacher release time (e.g., Sarah, EMA_{OCT}), to organize lunches for meetings (e.g., Sarah, EMA_{OCT2}), and she checked in regularly to offer support with meeting project expectations (e.g., Sarah, EMA_{NOV}, EMA_{MAY}). All of the coaches also offered in school support with the technology and with implementing the ideas that individuals wished to support in their classrooms. This in-school support was important given that teachers expressed tensions in terms of the demands on their time, including time to learn about technology and to integrate tools in practice (e.g., Kelly, Trans, GRP_{NOV}; Jennifer, Trans, GRP_{FEB}). By taking on some of the project demands and supporting teachers in their classrooms, the coaches helped to support our activities by mediating with respect to the project demands on teachers.

All coaches helped to mediate between external groups when it came to the need to report on our findings. In this case, some of the teachers were not comfortable or interested in formal presentations of our findings. When I invited teachers to contribute to a provincial conference presentation (Field notes, GRP_{OCT}; Trans, GRP_{FEB}, p. 1), for instance, only Kelly agreed. In addition, at our final meeting when Patricia suggested that teachers should present findings at their schools, teachers reported that they did not have the time or were not interested. Therefore, at times project leaders presented our findings (e.g., for the technology project, for the conference presentation, for district level trustees when requested). Teachers were involved in contributing to presentations, however. The project co-leads helped to mediate when it came to presenting for external groups by sharing responsibility for formal presentations when teachers were either unavailable or did not want to attend (e.g., at a provincial conference, for school district trustees, for a technology project "Wrap Up" meeting).

Mediating technical demands on teachers. Mediating can involve intervening within a collaborative group (Bruce, Jarvis, Flynn, & Brock, 2011). In this case, there appeared to be no disputes between participants but there was evidence in the data that there were tensions with respect to the technical demands of the project and that coaches helped to mediate these tensions. More specifically, coaches appeared to provide encouragement and they were available to support teachers in their classrooms.

The range of technologies that are available can be overwhelming for teachers and this was evident at times. Kelly, for instance, expressed her own frustration at our second meeting. She stated that

> What I'm finding is, I don't know if any other classroom teachers have the same, I don't know, not necessarily fear but the coaches are exposed more to what is out there than we are and so I find that in the last meeting and this meeting that apps and what not are brought to us but it's really the coaches who have the expertise in the apps so it would be nice to, as Sarah [Technology Coach] said, try one or two things and figure that out rather than a whole pile of stuff that... I don't know what's out there I guess. (Kelly, Teacher, GRP_{NOV}, p. 6)

As a project leader who wanted everyone to have a positive experience in this project, I experienced internal tensions when these kinds of frustrations arose (see Lazarus, 2020c). My analysis of the transcripts for motivating prompts, however, demonstrated that throughout the project coaches encouraged teachers to work within their comfort zones. At times, they offered encouragement by reminding us of the progress we were making and at other times they reminded us that it was okay to slow down.

In response to Kelly's frustrations, for example, Shelly (Instructional Coach) acknowledged that "I think we need to see this stuff like way more than once to wrap your head around, you know…. Yeah I think that's a really good point that we need to get comfortable and learn how to use it and then the students" (Shelly, Trans, GRP_{NOV}, p. 15). Coaches also acknowledged the progress we were making, particularly at the end of meetings, with prompts like, "I just want to say I think this is very exciting to hear from you guys just dipping in and amazing stuff that's coming out of the classroom so kudos to you guys" (Patricia, Trans, GRP_{NOV}, p. 6). The importance of this permission to slow down was evident at our final meeting when teachers were asked if they found the project overwhelming. The teachers expressed that they did not feel overwhelmed because they had the choice to pursue what worked for them. Given the potentially overwhelming possibilities when it comes to using technology in mathematics classrooms, this choice seemed to be very important for teachers.

Motivating our use of technology in assessment. The analysis of the data provided evidence of project leaders helping to motivate our activities, particularly when it came to our focus on using technology in assessment. Motivating involves establishing a safe space by offering friendly reminders, sometimes nudging for results, and encouraging participants to try new things (Bruce, Jarvis, Flynn, & Brock, 2011). My analysis of the transcripts for motivating prompts shows that project leaders, in this case instructional and technology coaches, nudged us to reflect on the ways in which technology can be used for assessment purposes and they provided encouragement, particularly when it came to the technical demands of the project.

At times, project leaders pushed our thinking about how technology might be used for assessment. For example, after sharing an idea for using graphing software (Desmos) that she learned from a teacher, Shelly challenged us to consider the teacher's role in using this tool for student self- and peer-assessment:

> **Shelly (Instructional Coach):** So I'm just wondering, is there a place and what is the place in terms of peer and... like that assessment *as* learning. Is this something that... and what does that look like in a classroom? Like what would you do with that? Just putting it on there without [...] going back to that assessment *as* learning piece, part of it is the teacher's role to kind of create the structure where they're taught to peer assess, not just to put it on there. So I wonder what the activity actually... like how you get it so that the kids are actually peer assessing as opposed to just posting?
>
> **Patricia (Instructional Coach):** Yeah. How do you kind of force the issue?
>
> **Shelly (Instructional Coach):** Because I don't know. (Trans, GRP_{OCT}, p. 18)

This segment shows some of the types of prompts coaches used to encourage us to think more deeply about using technology for assessment purposes. In their willingness to admit that these were some of their wonderings and that they "don't know" the answers, this segment also reinforces that coaches saw themselves as learning alongside teachers.

Mediating and motivating in schools. In addition to motivating the group, coaches played a key role between meetings by providing in-school instructional and technical support. They helped to mediate technical demands and to motivate individual teachers in their schools. With Brent's (Technology Coach) support, for instance, Christine (Teacher) developed her idea for incorporating a flipped classroom that she was working on. She learned about an online collaborative platform (Padlet) from our group meetings and Brent helped her to run with this idea by providing technical support at her school (see transcripts for GRP_{OCT}, GRP_{NOV}). Kelly, who was less experienced with technology, worked closely with Sarah. She seemed to appreciate this support. Near the end of one of our meetings, when an idea for using a new tool emerged, the coaches said that they were only showing the possibilities and Kelly (Teacher) responded with, "I need you to come in tomorrow" (GRP_{OCT}, p. 19). As a teacher in this inquiry, I worked closely with Shelly (Instructional Coach). In her role as an instructional coach, she worked with me to co-plan for activities, to carry out activities in my classroom (e.g., technical support), and to reflect on our experiences afterwards. Thus, she helped to motivate by offering her support and providing encouragement.

To summarize, this study has shown that project leaders helped to support (rather than direct) professional learning and inquiry activities. My analysis of the meeting transcripts and observations of the inquiry activities provided evidence of the ways project leaders shared leadership roles and responsibilities (Bruce, Jarvis, Flynn, & Brock, 2011). More specifically, this data shows that project leaders, particularly the coaches, shared responsibility for facilitating this technology-focused collaboration by helping to (i) *manage* the inquiry activities and classroom evidence, (ii) *model* technologies and technology-rich practices (at group meetings and in classrooms), (iii) *mediate* between the inquiry group and external groups, (iv) *mediate* technical demands on teachers, (v) *motivate* with respect to the use of technology in assessment, and to (vi) *mediate* and *motivate* by providing in-school instructional and technical support. Coaches in particular seemed to help mitigate the project demands on teachers by offering in-school support. These teacher support roles appeared to be important for facilitating the inquiry activities and teacher learning in this technology-focused inquiry.

Conclusions

Prior research has shown that how teachers learn about technology can influence their confidence with using technology in their mathematics classrooms (Thomas & Palmer, 2014). Thomas and Palmer found that teachers who were more confident with using technology tended to learn from their colleagues. Based on their findings, these researchers recommended that teachers should have opportunities to learn in supportive communities of inquiry in which heterogeneous groups of teachers discuss and reflect on their practices. My research helps to show how professional learning and inquiry processes might be supported in a technology-focused collaboration. To help prompt, bound, and nurture learning, I set up this inquiry to support the conditions for learning in a complex system (Davis & Simmt, 2003, 2009). I aimed to promote: (i) internal diversity by including a range of roles and participant attributes (e.g., interests, comfort with technology); (ii) redundancy with our shared experiences with teaching high school mathematics; (iii) organized randomness in our flexibly bounded focus on using technology in assessment; (iv) neighbour interactions through our opportunities to meet and share ideas (both face-to-face and online), and (v) decentralized control be providing opportunities for all participants to contribute to our learning. In this study of how our learning was supported, I examined participants' perspectives on what they felt was important for their learning and how project leadership responsibilities were shared across the coaches.

Thomas and Palmer's (2014) research has shown that teachers with higher confidence in using technology in practice tended to report that they learned, both formally and informally, from their colleagues. Likewise, the teachers in this case reported that they valued this opportunity to connect with their colleagues and to hear what other teachers were doing. Class time was precious, however, with teachers acknowledging that their progress in this project was impacted by interruptions during the school year. Time pressures have been identified by other researchers as a factor influencing implementation when it comes to learning about new technologies and to integrating technology in practice (e.g., see Forgasz, 2006; Goos, 2005; Thomas & Chinnappan, 2008; Thomas & Palmer, 2014). Other factors identified by these researchers included lack of technical support and support from colleagues. This inquiry was designed to provide teachers with support from colleagues and coaches, both through our interactions at group meetings and with coaches supporting teachers in schools.

Given time pressures and the geographical distance between schools, this group leveraged synchronous meeting technology (Google Hangouts) and asynchronous sharing platforms (Google Drive, Padlet) to enable more frequent interactions. From my analysis of participants' perspectives on these forms of communication, it appears that the pros of online communication can outweigh the cons. At our short online synchronous meetings, we shared and reflected on our experiences (typically in a roundtable format with teachers taking turns sharing). We used asynchronous tools to share resources and ideas between our meetings. My analysis of participants' perspectives demonstrates a need to be mindful of time pressures and the technical demands on teachers. The online communications were not perfect, and they were perhaps "awkward" at times. In this case, however, coaches stepped in at times to alleviate the technical demands by being on-site with teachers for our virtual meetings and by sharing ideas on our online platforms when teachers did not have time.

In addition to looking at participant perspectives on our learning, I wanted to examine how project leaders, particularly the coaches, shared leadership responsibilities. I used four leadership roles and responsibilities that emerged from Bruce, Jarvis, Flynn, and Brock's (2011) analysis of lead teachers' perceptions on their roles and responsibilities in collaborative action research (mediating, modelling, managing, motivating) to frame my analysis. Themes in my analysis of how our learning was supported indicate that the coaches helped to mitigate the technical demands and project demands on teachers by sharing these responsibilities. More specifically, there was evidence that the coaches helped to (i) *manage* inquiry activities and classroom evidence, (ii) *model* technologies and technology-rich practices (at group meetings and in classrooms), (iii) *mediate* between the inquiry group and external groups, (iv) *mediate* technical demands on teachers, (v) *motivate* with respect to the use of technology in assessment, and to (vi) *mediate* and *motivate* by providing in-school instructional and technical support. By sharing these responsibilities, the coaches appeared to play important roles in facilitating the inquiry activities and in supporting teachers in this technology-focused inquiry. We were fortunate to have access to four coaches. I expect, however, that this type of work could be supported by a smaller number of project leaders/coaches. Given the potential technical demands and time pressures for teachers, however, it appears that including at least one person in a teacher support role (e.g., instructional coaches and/or technology coaches) is important for facilitating inquiry processes and for supporting teachers in their classrooms.

Recommendations for Supporting a Technology-Focused Collaborative Inquiry

The above findings show that a heterogeneous group of educators can learn alongside one another in a technology-focused inquiry. Informed by the premise that learning can be enabled by the conditions for learning in a complex system (Davis & Simmt, 2003, 2006), I set up the inquiry to promote internal diversity, redundancy, neighbour interactions, organized randomness, and decentralized control. From my analysis of how this inquiry was supported, it appears that:

- *Educators can share responsibility for learning about the use of technology (in assessment) by having opportunities to share their ideas and experiences with colleagues in a supportive community.* In this case, teachers appreciated opportunities to learn from their colleagues. The importance of these opportunities is supported by the premise that new learning emerges from interactions in a learning system (Davis & Simmt, 2003; Davis & Simmt, 2006). The significance is reinforced by research that shows that teacher confidence with technology appears to be higher when teachers learn from their formal and informal interactions with colleagues (Thomas & Palmer, 2013).
- *Blending collaboration with synchronous (e.g., Google Hangouts) and asynchronous online tools (e.g., shared online folders, collaborative platforms) can enable more frequent interactions*. Despite the challenges, the advantages of online communications seemed to outweigh the disadvantages when technology is used purposefully. In this case, synchronous tools (e.g., Google Hangouts) made it possible to meet, and therefore share and reflect on our experiences, more frequently. Asynchronous tools (e.g., online folder, online collaborative platforms) were used to share ideas and resources at and between our meetings.
- *Project leader(s) can share leadership roles and responsibilities (Bruce, Jarvis, Flynn, & Brock, 2011) and a technology-focused inquiry can benefit from including at least one person who is in a teacher support role (e.g., instructional coach, technology coach).* The above findings show that project leaders, particularly individuals in teacher support roles, can share project leadership roles that can help facilitate inquiry activities, and they can support teachers in their schools and classrooms, particularly when it comes to mediating some of the technical demands of a technology-focused project.

CHAPTER 5: Leading while Learning in a Collaborative Inquiry: A Narrative of How I Developed a Deeper Understanding of Assessment AS Learning in Mathematics

Abstract: The importance of collaborative approaches to supporting professional learning and to conducting research has been recognized by professional mathematics teacher associations and researchers. The collaboration that is discussed in this article involved a small team of educators in exploring the use of technology in mathematics classroom assessment. In this article I examine my own experiences with learning alongside my colleagues and conducting research in this collaborative inquiry. Findings are presented in the form of a narrative of my thoughts and experiences as a project co-leader, teacher, and researcher. This narrative highlights some of the internal tensions that I encountered, including: deciding how much to direct our activities, questioning when to speak up and when to hold back, and deciding how to respond to some of the unanticipated (and sometimes uncomfortable) participant contributions. Opportunities for distributing leadership responsibilities (e.g., for facilitating meetings), and for using ongoing assessment to inform next steps as a project leader (e.g., subsequent meeting goals and plans) and researcher (e.g., ideas to pursue at subsequent meetings) are discussed. This article concludes with considerations for collaborative inquiry project leaders and researchers, including graduate students who wish to carry out 'insider research projects' with colleagues.

Keywords: Collaborative Inquiry, Nexus of Multimembership, Narrative of Experience

> *I completely agree with Jennifer—we need to think about the questions we are asking when students have access to technology for assessment. We should bounce some ideas! Generate questions that we can use with our students. This would be interesting data for my research and I could use some of these ideas in my own classroom. I want to jump in. To share some of the things I have tried. What I have learned from my own practices and from focusing on technology and assessment literature for the last couple of years. I have so many thoughts. But is it too soon? This is our first meeting! How will my jumping in influence this group? I am just getting to know everyone and I want to fit in. What if my enthusiasm is not shared? And possibly even worse; what if the group follows my lead and this is something that they are not actually interested in? What if I miss out on other opportunities to learn with them about issues that they are more interested in? I read a study recently, by a graduate student researcher/collaborative action research project facilitator, and teachers were quite happy to follow her direction. I want to avoid this. I will sit back.*

For now, I will make a note, listen, and wait. But now we are on to another topic and I wonder, have I missed a learning opportunity? Maybe I should have tried to steer our conversation....

These are just some of my thoughts as I aimed to lead, to learn, and to carry out research in a collaborative inquiry. I joined nine of my colleagues, including mathematics teachers, instructional coaches, and technology coaches, for this inquiry into the use of technology in mathematics classroom assessment. As a teacher, I wished to learn with my colleagues and to develop my teaching practices. As a project co-leader, I intended to promote a collaborative project in which teachers would support one another and share responsibility for our learning. And, I was studying our learning for my doctoral research. Thus, I was an individual at a nexus of multimembership in this collective (Wenger, 1998).

As I engaged in this collaboration, and monitored and critically reflected on my interpretations of the data, and on the ways I might be influencing our activities, I began to notice internal tensions arise. In this article I aim to provide insight into some of the internal challenges and into possibilities for leading, learning, and conducting research in a collaborative inquiry. I present findings in the form of a narrative that recounts some of my inner thoughts as I navigated experiences that prompted inner tensions, and I critically reflect on my efforts to manage multiple forms of membership (teacher, project leader, researcher) and to cultivate a shared sense of responsibility for this collaborative inquiry. Before presenting this narrative, I highlight the emphasis on collaborative approaches to supporting professional learning and research, and I discuss the contributions of this inquiry to research and practice.

Collaborative Approaches to Supporting Professional Learning and Research

Collaborative approaches to supporting professional learning and to conducting research are promoted in mathematics education. The National Council of Teachers of Mathematics (NCTM, 2014), for instance, states that mathematics teachers are professionals who "cultivate and support a culture of professional collaboration and continual improvement, driven by an abiding sense of interdependence and collective responsibility" (p. 99). Broadening this sense of a collective, scholars have argued that teacher-researcher collaborations are valuable for connecting the complementary knowledge and expertise from the distinct but related fields of teaching practice and academic research (Goos, 2014; Kieran, Krainer, & Shaughnessy, 2013). In the above opening reflection, I illustrate some of the internal tensions that a researcher and/or project leader might encounter in efforts to share ownership for a collaborative project. In this article, I explore some of the tensions that arose from my own efforts to learn alongside participants in this collaborative inquiry. More specifically, in this case I struggled with balancing being a leader and at the same time a learner, with deciding how much to direct our activities, and with questioning when to speak up and when to hold back, and responding to unanticipated (and sometimes uncomfortable) contributions.

Metaphorically, I aimed to support professional and research relationships that might be considered "symbiotic rather than parasitic […] [with] an exchange that reflects equilibrium in the relationship[s]" (Anderson & Freebody, 2014, p. 5). In other words, my intention was for everyone to contribute to our learning about the ways technology might help to improve our mathematics classroom assessment practices. As a teacher, a researcher, and a project leader in this inquiry, I aimed to learn alongside participants. Although this paper provides some sense of the work of the collective, here I illuminate an insider-outsider perspective by presenting my findings in the form of narrative of my experiences with navigating some of the tensions that emerged from my efforts to foster a sense of collective responsibility for our learning.

Prior to carrying out this study, as a graduate student and as a classroom teacher, I encountered various opportunities to collaborate with educators and with researchers. The following reflections highlight some of the experiences that led to my pursuing this collaborative inquiry.

> *In the Spring of 2015, after teaching high school mathematics for almost three years, I wanted to learn more about how I could use technology to support my assessment practices. Fortunately, throughout these first years teaching, I had the opportunity to continue to collaborate with my Master's thesis supervisor. Together we explored some of the ways technology might facilitate a math-talk classroom (Hufferd-Ackles, Fuson, & Sherin, 2004; Lazarus & Roulet, 2013a). Our experiences led us to question some of the implications of technology for assessment, however. I wanted to delve deeper into these implications. So, I pursued doctoral studies.*
>
> ….
>
> *Skipping ahead in this program, my research proposal is approved by the university while I am teaching mathematics part-time. Around the same time, all teachers in this district receive a call for technology innovation project proposals.*

> *I submit a proposal with Patricia, an instructional coach at my school, and our project is approved for the following school year. A team of ten educators (including teachers, instructional coaches, and technology coaches) will come together to explore the ways technology might be used to support assessment. The timeline for this project coincides with the data collection phase of my doctoral study. I am excited by this opportunity to connect research and practice and to collaborate with educators who share similar interests. I want this to be a teacher-directed project in which teachers share responsibility for our learning. But I am not sure how things will play out. How will I lead, learn, and conduct research in ways that support this intention?*

This reflection highlights some of the wonderings that I brought to this inquiry. I wondered, for instance, how would I be a 'leader' and a 'learner' simultaneously? How much would I need to direct our activities? In this article, I look at how my efforts to promote collective responsibility for our learning played out. The specific research question addressed in this personal inquiry is, "How can I, as a researcher and project leader, navigate tensions that emerge as I facilitate a professional learning and research collaboration while also being a colleague?"

This collaboration involved a team of 10 educators in exploring possibilities for using technology in their mathematics classrooms. This team of five high school teachers, four coaches (two instructional coaches and two technology coaches), and myself, as a researcher (and teacher), met five times over a period of approximately one school year. Together, we wrestled with the implications of technology use, with a view to assessment, by looking at both the affordances and constraints that technology provided for assessment. As we explored the ways that technology and assessment intersected in classrooms, we brought new learnings back to the collaborative inquiry group. For my research, I collected data from group meetings with participants, observations and reflections that were noted in a researcher journal, and materials that were shared among participants (e.g., shared documents that were created at meetings) (see Appendix C for a summary of the data that were collected for this study). In addition to analysing what we learned about using technology in assessment (see Lazarus, 2020a) and to examining how our learning was facilitated (see Lazarus, 2020b), I reflected on my experiences as an insider. In this paper, I focus on my experiences with supporting professional learning and research in a collaborative inquiry amongst peers.

Contributions

This article contributes an insider perspective to literature that highlights how a professional learning and/or research collaboration can be facilitated. First, I highlight some of the tensions that emerged when I tried to promote distributed leadership and equal participation within a complex system of relationships (Davis & Simmt, 2003; 2006). Second, I describe my experiences as an individual at the nexus of multimembership where I rode the edge of boundaries of different communities of practice (academic research communities and professional learning communities) (Wenger, 1998; Wenger-Trayner, Fenton-O'Creevy, Hutchinson, Kubiak, & Wenger-Trayner, 2014). Finally, I describe how I, as project leader, navigated some of the unique challenges and opportunities that arose as I facilitated a collaborative inquiry amongst peers.

Supporting Professional Learning and Conducting Research in a Complex System

While there is no single complexity theory, all versions emphasize that a complex system is "comprised of a large number of entities that display a high level of nonlinear interactivity" (Richardson & Cilliers, 2001, p.8). Such qualities might be illustrated in the collective interactions of ant colonies, cities, our brains, and even the web (Johnson, 2001, 2003). *Learning* in a complex system, whether it is student, teacher, or researcher learning, is collective rather than isolated (Davis & Simmt, 2003). Learning is an adaptive process that emerges and evolves as people engage with different ideas and challenges and it is influenced by the context and elements (people, ideas) of the system. Davis and Simmt's (2003; 2006) assumptions about what it means to know and learn in a complex system are reflected in my inquiry design. In particular, given that complexity is a theory of adaptation and change that emphasizes emergence through distributed control, self-organization, and collective cognition (Davis & Simmt, 2006; Johnson, 2001; Morrison, 2006), I sought to facilitate the emergence of new ideas and creative insights, with respect to our collective focus on using technology in mathematics classroom assessment, by supporting particular conditions for learning in a complex system.

Davis and Simmt (2003, 2006) have adapted qualities of complex systems from other fields (e.g., Capra, 2002; Johnson, 2001; Waldrop, 1992) to identify five conditions for prompting and bounding learning in a complex system: internal diversity, redundancy, organized randomness, decentralized control, and neighbour interactions. *Internal diversity* appears in the different attributes (e.g., expertise, experiences, interests) that members bring to a system.

Redundancy is found in common characteristics of group members (e.g., common language, shared experiences). *Organized randomness* means that the system is flexible to the emergence of new ideas and unanticipated directions, and that activities are bounded by a common focus or goal (e.g., by a shared focus on the use of technology in mathematics classroom assessment). To support *decentralized control*, no individual member is in charge of learning. Finally, *neighbour interactions* means that different ideas must "bump against each other" for new knowledge to emerge (Davis & Simmt, 2006, p. 156). From this complexity perspective, learning might be prompted, nurtured, and even bounded rather than caused, controlled, or directed (Davis & Simmt, 2003). In this article I examine my own journey as part of a collective that embraced this perspective on learning.

Nexus of Multimembership

We are all members of different communities of practice (Wenger, 1998). In the context of this collaborative inquiry, for instance, I was a member of an academic research community and I aimed to contribute a greater understanding of the use of technology in assessment and of how a technology-focused collaboration might be facilitated. At the same time, I was a teacher engaging in a professional learning community and my intention was to learn how to develop my classroom assessment practices. Figure 7 shows some of the related communities that I was part of and how these communities intersect.

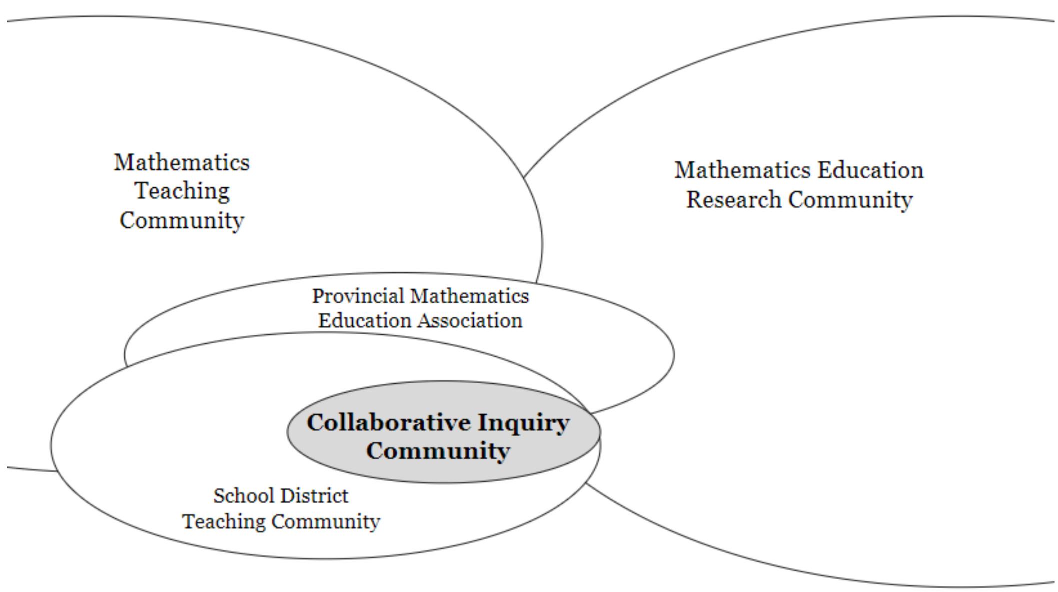


Figure 7. Intersections of Communities of Practice

This figure shows how I was part of the inquiry community that is at the heart of my study, and that this community intersected with larger and overlapping communities; including the mathematics teaching and research communities that I engaged in as a teacher and researcher. In addition to being part of these communities, I was a member of a school district community—a community in which educators in various roles (e.g., teachers of various subjects, consultants, administrators) aimed to support students in a particular region. I, and some of the other members of the inquiry and school district were also members of a provincial mathematics association—an association that provided opportunities for mathematics educators to connect with one another for the shared purpose of contributing to mathematics education in the province. Throughout this project, I participated in these communities in different ways. I also navigated different internal tensions as I aimed to manage different forms of membership in this inquiry, particularly as a member of a teaching community and at the same time an insider-outside researcher.

The concept of a community of practice is informed by social learning theory. It is more than a group of people (e.g., educators and/or teachers) and has three dimensions (Wenger, 1998, p. 83). It involves "mutual engagement" (e.g., drawing on contributions and knowledge of all participants); it is a "joint enterprise" (e.g., everyone shares responsibility for learning); and it draws on a "shared repertoire" (e.g., a shared discourse and way of doing things). In each of the above mentioned communities, for instance, I engaged with different groups of people for the shared purpose of learning about and contributing to mathematics education. The definition of a community of practice may not stem from systems theories but in an essay that explores the "career" of this concept, Wenger (2010) has argued that it is well aligned with these theories. More specifically, he has argued that a community of practice might be considered a simple social system, while interrelated communities of practice might be considered complex social systems. I would argue that this inquiry, happening at the intersection of my research and practice, was a complex social system. Wenger's theory is valuable here since it emphasizes the social aspect of this collaboration. Some of the tensions that emerged as I negotiated a nexus of multimembership at the boundaries of complementary yet different communities of practice (academic research and professional practice) are highlighted in this paper.

Multimembership can involve "ongoing tensions" that are never resolved (Wenger, 1998, p. 160). The complexity of negotiating a nexus of multimembership is illustrated in different stories of practice that are included in Wenger-Trayner, Fenton-O'Creevy, Hutchinson, Kubiak, & Wenger-Trayner (Eds.) (2015) book *Learning in Landscapes of Practice: Boundaries, Identity, and Knowledgeability in Practice-Based Learning.* Fenton-O'Creevy, Dimitriadis, and Scobie (2015), for instance, offered three stories that explored the experiences of negotiating identity in new settings. A common feature in each of these stories is that each practitioner moved from a situation in which they were considered highly competent into a situation where they experienced incompetence. After finding that cross-boundary learning can involve experiences of failure, can challenge who you are, and can elicit difficult emotions, Fenton-O'Creevy, Dimitriadis, and Scobie argued that if we are to take the learning process seriously, we need to consider the process of 'learning to be' in addition to 'learning to do' in a community of practice (p. 42); we need to acknowledge the emotional and identity work that goes into experiences of multimembership. In this paper, I focus on my experiences with learning to be in a collaborative inquiry.

While some researchers have emphasized the importance of connecting research and practice by showing how teachers might participate as key stakeholders in research (Kieran, Krainer, & Shaughnessy, 2013) and how teachers and researchers might work together to create knowledge in mathematics education (Goos, 2014), others have argued that there can be a clash between the two worlds—of K-12 teaching and academic research (Labaree, 2003). Labaree, for instance, discussed a "cultural clash" that can happen when these communities collide. More specifically, he argued that cultural tensions can emerge from the sometimes drastic differences in the ways we look at education and our work in education: from normative to analytical, from personal to intellectual, from the particular to the universal, and from experiential to theoretical. Despite these kinds of potential tensions, Labaree acknowledged that research can offer an additional way to understand education (Labaree, p. 16). The collaboration that I was part of for this study was designed to connect research and practice.

To briefly summarize, I engaged in this project as a researcher, a teacher, and a project leader. Managing different forms of membership at the boundaries of different communities of practice can be challenging yet interesting areas for study (Wenger, 1998). The findings that are presented in this paper offers insight into the ways I navigated tensions that emerged from my efforts to facilitate a collaborative inquiry while managing multiple forms of membership in a complex learning system. Before presenting these findings, I will describe the collaborative inquiry design.

The Collaboration

Different language might be used to describe a practitioner learning and/or research collaboration, and I believe that a discussion of this language is useful to clarify how I position this collaborative inquiry. Terms like *Professional Learning Community (PLC)*, *Community of Practice*, *Practitioner Inquiry*, *Practitioner Research*, *Collaborative Inquiry*, *Action Research*, and *Collaborative Action Research* can support different agendas and epistemological assumptions (Cochran-Smith & Lytle, 2009). An underlying assumption in most cases, however, is that the practitioner is a "knower and agent for educational and social change." (Cochran-Smith & Lytle, 2009, p. 37). In other words, practitioners are considered key stakeholders in these collaborations. The inquiry discussed in this paper was designed to embrace this assumption and my plans for this project involved drawing on the complementary knowledge and experiences of all participants.

I use the term *collaborative inquiry* in this paper to describe the work that participants engaged in. Cochran-Smith and Lytle (2009), who have used the terms *practitioner inquiry* and *practitioner research* interchangeably, recognized that *inquiry* is often considered a softer term than *research*. They chose to use practitioner inquiry as an umbrella category for research in which participants actively contribute to a study and are no longer "objects of someone else's inquiry, or the informants and subjects of research conducted by outsiders" (Cochran-Smith & Lytle, 2009, p. 41). Eisner (1998), who also considered *inquiry* as a broader concept than research, has clarified that research might be considered an example of an inquiry but inquiry is not necessarily an example of research. Like Eisner and Cochran-Smith and Lytle, I use the broader, and perhaps softer, term *inquiry* to describe the work that participants engaged in.

Researchers have questioned the legitimacy of the term research to describe teacher inquiry activities. Steele (2012), for example, carried out action research with colleagues for her doctoral study and, based on her findings, she questioned whether their work should be called research. Steele found that teachers tended to rely on stories of their experience rather than on collecting evidence from other sources (e.g., student work). Perhaps this connects to Labaree's (2003) suggestion that there can be a tension between experiential and theoretical (research) knowledge in the transition from practice to research. Given the data collection limitations, Steele wondered if "[r]eplacing the moniker action research with facilitated professional learning community downplays the lack of data collected by the participants and portrays the work of the participants in a more accurate and positive light" (Steele, 2012, p. 30). Even though research might be more challenging given the demands of practice, practitioner inquiry can be a valuable form of inquiry and a legitimate form of research. In his response to a theme issue of the *Educational Researcher* titled *Research for Doctoral Students,* Anderson (2002) reflected on issues of rigour, status, and purposes of practitioner and academic research and argued for the legitimacy of practitioner inquiry as a form of research, particularly in doctoral programs where many students work in schools. Kieran, Krainer, and Shaughnessy (2013) have also shown how teachers can be key stakeholders in educational research, with five international examples of teachers researching their own and their colleagues' practices to "illustrate how traditional barriers between research and practice are being replaced by synergistic interactions between the two, enabling the intersection of the two worlds" (p. 361). In this context I was participating at the intersection of both worlds, as a researcher and a teacher, and my intention was to connect my research and our professional through a collaborative inquiry.

Like in Steele's (2012) study, the inquiry that is discussed in this paper included two layers of simultaneous inquiry. One layer included the collective practitioner inquiry activities, and the second layer was my documentation of the teacher work for my research. Steele acknowledged a potential tension, first identified by Capobianco, Lincoln, Canuel-Browne, and Trimarchi (2006), with the location of ownership in a simultaneous research project. Steele questioned, for example, "Does one research set take precedence over the other? Do they function separately or in hierarchical relation to each other" (p. 24). Likewise, as a project co-leader working to support professional learning and research, a high school teacher interested in exploring the use of technology in my own practices, and a researcher documenting the emergence of professional learning in this inquiry, I experienced tensions when it came to navigating simultaneous layers of inquiry.

Rather than having one layer of inquiry take precedence over another (e.g., my researcher over the district project or vice versa), my intention was for *my research* and *our inquiry* activities to function together. To support this intention, I aimed to have participants share ownership for this project by involving them in activities that have been shown in similar collaborative projects (e.g., see Avgitidou, 2009; Bruce, Flynn, & Stagg-Peterson, 2011;

Suurtamm et al., 2017). These activities included negotiating project goals and plans, sharing and reflecting on classroom experiences and evidence of student learning, making decisions about next steps, and contributing to reports on findings. In this paper, I refer to a project in which participants share ownership for learning as reflecting equilibrium in participant (and researcher) relationships. In other words, while I acknowledge that participation is something that evolves and is influenced by various factors in a collaborative project (Avgitidou, 2009), this inquiry was designed to promote equilibrium by supporting the conditions for learning in a complex system. The narrative and discussion that follows, however, shows that I experienced inner tensions as I aimed to cultivate a collective sense of ownership for this collaborative inquiry.

A Narrative Approach

A researcher is almost never merely a researcher experiencing the experience de novo, but is a person who almost always has personal experiences related to the practical situations
Xu & Connelly (2010, p. 360).

I brought my personal experiences—with learning alongside my colleagues in professional learning communities and with carrying out research activities in collaborative projects—to this collaboration. This was my first experience, however, with leading and learning as a teacher, researcher, and project leader in a collaborative inquiry. Through a narrative in this article, I aim to recount some of my inner thoughts and experiences with navigating this collaboration. Narrative is a qualitative form of inquiry that is most appropriate for capturing detailed stories of individual experiences (Creswell, 2013; Xu & Connelly, 2010). It is an “invitation to participate”; it presents an opportunity to be "read, and lived, vicariously by others" (Connelly & Clandinin, 1990, p. 8). The narrative in this article is an invitation for the reader to participate in this nexus of multimembership. More specifically, the narrative that follows offers insight into the types of internal tensions that I experienced as a project leader, a teacher, and a researcher in a collaborative inquiry.

The team came together for five group meetings—three face-to-face and two virtual synchronous meetings using Google Hangouts (see Table 3. Summary of Group Meeting Dates, Attendance, and Codes). This narrative emerged from my analysis of the meeting transcripts, my observation notes, and reflections that I documented in the transcripts and in my researcher journal. I read and re-read these data and my reflections, and highlighted my personal wonderings and internal tensions, and I documented themes that I observed throughout. Some of my thoughts were captured in the transcripts, particularly when I talked about my experiences during the meetings (e.g., when prompted by coaches to reflect on my own learning). More often, my reflections were documented in observation notes and my researcher journal. During meetings, for instance, I recorded some of my wonderings in my journal (e.g., my wonderings about how to respond to ideas that were shared). After meetings, as I transcribed data, I added notes to the transcripts and highlighted instances that struck me (e.g., how I might have responded differently, ideas that we might pursue in subsequent meetings). This was a form of self-analysis, or self-assessment: What moves was I making? Were they helpful or harmful? Was I leading too much or not enough? Was I filling silences? Was I letting good ideas get lost? As I continued to organize my reflections, I focused on themes that emerged with respect to the process of learning to be in this community. I started to notice that I had experienced internal tensions that prompted me to reflect more carefully on my own influence on the inquiry activities. In the narrative that follows I highlight moments that prompted some of these tensions. By describing some of my experiences and my inner thoughts in this narrative, my intention is to present the reader with an opportunity to participate in some of the internal tensions that can arise at the nexus of multimembership in a collaborative inquiry.

The Narrative

In the Fall of 2015 I was excited by the opportunity to connect my research and professional learning plans in a collaborative inquiry with colleagues who shared an interest in developing their classroom assessment practices with technology. I felt that this district project presented an opportunity to extend my learning (and other teachers' learning) by making it possible for coaches and teachers from different schools to connect with one another. So, I helped to co-plan for a professional collaboration that aligned with my research plans. Given the emergent nature of the project, it was impossible to anticipate in advance exactly how this inquiry would play out. As I learned 'to be' in this community, I grappled with tensions that included balancing how to be a leader and to, at the same time, be a learner, deciding when to speak up and when to hold back, and questioning how to respond to unanticipated, and sometimes uncomfortable, contributions that emerged.

While I strived to promote interactions and to distribute control so that no individual was 'in charge,' I constantly questioned my own influence on the activities. As a graduate student with an understanding of research in the area, and a high school teacher who was comfortable with implementing different technologies in practice, I worried about being perceived as an expert. Since I intended to learn with my colleagues, and I wished to prompt opportunities for teachers to learn from one another, this perception would have been in direct conflict with my intentions. By no means did I feel like an expert and I wanted to avoid being perceived this way. I saw myself as being confronted with technology that is always changing and, despite my comfort with exploring new tools, I felt that I had a lot to learn. I also realized that I had less teaching experience than most teachers in the group. It was after our first group meeting when Shelly and I presented some of our preliminary findings at a district level meeting when I realized that my experiences as a researcher and my role as a project leader might lead to assumptions about my expertise.

During this presentation, Shelly and I gave an overview of the project and some of the preliminary findings. Although several district leaders expressed appreciation for our findings, one person questioned how realistic it might be to replicate this project given that this team included people like us. This question struck me. It seemed that there was an assumption about our expertise in this group. I wondered: Why is replicability so important? Isn't each learning community, and therefore each learning journey, unique? And how can any researcher, educator, or even group of educators, be an expert when each classroom environment is unique, and when technologies are always changing? The question about the relevance of this project for others, and the possible assumption about our expertise, stuck with me, however.

I felt that there were no experts in charge of our learning and that the diversity in this group was a real strength. This group included instructional and technology coaches who brought training and experiences with working with teachers in different contexts, myself as a researcher and teacher with a few years of teaching experience, some teachers with many years of teaching experience, and another teacher in his first year of teaching. Some teachers were more comfortable with using technology and with others not. This diversity was important to me, since I wished to draw on a variety of perspectives. It seemed impossible for any individual or even the group as a whole to really be an expert.

I often wondered how my contributions to the conversations might influence participants, however. If I spoke up, would I be imposing my own ideas on the group? If I held back, would I let valuable learning or research opportunities get lost? I brought my own interests, assumptions, and research agendas to this inquiry, and at times ideas emerged that I would have loved to pursue. During our first group meeting, for instance, Jennifer (Teacher) shared an observation that resonated with my own teaching experiences. Reporting on a discussion that she had with Brent (Technology Coach), she explained that they both noticed that technology is often used to support student learning but issues arise when students are allowed to use technology to demonstrate their learning:

> We talked about quite a few things but observation-wise, technology being used more for investigations and like the learning [stressing "the learning”] as opposed to the demonstration of your learning [...] but we were talking about the struggle with, okay if you are going to use it for that summative piece then we have to be designing things that are... activities that are not going to be compromised - the integrity of it won't be compromised if they have access to whatever they want to have access too, right? So it's a shift in the type of questions that we're asking or what we're having them do I think is the big piece. And how to get around that. (Jennifer, Teacher, Trans, GRP_{OCT})

I had experienced this struggle as a teacher and it was part of the reason for my pursuing this inquiry. The implications of allowing students to use technology to demonstrate their learning was important to me. As I listened to this conversation unfold I wondered, should I speak up or should I hold back? Would expressing my own ideas at our first meeting end up influencing participants or directing the inquiry before others had the opportunity to share? So, I chose to listen without responding. I made a note in my research journal to pursue this idea during my subsequent analysis of the meeting transcript. I wondered, however, if a good idea might be lost and I questioned whether I should have said something.

But this idea was not lost. Later on, Shelly asked Jennifer to repeat her comments to capture them in our meeting notes. Jennifer summarized that **“**the biggest one was the, preserving the integrity,” and “figuring out how to ask the right question so that it doesn't matter that they have access to whatever they want to have access to. That they can't really cheat with open book. Open world” (Trans, GRP_{OCT}, p. 6). I chose to respond this time, saying “That was one of my big questions too. Like they have that PhotoMath app now and they were working on quadratic, solving quadratic equations or something, and [student] pulls out this photo app and he's scanning questions in the textbook. He's like, ‘This thing will tell me the solution’ [...] ‘That's cool but....[others laugh] Now what do I do'” (Trans, GRP_{OCT}, p. 6)? Shelly asked, “Is it cheating if they leave school and they're going to use that in their life?” (Trans, GRP_{OCT}, p. 6).

Even though I never responded to this question, I agreed with Jennifer, who explained that it depends on the mathematics expectation that is being assessed or evaluated. In this kind of situation I seemed to be experiencing a tension with being a project ‘leader’ and at the same time being a ‘learner’. As a researcher, I noted this tension in my research journal. As a project leader, I chose to listen without jumping in again. As a teacher, I chose to pursue this idea in my own teaching practice by considering how technology might enhance the ways students demonstrate their learning in mathematics. Fortunately, the interactive nature of the inquiry made it possible for me, like everyone else in the group, to adapt and choose the ideas that would connect to different teaching practices. I certainly appreciated this opportunity.

Seeing people struggle was sometimes discomforting. I wanted this inquiry to be a productive and positive experience for everyone. So I felt uncomfortable when participants expressed frustration with some of the challenges that arose along the way. As an example, Kelly expressed that she felt overwhelmed by all of the technologies that are available:

> What I'm finding is, I don't know if any other classroom teachers have the same... I don't know, not necessarily fear but the coaches are exposed more to what is out there more than we are and so I find that in the last meeting and this meeting that apps and what not are brought to us but it's really the coaches who have the expertise in the apps so it would be nice to, as Sarah said, try one or two things and figure that out rather than a whole pile of stuff that... I don't know what's out there I guess. (Kelly, Teacher, Trans, GRP_{NOV}, p. 6)

I noted Kelly’s frustration in my research journal and Patricia, who was facilitating this meeting, responded by acknowledging that this was a “good point.” I continued to worry about Kelly feeling overwhelmed, however. I did not see Kelly between group meetings but I did see Sarah, who sometimes worked with Kelly, as a technology coach at her school. I asked Sarah how Kelly was doing. Sarah reiterated that sometimes people get excited about everything but they need to build capacity on a few things rather than taking on too much and becoming overwhelmed (Sarah, Technology Coach, SUB_{DEC}, p. 1). I noted her response in my research journal and considered a possible theme that connected to the technology in assessment focus. In terms of Kelly’s feelings about the demands of the project, however, I noticed over the course of this inquiry that she gained confidence with the technology. By the end of the project I was fascinated by her willingness to try new things. Perhaps some of the different roles in this project (e.g., teachers, instructional coaches, technology coaches) helped Kelly to gain confidence with technology. As uncomfortable as it was to encounter this frustration at the time, her feedback was valuable as it prompted me and the coaches to reflect on ways to support her and other participants who might be experiencing similar frustrations.

Since this inquiry was highly interactive, project plans and research methods evolved along the way. I adapted my research plans to fit with the district project requirements and then, with input from coaches and teachers, the inquiry and research plans took shape. It would have been impossible to predict the actual inquiry and research paths in advance. This unpredictability was uncomfortable at times. I came to this project, for example, with particular ideas and assumptions about how the activities might be enacted but our path evolved. I was constantly assessing and analysing the interactions and ideas that emerged and reflecting on my own learning and interpretations of the data. Part way through the project, I wanted a second opinion on my interpretations of the data so I invited Shelly (Instructional Coach) to review the meeting transcript and we compared our observations. We met prior to the third group meeting and our analysis of these transcripts informed plans for our next group meeting. For instance, we were finding that some ideas for using technology involved using technology more "for the sake of it" while other ideas were more transformative. We decided that it would be worthwhile to ask Sarah (Technology Coach) to help clarify the different ways technology might be used by introducing a technology framework (Puentedura, 2013). This is only one example of how our assessment of the inquiry activities, and in this case co-analysis of the research data, informed subsequent plans.

Our inquiry goal was to explore strategies for using technology to support mathematics classroom assessment. My research goal was to examine the professional learning processes and knowledge of technology in assessment that emerged. The inquiry plans that were articulated in my research proposal involved establishing a shared focus on using technology to support different purposes of mathematics classroom assessment. Over the course of our inquiry, however, I noticed connections between these purposes of classroom assessment and other layers of assessment (or analysis) that arose in this professional inquiry and research context.

The connections became clearer to me in December, during a planning meeting with instructional coaches (Shelly and Patricia) and a technology coach (Sarah). At one point during this meeting I described my plans for integrating some of the ideas for using technology in assessment that were shared by other participants in order to develop an assessment task that would allow students to use technology to demonstrate their learning. As I shared my thinking, coaches asked questions and offered suggestions (e.g., to consider how students would use the technology, to give students a time limit for the videos that they would be creating so that they do not get carried away). Before we left this meeting, I told the coaches that their questions influenced my thinking and would therefore change my initial plan. Shelly's response to this comment struck me as an exciting connection between student self-assessment to support mathematics learning (assessment *as* learning) and teacher self-assessment to support professional learning:

> **Me:** So now I'll probably go home and think about why... [Shelly laughs] and the task that I was planning will look different because of how you questioned my thinking about it…. Yeah, it will look different.
>
> **Shelly (Instructional Coach):** The assessment *as* learning...
>
> **Me:** Yeah, because I didn't see that in there before....
>
> **Shelly (Instructional Coach):** But the assessment *as* learning, *as* you're assessing your own mind. Wow, it's like a mirror that just keeps going back and forth.... Dual mirrors and you never get to the end of it because you keep getting bigger and bigger. (Trans, SUB_{DEC}, p. 11)

I was fascinated by this "dual mirrors" connection; the idea that the purposes of classroom assessment (e.g., assessment *as* learning) might apply to multiple layers of learning in this inquiry and the parallel hall of mirrors metaphor for my own introspections. As I continued to collect data and to write up my research findings, I continued to observe connections between the purposes of classroom assessment and other layers of learning that were interacting in this inquiry; including the collective professional learning of the inquiry group, and my own learning as a graduate student.

I discussed this observation with Shelly and explained, “It’s funny because we’re focusing on classroom assessment but I’ve been thinking about assessment of our learning." Shelly told me that this is something that the coaches have been considering, particularly with respect to the question, “How do we assess our work in the sense of how effective we are and how can we change?” (Shelly, Instructional Coach, Trans, SUB_{JAN}, p. 6). She felt that addressing this question would be good learning for her as a coach, and even good learning for the system.

I began to pursue connections to the multiple layers of assessment, extending my thinking about classroom assessment to the professional learning and research processes. As I write this story of my experiences, for example, I feel that I am engaging in assessment *as* learning by critically reflecting on (self-assessing) my understandings of the data that were collected. As a researcher, I see myself as having engaged in assessment *for* learning along the way by analysing data and using my analysis to inform adjustments to the inquiry and research plans. My learning is demonstrated (assessment *of* learning) in my reports on the findings, including a doctoral dissertation and oral defense. This learning, or research, will be judged in relation to university goals, and to the standards of the different journals that the articles in this thesis will be submitted to. From these kinds of experiences, I started to see formative assessment as being integral to navigating some of the internal tensions with deciding how to respond in different situations and with adapting plans along the way. If formative assessment is so important to student learning (Black & Wiliam, 1998), shouldn't it be just as important to supporting teacher learning? And to supporting my own learning as a researcher? Perhaps the moments in this narrative that prompted me to critically reflect on my influence in this inquiry reflect my own assessment *as* learning.

Discussion

The specific research question addressed here is, "How can I, as a researcher and project leader, navigate tensions that emerge as I facilitate a professional learning and research collaboration while also being a colleague?" From this self-analysis of my experiences, distributing control and using ongoing assessment appeared to help me with navigating the nexus of multimembership; including managing the roles of being both a leader and a learner, and supporting equilibrium in the collaborative inquiry and research relationships.

Distributing Control

Like others (e.g., Fenton-O’Creevy, Dimitriadis, & Scobie, 2015; Steele, 2012), I grappled with difficult emotions when it came to managing multiple roles in this project. I was uncomfortable when I encountered what I felt were assumptions that I might be an 'expert'. First of all, assumptions about my expertise directly conflicted with the underlying complexity theory assumptions about the interactive nature of learning in a complex system (Davis & Simmt, 2006;

Johnson, 2001; Morrison, 2006). Secondly, it seems impossible for any teacher to be an expert when technologies are constantly changing. I felt that I had a lot to learn (my reason for conducting this research). Because of what I learned from prior research about the complexity of navigating a collaborative research project (e.g., Steele, 2012), followed by instances that led me to wonder about participant perceptions of expertise, I continually questioned my influence and whether it was supporting or inhibiting my intention to decentralize control for our learning.

Some of the experiences that are highlighted in the above narrative show that I questioned when (and how) to contribute and when to hold back. I was aware, from prior research (Bruce, Jarvis, Flynn, & Brock, 2011), that leadership is important in a collaborative inquiry, and I found that particular leadership roles and responsibilities were evident in this context (see Lazarus, 2020b). I also realized that distributed leadership (as opposed to authoritative leadership) can be supported by distributing leadership responsibilities across participants, and that leaders can "emphasize the best and most creative contributions of those around them, rather than commanding obedience or even leading by example" (Bruce, Jarvis, Flynn, & Brock, 2011, p. 44; Spillane J. , 2005; Spillane, Halverson, & Diamond, 2004). Sometimes I struggled, however, with deciding whether or how to jump in when I noticed what I considered to be good ideas. At these times, I wondered whether pursuing some of these ideas might lead to my directing our activities. Or, by not responding on the other hand, was it possible that important learning and/or research opportunities were lost?

As an insider-outsider researcher in this context, I was also concerned about the location of ownership in this simultaneous inquiry and research project. Prior research has shown that it is possible for one project to take precedence over another, even when a researcher aims to support equilibrium in the relationships (e.g., Capobianco, Lincoln, Canuel-Browne, and Trimarchi, 2006; Steele, 2012). This concern reinforced my struggle with deciding how to contribute when I thought that responding might impact the activities (e.g., early in the project before a collaborative culture was established). In this case, I found that distributing project leadership responsibilities with the coaches (e.g., for facilitating meetings, for ensuring that project expectations were being met) and decentralizing control for our learning through efforts to establish an environment in which teachers contribute ideas and share their experiences helped with navigating this tension. With coaches sharing responsibility for facilitating our meetings (e.g., chairing meetings, taking meeting notes), for instance, I had opportunities to listen and observe, to assess what was happening, and to reflect on how I might respond.

Thus, my experience was different from Steele (2012), who experienced a tension that she called the "Researcher/Facilitator dilemma" (p. 25) when she aimed to facilitate and conduct her doctoral research in a collaborative action research project. Steele's findings show that even a very experienced facilitator whose intention is to give the greatest degree of autonomy to participants and the least degree of authority to the facilitator/researcher, might not realize this intention, due in part to inexperience with navigating these multiple roles. In this case, I found that by distributing leadership roles and responsibilities, I had more opportunities assess what was happening before determining my next steps. By informing my responses and subsequent research plans, these opportunities helped me to navigate tensions of multimembership (being a leader and a learner) and of supporting equilibrium in the inquiry and research relationships.

Assessment *for* Learning and Research

As I engaged in this inquiry and simultaneously analysed the findings for my own research purposes, I became more aware of connections between the classroom assessment ideas that we were exploring, and the ways ongoing assessment of this project helped to support professional learning and research. The importance of classroom assessment for supporting student learning in mathematics is accepted by researchers (e.g., see Black & Wiliam, 1998; Suurtamm et al., 2016) and by professional mathematics education associations (e.g., NCTM, 2014). I started to note connections between the importance of classroom assessment and the importance of assessment for supporting our activities. Ongoing assessment (or data analysis) that informed the project as it unfolded seemed to be an important aspect of this professional learning and research collaboration.

Inquiry and research plans evolved over the course of this project and ongoing assessment of the inquiry activities helped to inform our next steps. Simon (1995) exemplifies how assessment of conditions that are encountered over the course of a journey, using the metaphor of a sailing journey, can inform planning:

> Consider that you have decided to sail around the world in order to visit places that you have never seen. One does not do this randomly (e.g., go to France, then Hawaii, then England), but neither is there one set itinerary to follow. Rather, you acquire as much knowledge relevant to planning your journey as possible. You then make a plan.

> However, you must constantly adjust because of the conditions that you encounter. You continue to acquire knowledge about sailing, about the current conditions, and about the areas that you wish to visit. You change your plans with respect to the order of your destinations. You modify the length and nature of your visits as a result of interactions with people along the way. You add destinations that prior to your trip were unknown to you. (Simon, 1995, p. 137)

In this case, the initial inquiry plans were articulated in my research proposal and in the school district technology project proposal. These plans were informed by my prior experiences and knowledge of relevant theory and research (as a project co-lead, Patricia also contributed to the initial district project plans). Just like in a sailing trip, plans changed as we gained insight into conditions that were unknown to us prior to this journey.

We planned to explore various technologies and to consider how these tools might support specific assessment purposes. We changed course, however, as we realized that it was more important for this group to focus more closely on formative assessment (see Lazarus, 2020a). We also began to realize that we might be moving too fast. During our second meeting, for instance, when Kelly expressed that she felt overwhelmed by all of the technologies, coaches responded by emphasizing that we needed to slow down and focus on a smaller number of tools (Trans, GRP_{NOV}). This feedback was helpful—we adjusted our inquiry plans to avoid overwhelming teachers. Since several teachers had expressed interest in learning more about a particular tool, we added a destination—Sarah (Technology Coach) prepared a session to introduce this tool at our next face-to-face meeting. Thus, by assessing comfort with technology and what teachers were expressing interest in learning more about, we changed plans to adapt to conditions that were unknown to us prior to this learning journey.

In addition to the more informal assessment that happened during meetings, my more formal analysis of the research data helped to inform some of our next steps. After transcribing data from the first two meetings, for instance, I discussed my interpretations and compared observations with Shelly (Instructional Coach). We started to notice connections between some of the ideas that were emerging to different technology frameworks that are identified in the literature. This appeared to be an appropriate time to introduce a technology framework to the team. Since the SAMR Model (Puentedura, 2013) was being used in the district at this time, we invited Sarah to introduce this framework at our third meeting.

These examples illustrate only some of the ways that assessment by project leaders and by a researcher was used to support the inquiry activities by informing our next steps. There seems to be a parallel between the importance of using ongoing assessment to support student learning and of using ongoing assessment to support professional inquiry and research activities emerged. In this case, parallel to Black and Wiliam's (1998) argument that the information that is gathered from classroom assessment is essential for adapting teaching to meet student needs, I would argue that ongoing assessment of professional inquiry and/or research activities is important for adapting research and inquiry plans to meet participant needs.

To summarize, this project was very dear to me. I was passionate about learning how to improve my teaching practices. I was a project leader who had the opportunity to co-lead a project that aligned with my personal and research interests. As the narrative shows, this learning and research journey was not smooth, however. I struggled with deciding when to speak up and when to hold back. I felt uncomfortable when participants were frustrated. I found it challenging to decide how much direction to provide. As I reflected on these inner tensions and on my experiences in this inquiry, I began to see opportunities to distribute leadership responsibilities (i.e., for facilitating the meetings) and to use ongoing assessment of the inquiry activities to help navigate these internal tensions of multimembership. As a project leader and researcher, I noticed that reflecting on our learning with colleagues between meetings and analysing data that were collected for this study appeared to help guide our next steps. By relinquishing singular control during our meetings, I found opportunities to listen and observe what was happening and to use ongoing assessment to inform my contributions. At times, I noticed myself feeling that I might have contributed more. Other times, I appreciated the opportunity to step back when I was unsure of how to respond. As a teacher and researcher, it seemed that sharing control helped to enable opportunities for me to listen and learn with my colleagues. As a project leader and researcher, holding back was sometimes uncomfortable but it also seemed that listening, observing and assessing our activities helped to inform my contributions.

Conclusions and Considerations for Research and Practice

Through this personal inquiry I aimed to address the question, "How can I, as a researcher and project leader, navigate tensions that emerge as I facilitate a professional learning and research collaboration while also being a colleague?" The narrative and discussion above show how I grappled with learning to be a leader and a learner in a nexus of multimembership (Wegner, 1998). From Steele's (2012) and Avgitidou's (2009) research, I realized the complexity of efforts to be an insider-outsider researcher and facilitator in this kind of a collaboration. Like Steele (2012), who reflected on her experiences as a researcher, facilitator, and participant in a collaborative (action research) project, I struggled with enacting multiple forms of membership at the same time. I also realized, from Avgitidou's study, that external researchers as facilitators need to be flexible and sensitive to the context. Unlike in Steele's and Avgitidou's projects, however, I worked with instructional coaches and technology coaches who shared project leadership responsibilities, including the responsibility for facilitating our meetings. I still experienced tensions, however, including deciding when to speak up, when to hold back, and how to respond to unanticipated participant contributions.

From this personal inquiry—a form of assessment *as* learning—I have learned that while it can be uncomfortable to share leadership responsibilities, doing so can present valuable opportunities to observe, listen, and assess what is happening. While my journey navigating this nexus of multimembership was not smooth, findings from this personal inquiry suggest that distributing control (or leadership) and using ongoing formative assessment might support project leaders and/or researchers in their efforts to lead and learn alongside their colleagues in a collaborative inquiry.

CHAPTER 6: Conclusions and Implications for Research and Practice

In this chapter I report on my conclusions and on implications of this study for research and practice. First, I address themes that emerged in connection to my research questions. Then, I discuss considerations for using technology in mathematics classroom assessment, for supporting learning in a technology-focused collaborative inquiry, and for project leaders and researchers who intend to engage in a professional learning and/or research collaboration. Then, I summarize research contributions and limitations of this study, and I outline recommendations for further study. Finally, I provide a statement of conclusions that can be drawn from this work.

Addressing my Research Questions

In this *thesis by articles* I present findings from my qualitative study of *what* was learned about using technology in mathematics classroom assessment and of *how* this learning was supported in a collaborative inquiry (see Appendix A for a summary of the articles in connection to research questions and data collection for this study). I examined the learning that emerged in this collaborative inquiry with different lenses in the three articles that are included in this thesis. In the first article I looked at *what* was learned about using technology in mathematics classroom assessment and at how our collective focus on using technology to support particular assessment purposes took shape. In the second article I analysed *how* our learning about the use of technology in assessment was supported. In the third article I examined internal tensions that arose from my multimembership—as a teacher participant, project co-leader, and researcher—in this collaboration with my colleagues. Together, the three articles provide insight into the group's learning about how technology can be used in mathematics classroom assessment and into how a technology-focused inquiry can be supported. Three overall research questions were addressed in this study:

- *What* was learned about the use of technology in mathematics classroom assessment through a collaborative inquiry?
- *How* was our learning supported in this technology-focused collaborative inquiry?
- How did I, as a researcher and project leader, navigate tensions that emerged as I engaged in a professional learning and research collaboration with my colleagues?

Four overall themes took shape in connection to these research questions. Firstly, participants emphasized the importance of using technology to enrich their current assessment practices. Secondly, it was evident in my analysis of how our learning was supported that professional learning and inquiry processes were supported by multiple roles; including project leaders (coaches) who shared leadership roles and responsibilities (managing, mediating, motivating, modelling) (Bruce, Jarvis, Flynn, & Brock, 2011), teachers who shared responsibility for supporting each other's professional learning, and online communications, which helped to enable the sharing of resources and experiences. Thirdly, the analysis of my experiences in this inquiry provided evidence that distributing control for this inquiry appeared to help myself (as a project leader and researcher) to support equilibrium in the research relationships. Finally, this analysis also highlighted previously under-developed connections between the purposes of classroom assessment and other layers of assessment (or analysis).

What Was Learned? Using Technology to Enrich Assessment Practices

The educators who chose to participate in this inquiry joined because of a shared interest in working together to explore the use of technology in assessment. This study draws on the insights of these educators who, as key stakeholders in educational research, bring valuable perspectives from the field to research (Kieren, Krainer, Shaughnessy, 2013). The analysis of what was learned in this inquiry (Chapter 3) reveals themes in these educators' insights into using technology in mathematics classroom assessment.

Participants brought a range of teaching experiences, comfort with technology, and interests to this inquiry. Even though teachers expressed their appreciation for opportunities to explore ideas together, themes in the analysis of this inquiry suggest that the possibilities for integrating technology in practice can be overwhelming for teachers. At all three of our face-to-face meetings, teachers emphasized that it was important to choose a manageable number of ideas for using technology. At the beginning of the project, for instance, Kelly (Teacher) seemed to be overwhelmed by the possibilities. She expressed her frustration during our second group meeting (GRP_{NOV}). By our third meeting, however, she expressed appreciation for the opportunities "to hear what other people are doing" and for being able to try new things, without taking on more than she could "manage" (p. 20). Other teachers emphasized that there are "lots of technologies out there" (Christine, Trans, GRP_{FEB}, p. 7) so it's important to pick one or two things to work on and "just keep adding" (Liz, Trans, GRP_{FEB}, p. 7). Even though the inquiry was designed to promote open exploration so that teachers could chose to explore technologies or ideas that they were interested in, it was also bounded by our a shared focus.

In this case, *liberating constraints* (Davis & Simmt, 2003) appeared to be reflected in the flexibly bounded inquiry focus. Liberating constraints aim to balance diversity and redundancy in a complex system by providing sufficient organization and at the same time embracing the emergence of unanticipated contributions. From this perspective, diversity is important for generating new ideas and creative insights into problems that are encountered in practice. Redundancy is essential for enabling interactions. In this case, participants negotiated and refined a shared inquiry focus that was designed to be broad enough to allow individual teachers with diverse interests and confidence with technology, to pursue different technologies and ideas for using technology in assessment. My analysis of the data showed that Christine (Teacher), for instance, seemed to be quite confident with using technology. She explored ways to integrate some of the tools that were discussed at our first meeting to develop a "flipped classroom" idea that she came to this inquiry with. Liz (Teacher), on the other hand, appeared to be less confident with technology. She expressed her interest in learning more in order to better support her students. Despite this kind of diversity, my study of participants' contributions to this inquiry revealed that the group was able to establish a shared focus that embraced diversity in individual goals, and at the same time enabled sharing around a common goal―to enrich practices by using technology to in assessment *as, for,* and *of* learning in mathematics.

Another key theme that emerged from my analysis is that technology should be used for more than "the sake of it." After our first two meetings, when Shelly (Instructional Coach) and I began to notice teachers seeing little or no value in using technology in certain ways but they identified opportunities for using tools like dynamics mathematics software to enrich their practices, we decided that it would be worth introducing a technology framework that describes how technology might be used to enhance or transform classroom practices. Sarah (Technology Coach) introduced a framework (Puentedura, 2013), with ideas for using technology to *enhance* and possibly even *transform* assessment (see Appendix K for a copy of the Google slides that she created for this presentation). This framework seemed to be important to group members. Kelly, for instance, felt that it should be included in the presentation of our findings at a provincial mathematics conference. This framework appeared to clarify how the group could think about using technology for more than the sake of it.

Despite the teachers different approaches to incorporating technology into their practices, common themes emerged in the ideas for using technology in assessment *as, for,* and *of* learning.

This study revealed that they found opportunities to enrich formative assessment practices (assessment *as* and *for* learning) by helping to improve the immediacy of feedback for students and teachers, by supporting mathematics investigations and self-assessment, and by making it possible to capture and share student thinking. These kinds of opportunities for formative assessment echo findings from prior classroom based studies that describe how technology can support teachers' new and existing formative assessment practices (Clark-Wilson, 2010; Panero & Aldon, 2016). In terms of assessment *of* learning, some participants found that technology made it possible for students to engage with more complex problems in summative assessments, and to demonstrate more complex understandings and problem-solving processes. Participants also emphasized that in order to preserve the integrity of a summative assessment, teachers need to carefully consider the purposes of an assessment and then decide whether and how technology can support these purposes. A similar message was articulated by Webel and Otten (2015) who argue that when students have access to technology (PhotoMath), teachers need to reconsider what it is they expect students to do. Overall, a key theme for this inquiry community appeared to be the need to move beyond using technology "for the sake of it" and to instead use it to "up the ante of," or enrich, assessment.

How Was Our Learning Facilitated? Enabling Interactions and Distributing Leadership

A central theme that emerged from my analysis of how our learning was facilitated involved the importance of participants' sharing responsibility for our learning and for the inquiry processes. The inquiry was designed to embrace the premise that conditions for learning (internal diversity, redundancy, organized randomness, decentralized control, and neighbour interactions) can help to prompt, bound, and nurture emergence (Davis & Simmt, 2003). Therefore, this inquiry was designed to promote the emergence of ideas for using technology in mathematics classroom assessment by drawing on the conditions for learning.

The importance of *neighbour interactions* was emphasized by teachers. On several occasions, teachers stressed that they valued the opportunities to meet and share ideas, resources, and their experiences (Trans, GRP_{NOV}; Trans GRP_{FEB}). At our final meeting, for instance, Shelly asked the group about the value of this support system and Liz articulated the importance of this opportunity for her to meet with teachers from different schools:

Shelly (Instructional Coach): And how much was the support system of value. Either this piece about the sharing with colleagues or something? Was there a place for that? Or wasn't really that impactful?

Liz (Teacher): I think it's very important because sometimes when we're in a smaller school... even though I'm in a large school, it's a small number of teachers that teach certain subject areas, right? So to have someone to ask a question or when you show up or something like this, that's very important. Right? I need the support. I need the extra help. Or someone to say, "Try this." Or, you know... very very important. (Trans, GRP_{FEB}, p. 8)

This position was echoed at the previous face-to-face meeting, with participants expressing the need to share ideas and resources more regularly, and with Jennifer emphasizing informally after that meeting, that she appreciated the opportunity to collaborate outside of her school.

Technology appeared to help enable neighbour interactions (Davis & Simmt, 2003) by making it possible for this group to interact more frequently than would have been possible by face-to-face alone. Teachers from different schools were able to check in between face-to-face meetings by using a synchronous online meeting platform (Google Hangouts). Technologies were also used to facilitate sharing. This group used an online folder (Google Drive) and an online collaborative platform (Padlet) to share and organize different ideas, resources, and experiences (see Appendix I). Neighbour interactions were an important feature of this inquiry, and technology helped to enable these interactions.

Teachers brought a range of interests, perspectives on assessment, and knowledge of mathematics, pedagogy, and technology to this inquiry. Thus, the inquiry was designed to support *internal diversity*. The involvement of both technology coaches and instructional coaches was unplanned. In addition to supporting the professional learning and inquiry processes, the coaches offered unique perspectives, experiences, and expertise that contributed to the internal diversity within this group. Within this diverse community, *redundancy* was supported by the shared experiences with supporting student learning in high school mathematics, in the same English-speaking school district in Ontario, Canada. In this case, diversity was supported to help prompt the emergence of different ideas and creative insights, while redundancy was necessary to help enable our interactions.

Organized randomness (liberating constraints) was reflected in the flexibly bounded focus on using technology to support particular purposes of assessment. The focus was bounded yet offered multiple entry points and allowed for the emergence of unanticipated directions and ideas. The need for liberating constraints was reflected in statements by participants about the importance of teacher choice (liberating) and of narrowing the focus to something that is manageable (constraints), particularly in a technology-focused project when there are so many tools available. The value of being able to choose what to focus on, and to narrow down the focus to something that is manageable, was stressed during the final meeting:

> **Christine (Teacher):** Yeah. Like I probably never would have tried Padlet had it not been for this and now I feel pretty comfortable with it. It gave me an excuse just to kinda try some things. And certainly there's lots of technologies out there. Like I haven't used Kahoots a whole lot. Like there's other ones that sure I could try but I've kinda picked a few that are working okay with me and I'm kinda running with them because....
>
> **Patricia (Instructional Coach):** Which makes sense.
>
> **Kelly (Teacher):** That's what we were saying at our session that there's so much. Pick a couple and do well with the couple that you do.
>
> **Liz (Teacher):** They just keep adding. Like I know for sure next year I'm going to add to it and do more. (Trans, GRP_{FEB}, p. 7)

At this same meeting, participants expressed that they felt more knowledgeable when it came to using technology. However, as is reflected in the above statement, liberating constraints appeared to be important for focusing our learning. In Chapter 3 I highlighted how this group narrowed down a focus by collectively developing a framework for considering the use of technology in assessment *as, for,* and *of* learning.

In this case, the intention was to *decentralize control* by supporting a distributed leadership approach (Bruce, Jarvis, Flynn, & Brock, 2011; Spillane, 2005). The data revealed that project leaders (coaches) helped to facilitate the inquiry activities by sharing leadership roles and responsibilities (Bruce, Jarvis, Flynn, & Brock, 2011). I used four leadership roles and responsibilities that emerged from Bruce, Jarvis, Flynn, and Brock's (2011) analysis of lead teachers' perceptions on their roles and responsibilities in collaborative action research (mediating, modelling, managing, motivating) to frame my analysis of the project leadership in this context. This analysis revealed that coaches, who were in teacher support roles, helped to mitigate the technical demands and project demands on teachers by sharing these responsibilities. Given the additional demands of a collaborative inquiry project (e.g., organizing activities, managing evidence of student learning, preparing for presentations of the findings), and particularly a technology-focused project (e.g., learning about technologies, teaching students how to use technologies, dealing with technical issues), I would argue that having the support from at least one person in a teacher support role (e.g., instructional coaches and/or technology coaches) is important for facilitating inquiry processes and for supporting teachers in a technology-focused collaboration.

To summarize themes that connected to how this collaborative inquiry focused on technology in assessment was facilitated, this analysis revealed that teachers appreciated opportunities to be exposed to new (to them) technologies and to hear what other teachers were doing. In other words, it was important to enable neighbour interactions. In this case, blending our interactions with both face-to-face and online communications appeared to help enable more frequent sharing. Additionally, my analysis of the data shows that the coaches took on project leadership responsibilities that facilitated our inquiry activities and supported teachers in their classrooms. Therefore, the data reflects the value of opportunities for teachers to share in a "support system" with their colleagues, and that these opportunities can be facilitated by online communications and by project leaders, particularly by coaches who are available to support teachers in their classrooms.

How Did I Navigate a Collaborative Inquiry with Colleagues? Using Assessment *for* Learning and Research

An unanticipated theme emerged as I carried out this study and examined my experiences with navigating tensions that arose from my efforts to lead and learn through a collaborative inquiry with my colleagues (see Chapter 5). I began to notice parallels between the purposes of assessment that were outlined in our co-constructed classroom assessment framework (see Appendix D), and the purposes of data analysis and reflection (which could be viewed as assessment) within this collaborative inquiry. I found that I engaged in the three purposes of assessment (*as, for,* and *of* learning) and that ongoing formative assessment (assessment *for* learning) helped with navigating some of the tensions that I encountered in my efforts to lead and learn (as a teacher, researcher, and project leader) in this context.

Purposes of Assessment. Our classroom assessment framework was informed by the assessment policy in this context (Ontario Ministry of Education, 2010). According to this policy, *assessment* is the activities undertaken by teachers or students that involve gathering information about student learning. There are different purposes of classroom assessment. Firstly, assessment *as* learning focuses on developing students' capacity to self-assess (Ontario Ministry of Education, 2010). From this perspective, students develop their abilities to set goals, self-monitor their progress with respect to these goals, determine their next steps, and reflect on their thinking and learning. Secondly, assessment *for* learning is an interactive process that is carried out by the teacher to support student learning (Ontario Ministry of Education, 2010). The teacher uses assessment information to inform instructional decisions. The purpose of both assessment *as* and *for* learning is to improve student learning. Finally, the purpose of assessment *of* learning is to summarize learning at a specific time (Ontario Ministry of Education, 2010). The information that is gathered for assessment *of* learning is used to make judgements about student learning and to communicate achievement information to students, parents, teachers, and others (Ontario Ministry of Education, 2010). The inquiry group examined how technology might be used to support these three assessment purposes in a mathematics classroom.

Over the course of this inquiry, I began to notice connections between the purposes of classroom assessment and the purposes of assessment (or analysis) within our collaborative inquiry. It is unclear when I started to realize the connections but during my analysis of a coaches' meeting transcript, I found that Shelly had identified parallels between assessment *as* learning in a classroom context and assessment *as* learning in a professional learning context. During this meeting, as I self-reflected on my plans for integrating technology in assessment, Shelly pointed out that I, like a student, was engaging in self-assessment:

> **Me:** So now I'll probably go home and think about why... [Shelly laughs] and the task that I was planning will look different because of how you questioned my thinking about it…. Yeah, it will look different.
>
> **Shelly (Instructional Coach):** The assessment *as* learning...
>
> **Me:** Yeah, because I didn't see that in there before....
>
> **Shelly:** But the assessment *as* learning, *as* you're assessing your own mind. Wow, it's like a mirror that just keeps going back and forth.... Dual mirrors and you never get to the end of it because you keep getting bigger and bigger. (Trans, SUB_{DEC}, p. 11)

In this segment of the transcript, Shelly identified my self-assessment of my teaching plans as assessment *as* learning. She observed a connection between assessment *as* learning in a classroom context and in a professional learning context as "dual mirrors" that keep going back and forth. In other words, assessment *as* learning, which is valuable for supporting student learning in a classroom (Earl, 2013), was evident in this instance.

During a subsequent informal conversation with Shelly, she used the self-similarity of fractals as another way to conceptualize parallels between purposes of classroom assessment and purposes of assessment in a professional learning context (Field Notes, INF_{MAY}). The extension of fractals in connection to teaching, learning, and research in mathematics education has been recognized in academic literature (Suurtamm, 2011). Suurtamm (2011) described how self-similarity and iteration, important properties of fractals, can have an impact beyond mathematics and physics. Suurtamm described self-similarity by explaining that "on close inspection of a fractal object, each part of the object resembles the object as a whole, often through several orders of magnitude" (p. 27) and she offered examples to illustrate how fractals might appear in mathematics education. In one research project, for instance, Suurtamm noticed self-similarity between a collaborative community of teachers and the collaborative communities that were developing in classrooms. Likewise, in the context of the collaborative inquiry that is described in this thesis, there seemed to be similarity in the ways I began to think about classroom assessment and assessment in a collaborative inquiry.

I wondered if assessment (or analysis) in a collaborative inquiry might be conceptualized in the same way as classroom assessment. More specifically, if the definition of classroom assessment includes the activities that a teacher or student engages in to gather information that is used as feedback to modify teaching and learning activities (Black & Wiliam, 1998; Ontario Ministry of Education, 2010), assessment (or analysis) in a collaborative inquiry might include the activities that a project leader, researcher, or participant engages in to gather information about participant learning that is used as feedback to inform inquiry or research activities. A project leader, for example, might use the information that is gathered from observations or conversations with participants to inform subsequent meeting plans. A researcher might use the information that is gathered from data collection to alter his or her research activities. Like in a classroom context, the feedback that is gathered by participants, project leaders, and researchers might be used for different purposes: *as, for,* and *of* learning. Further discussion of the ways the different purposes of assessment might appear in a collaborative inquiry follows below.

Assessment *as* learning. Extending the definition of assessment *as* (student) learning in a mathematics classroom, assessment *as* learning in a collaborative inquiry focuses on participants' capacity to self-assess their own learning. Professionals and researchers engage in assessment *as* learning by setting goals, monitoring their progress, and determining their next steps. Evidence of these activities emerged in this collaborative inquiry.

In this context, participants set goals, monitored their progress, and identified their next steps. The goal setting processes, which involved negotiating and refining a collective focus on using technology to support mathematics classroom assessment and then having teachers identify individual goals that fit within that focus, is described in Chapter 3. Throughout the inquiry, teachers shared their progress and identified their next steps. At the first group meeting, for example, I shared my own goal "to use technology (e.g., Nearpod, screencasting, Kahoot) to get students more involved in assessing their own learning" (Doc, GRP_{OCT}). At subsequent meetings I reported on my progress and identified my next steps. Other teachers identified their own goals, all under the umbrella of our collective focus on using technology to support assessment. They also reported on their own progress at subsequent meetings. By engaging in these kinds of processes, teachers were self-assessors of their own learning.

As a graduate student, I engaged in assessment (analysis) *as* learning throughout all aspects of the research processes: from developing the study goals to monitoring the research progress and determining my next steps. My research goals were articulated in a research proposal and are summarized in the first chapter of this thesis. I monitored my research progress with respect to the study goals by constantly reflecting on the collective knowledge of technology in assessment that emerged in the field. I also monitored my research progress by self-reflecting on my interpretations of the data and on my influence in the field. I analysed data along the way and used the insight that I gained from this process to monitor my research progress and to inform my next steps as a researcher. The feedback from ongoing assessment (analysis) of the inquiry activities was valuable for navigating this inquiry as an insider researcher and project co-lead (see Chapter 5). By analysing the data between inquiry group meetings, for instance, I was better able to make more informed decisions about how to adapt my research plans along the way. Therefore, assessment (or analysis) *as* learning was evident in the ongoing self-assessment of my interpretations of the data and in my self-assessment of the research processes. Like in a mathematics classroom, assessment *as* learning was evident in the use of data analysis to monitor my research progress and to inform my next steps in the research process.

Assessment *for* learning. Extending the definition of assessment *for* learning in a mathematics classroom, a project leader in a collaborative inquiry might use assessment *for* learning to determine where participants are at, where they need to go, and how best to get there.

In this collaborative inquiry, project leaders used ongoing assessment to support the inquiry activities and professional learning. In terms of supporting inquiry activities, assessment informed planning and facilitation. During our second meeting, for example, it became clear when one participant (Kelly) expressed frustration with being overwhelmed by all of the technologies, that teachers needed permission to slow down and choose a manageable focus:

> **Kelly (Teacher):** What I'm finding is, I don't know if any other classroom teachers have the same, I don't know, not necessarily fear but the coaches are exposed more to what is out there than we are and so I find that in the last meeting and this meeting that apps and whatnot are brought to us but it's really the coaches who have the expertise in the apps so it would be nice to, as Sarah said, try one or two things and figure that out rather than a whole pile of stuff that... I don't know what's out there I guess.
>
> **Patricia (Instructional Coach):** That's a good point though. So rather than touching on many.
>
> **Kelly:** I think so because if part of the focus is on how are we using it for assessment, unless we can really get our hands thoroughly on an app or a piece of software, if you're... myself for instance, if I'm constantly kind of fighting and trying to figure out how to use it and how to figure out how to tell the kids how to use it, using it for assessment is way down the list [Liz agrees]. It's more about figuring out the technology versus I'll quick try it out. Like this afternoon we're going to try out Explain Everything. I hope that the kids might be able to do something with assessment after we do a little figuring that out this afternoon. I don't know. Like I'm hoping that a lot of the other classroom teachers are maybe at the same stage.
>
> **Patricia:** Yeah I think that's a really good point that we need to get comfortable and learn how to use it and then the students. Good point.

In this case, project leaders received important information about where Kelly (and likely other teachers) were at in terms of her learning about the technology. Patricia, who was facilitating the meeting, addressed this learning need in the moment by acknowledging that it was a good point and encouraging everyone to gain comfort with a smaller number of tools first. Therefore, this instance exemplifies that the feedback appeared to help project leaders gain insight into where participants might be at (e.g., when they felt overwhelmed by the technology), where they might need to go, and how best to get there (e.g., by focusing on a small number of tools).

In addition to using assessment *for* learning in the moment, like Patricia did when she responded to Kelly by encouraging everyone to gain comfort with the technology first, assessment information was used to inform subsequent inquiry plans and to support professional learning. During a planning meeting, for example, coaches reflected on Kelly's feedback and decided that at the next group meeting, we would focus on one tool that many participants had expressed interest in (Trans, SUB_{DEC}). Coaches also responded to this learning need by offering more in-class support. Sarah, a technology coach, for example, worked more closely to support Kelly with integrating in her classroom. The feedback from Kelly exemplifies how a participant contribution provided information about where one teacher was at in terms of the need to gain more comfort with technology. This feedback provided the facilitator (Patricia) with important information and helped to inform next steps for the inquiry activities and for supporting professional learning in classrooms. Thus, the use of this feedback illustrates how assessment *for* learning might be used to support professional learning and inquiry processes.

Assessment *of* learning. Extending the definition of assessment *of* learning in a mathematics classroom, assessment *of* learning in a collaborative inquiry involves summarizing learning (or research findings) at a given point in time. This information is used to communicate findings to different audiences. In this case, participants demonstrated their learning and communicated findings to different audiences by contributing to final reports, including presentations and a website that was developed to share findings with other educators in the district.

Teachers acknowledged the importance of sharing our findings but most were not interested in doing formal presentations (Trans, GRP_{MAY}). They were, however, open to sharing more informally (e.g., planning for presentations, sharing with colleagues during more informal conversations) (Trans, GRP_{MAY}). Given the lack of interest in formal presentations, participants were invited to facilitate presentations but it was not an expectation (Trans, GRP_{OCT}). They did, however, contribute to planning for presentations and other reports. During our third group meeting, for example, team members helped to organize a presentation for a provincial conference presentation. The findings from this project were shared at three different presentations. Shelly and Sarah joined me for a presentation to district trustees; Shelly, Kelly, and I presented findings at a provincial conference for mathematics teachers; and Shelly, Patricia, and I presented a final report for the district project. In this case, assessment *of* learning was evident in the ways participants demonstrated their learning and communicated findings to different audiences by contributing to these conference presentations.

Assessment *of* learning was also evident in this research. I collected and analysed a range of data sources and have demonstrated my learning in this thesis. In Chapter 3, I analysed and reported on what was learned about the use of technology to support mathematics classroom assessment. In Chapter 4 and 5, I examined and reported on aspects of the collaborative inquiry processes. These three articles represent my assessment *of* the professional learning and inquiry processes.

In summary, parallels between the purposes of mathematics classroom assessment were evident in this collaborative inquiry. Ongoing assessment of the inquiry activities appeared to be valuable for supporting professional learning and research in this context. Assessment *as* learning was reflected in the ways participants engaged in self-assessment; including goal setting, monitoring progress, and determining next steps. Themes in Chapter 5 suggest that project leaders can use assessment *for* learning to help determine where participants are at, where they needed to go, and how best to get there. More specifically, ongoing assessment of participant contributions seemed to support inquiry processes (e.g., informing facilitator decisions, informing inquiry plans) and professional learning (e.g., how coaches might support teachers in their classrooms). Finally, assessment *of* learning was apparent in the final reports that were created to demonstrate our (and my) learning. In other words, findings from my personal inquiry into my own experiences in this community provide insight into some of the ways project leaders and/or researchers might engage in multiple layers of assessment and might consider using ongoing assessment to inform their next steps.

Summary of the Themes

To summarize more briefly, several themes emerged from this study of *what* was learned about using technology in assessment and of *how* learning was supported through a collaborative inquiry:

- *A proscriptive structure appeared to be established through the process of negotiating and refining a shared focus on using technology in assessment as, for, and of learning in* *mathematics.* Despite the diverse ways in which teachers approached the use of technology in assessessment, our shared focus on using technology to enrich assessment *as, for,* and *of* learning in mathematics appeared to ***bound*** this inquiry. My analysis of what was learned about using technology for these purposes revealed that participants found that technology can support formative assessment (assessment *as* and *for* learning) by helping to improve the immediacy of feedback to students and teachers, by promoting student self-assessment, and by making it possible to capture and share student solutions. Ideas for using technology to change the ways students can demonstrate their learning in mathematics (assessment *of* learning) also emerged.

- *Since the possibilities for integrating technology in assessment can be overwhelming, teachers valued being able to choose and/or to adapt a manageable number of tools and/or strategies to support their individual goals.* Thus, while our interactions seemed to help ***prompt*** learning by providing opportunities to share and hear what other teachers were doing, there was diversity reflected in the ways teachers thought about using technology in assessment.
- *When it came to supporting learning about using technology in assessment, teachers reported their appreciation for opportunities to share ideas and to hear what other teachers were doing. Online communications were not perfect but they did appear to help enable this sharing. In addition, there was evidence that coaches helped to mitigate some of the project demands and technology demands on teachers by taking on leadership responsibilities (Bruce, Jarvis, Flynn, & Brock, 2011) and by supporting teachers in their classrooms.* Thus, the analysis of how our learning was facilitated suggests that teachers, project leaders, and online communication technologies can help to ***nurture*** learning in a technology-focused collaborative inquiry.
- *Inner tensions can arise from a project leader and/or researcher's efforts to lead and learn alongside colleagues in a collaborative inquiry.* Thus, the analysis of tensions that I encountered in this inquiry revealed that inner tensions can arise from efforts to ***nurture*** learning in a collaborative inquiry. In this case, for instance, I struggled with deciding when to speak up and when to hold back and with how to respond to unanticipated participant contributions. These struggles reflect the complexity of my efforts to manage multiple forms of membership (teacher participant, project co-learder,

and researcher) and to at the same time maintain a delicate balance between providing too much and too little direction. In other words, I struggled at times with managing organized randomness in this learning system (Davis & Simmt, 2003).

Connecting these themes in the articles, an overall theme in this thesis appears to be that learning in a technology-focused collaboration can be *prompted* by neighbour interactions, *bounded* by a proscriptive shared focus, and *nurtured* by opportunities for teachers to meet and share ideas, by blending face-to-face and online communications, and by having project leaders who share leadership responsibilities and help to mitigate project demands and technology demands on teachers.

Implications for Research and Practice

This study was motivated by personal, practical, and intellectual (research) goals (Maxwell, 2013). Personally, I wished to learn with my colleagues and to develop my own practices with respect to the use of technology in mathematics classroom assessment. The vignette in the conclusion to Chapter 3 describes some of the ways I adapted ideas that emerged to support my practices. Practically, I hoped that this study would contribute ideas for using technology in assessment and for facilitating a technology-focused collaboration. Intellectually, this study was designed to provide insight into *what* was learned and *how* this learning was facilitated in a collaborative learning system. In this section I highlight some of the personal, practical and research contributions of this study though a discussion of considerations for integrating technology in assessment, for supporting a technology-focused collaborative inquiry, and for project leaders and/or researchers who wish to engage in a collaborative inquiry. I conclude with a discussion of limitations to this study and recommendations for further research.

Considerations for Incorporating Technology in Assessment

By drawing on the insights of educators—key stakeholders in educational research (Kieran, Krainer, Shaughnessy, 2013)—the findings in Chapter 3 of this thesis reveal practical ideas and considerations for teachers who wish to use technology in mathematics classroom assessment. More specifically, these findings show that in order to avoid overwhelming teachers with the possibilities, it is important for teachers to choose a manageable number of tools and/or ideas to "up the ante" of (or to enhance/transform) their current assessment practices. In other words, when it comes to developing practices with technology, teachers need permission, and perhaps even encouragement, to take it slow.

The analysis of what this group learned has also shown that a key affordance for teachers can be the opportunity to use technology to improve the immediacy of feedback. Teachers found ways to use technologies, such as student response systems and online sharing platforms, to more efficiently access evidence of student learning and to use this information to help guide their teaching and/or to support their students' learning. Teachers also reported finding that when students used technologies, including dynamic mathematics software, online search engines, and online sharing platforms, to verify their thinking or to investigate relationships, they began to self-assess their learning. These kinds of themes in the data reveal that for this inquiry group, a key affordance for using technology appeared to be the opportunity to provide more immediate feedback to students.

Prior research and academic literature highlights similar affordances for formative assessment in mathematics. Through vignettes of current classroom assessment practices, for instance, Olsher, Yerushalmy, and Chazan (2016) envisioned possibilities for harnessing technology "to support the work of teachers by providing them with immediate access to views of the work of large groups of students working on open response tasks, categorizing them to fit relevant characteristics for the teacher to attend to, and also freeing up teachers' attention for student solutions that are out of the ordinary" (p. 16). Other researchers have shown that digital tools can support the processes of collecting, interpreting, and exploiting evidence of student learning and can therefore facilitate a teacher's understanding of students' knowledge (Panero & Aldon, 2016). Panero and Aldon's study shows that these technology affordances can make the processes of discussing student responses more efficient. In their study, both the teacher and students took advantage of the interpretation of data: the teacher modified his teaching regarding students' responses and students improved their learning in response to the teacher's feedback (Panero & Aldon, 2016).

An important potential issue that was not discussed in this inquiry concerns the need to manage increased amounts of classroom data. This issue was identified by Clark-Wilson (2010), who also found that with technology (shared response screens) teachers can develop new (and support existing) formative assessment practices by gaining insight into students' sense-making processes and by presenting opportunities to support students' self- and peer assessment. Clark-Wilson's findings suggest that even though a key advantage of using technology for formative assessment may be the opportunity to access more immediate feedback, a corresponding consideration appears to be need for teachers to develop new strategies for managing increased amounts of student evidence that can be gathered with technology.

In terms of the implications of technology for summative assessment, participants identified opportunities for students to demonstrate more conceptual understandings and problem solving processes. Kelly, for instance, shared an example of a summative assessment that her students used to demonstrate their conceptual understandings of quadratic relations (see Appendix M). The vignette of my own practices in the conclusion to Chapter 3 shows that I explored the possibility of having students use a screencasting application to demonstrate their understanding of connections between numerical, graphical, and algebraic representations of quadratic relations. This finding, that teachers can, and likely should, refocus their assessment goals when students have access to technology, echoes Webel and Otten's (2015) suggestion (in a professional publication for mathematics teachers). In this case, teachers identified a key consideration to be the need to "preserve the integrity" of summative assessments by keeping in mind the purpose of the assessment and how technology can support this purpose. For instance, if the goal is to have students to demonstrate their graphing skills then allowing access to graphing software is likely problematic. If the goal is for students to show their ability to interpret and make connections between mathematics representations, however, the same technology might allow students to focus on demonstrating problem solving processes.

To summarize, this study demonstrated that teachers who wish to develop their assessment practices with technology should consider some of these deeper-level assessment issues:

- How technology can be integrated to enrich current assessment practices. Puentedura's (2013) SAMR Model might be used as a framework for thinking about possibilities for enhancing and/or transforming what is possible without technology;
- How to more efficiently access and use evidence of student learning to inform teaching (assessment *for* learning);
- How to integrate technology for greater student self- and peer-assessment in mathematics (assessment *as* learning);
- What mathematics learning expectations are in focus for students, and when / how technology can make it possible for students to demonstrate their learning in new ways (assessment *of* learning).

These considerations provide insight into the ways teachers might think about integrating technology into their mathematics classroom assessment practices. I am not claiming here that teachers should incorporate technologies in particular ways. This study did show, however, that teachers can explore the use of technology to support their current practices by focusing on a manageable number of ideas and/or tools that connect to their teaching and learning goals. The considerations discussed here may help guide teachers in their efforts to embrace the use of technology in their mathematics classroom assessment practices.

Considerations for Supporting a Technology-Focused Inquiry

The analysis of teachers' perspectives on how their learning was supported revealed the importance of providing teachers with opportunities to learn in a supportive community with their colleagues. When teachers were asked about the value of this "support system," or about how they could best support each other, they expressed their appreciation for the opportunities to hear what other teachers are doing, to be exposed to things (e.g., technologies) that they didn't know were out there, to be prompted to change their practices, and to have support from their colleagues. Comments from the teachers in this inquiry group are highlighted in Table 4.

Table 4. **Teachers' Perspectives on their Learning in a Technology-Focused Inquiry**
Christine: I think the biggest bonus of something like this is just chat with people, right? Like to bounce ideas. And when you have an opportunity to talk to people about things, you try things that otherwise you wouldn't even come up with because those ideas get generated from that. So even talking to people in your department, which sadly as a profession we don't often have the time to do. Just the way the days are scheduled. So you almost need an excuse like something like this. And as hard as it is to take that day or to take that afternoon, or whatever it is, it forces you to do those things and it changes, perhaps the way that you would do things **Christine:** I mean sometimes people don't go and seek support necessarily or seek out things because they don't even know it exists. [SK says "mhm" and KO says "yeah."] Right? So I'm not going to ask about something that I don't even know is out there but if you know it's out there then maybe you're going to say, "Hey this might be something I'm going to use" and there are clearly a lot of supports that we have right now in the board in order to help you get there if that's what you're interest in. And if you're not, so be it. That's your choice. **Kelly:** Well I think when we started, like I was one of those... I didn't know that half of these things existed. So how do you use them if you don't know they're there? **Kelly:** It's nice to hear what other people are doing [...] I think, without taking on more than I can really manage and know that that's alright because it's just too many balls in the air. **Liz:** I think it's very important because sometimes when we're in a smaller school... even though

> I'm in a large school, it's a small number of teachers that teach certain subject areas, right? So to have someone to ask a question or when you show up to something like this, that's very important. Right? I need the support. I need the extra help. Or someone to say, "Try this." Or, you know... very very important.
>
> **Jennifer:** I just think the sharing [...] just sharing of experiences and resources and being willing to share like, "I did this and it was like, it did not work." Or like, "I thought this was great and then it just..." Like sharing your, not mistakes because they're not like, but just, yeah, successes but also.... [...] "This didn't go so well and being honest about that because, I think, it's just like we were talking about with the kids seeing other kids mistakes up there, right. It's like that makes them feel like, "Okay I'm not the only one making them."

In other words, teachers appreciated being able to share and to hear about other teachers' experiences. Thus, when it comes to supporting teachers who wish to learn more about integrating technology into their practices, it appears that consideration should be given to providing teachers with opportunities to learn with their colleagues in a supportive community.

The importance of promoting these opportunities is supported by the notion that the emergence of new ideas and creative insights (in this case into the use of technology in assessment) can be prompted by neighbour interactions (Davis & Simmt, 2003). The significance is reinforced by research that shows that teacher confidence with technology appears to be higher when teachers learn from their formal and informal interactions with colleagues (Thomas & Palmer, 2014). But how can these interactions be facilitated in a technology-focused inquiry?

Thomas and Palmer (2014) recommended that a small heterogeneous group of educators can be organized to form a "classroom audience" in which teachers take turns sharing shortened lessons that incorporate technology and having these lessons become the "center of community discussion and reflection" (p. 86). Reflecting this position, this collaborative inquiry involved having different technologies and ideas for using these technologies in assessment become the center of this community's discussion and reflection. While it may be important for teachers to discuss and reflect on the possibilities, the analysis of teachers' learning about the use of technology in assessment revealed that even though teachers might appreciate these opportunities to "see things" they didn't know existed, they can become overwhelmed by the possibilities. Thus, when it comes to facilitating a technology-focused inquiry, consideration should be given to making it possible for teachers to choose a manageable number of ideas and/or tools to explore.

The analysis of how this inquiry was supported also revealed that project leaders shared responsibility for supporting this technology-focused collaboration by helping to (i) *manage* the inquiry activities and classroom evidence, (ii) *model* technologies and technology-rich practices (at group meetings and in classrooms), (iii) *mediate* between the inquiry group and external groups, (iv) *mediate* technical demands on teachers, (v) *motivate* with respect to the use of technology in assessment, and to (vi) *mediate* and *motivate* by providing in-school instructional and technical support. The coaches seemed to help mitigate the project and technical demands on teachers by offering in-school support. Thus, these findings suggest that consideration should be given to involving project leaders in sharing these leadership roles and responsibilities, and to including people in teacher support roles (e.g., instructional coaches, technology coaches) who are available to support teachers in their classrooms.

Further research is needed to describe how coaches (or perhaps curriculum consultants) can support teachers in their classrooms. Reflecting on her role as a coach in this inquiry, Shelly posed the possibility of "interjecting" ideas when appropriate:

> And I wonder about the coaching role, helping them to see the places they can interject it. That might be a... if they got the content knowledge then.... if there's some explicit thinking around inserting technology. Because it's hard to do it on your own when you're not familiar with it, right. So whether with a colleague or with a coach or.... (Shelly, Instructional Coach, Jan. 26, p. 9)

Even though further study is needed, coaches might consider the ways they can "interject" ideas for using technology to support teachers current practices. In addition, as instructional and/or technology leaders, coaches might consider how they can support teachers by helping to model, mediate, motivate, and manage their classroom activities (extension of their role in leading collaborative activities).

To briefly summarize, this study shows that educators with a range of teaching experiences, comfort with technology, and interests with respect to the use of technology in assessment can work together to grapple with developing their practices. When it comes to facilitating similar inquiries, the findings show that consideration should be given to:

- providing opportunities for teachers to share their ideas and experiences in a supportive community;

- blending collaboration by incorporating online communications (synchronous and/or asynchronous) to enable more frequent and dynamic sharing;
- ensuring that teachers can choose a manageable number of ideas and/or technologies to explore;
- including people in teacher support roles (technology coaches or instructional coaches) who can interject relevant ideas when appropriate, take on project leadership roles and responsibilities (Bruce, Jarvis, Flynn, and Brock, 2011), and can help mitigate the project and technical demands on teachers.

These considerations provide insight into how a technology-focused collaborative inquiry might be supported.

Considerations for Project Leaders and Researchers in a Collaborative Inquiry

Findings from my personal inquiry into tensions that arose as I navigated multimembership—as a teacher, researcher, and project co-leader—in this collaborative inquiry, revealed that I struggled with deciding how much to direct our activities, with questioning when to speak up and when to hold back, and with deciding how to respond to some of the unanticipated (and sometimes uncomfortable) participant contributions. Prior research has shown similar "researcher/facilitator dilemmas," and has demonstrated the complexity of enacting participant, researcher, and facilitator roles at the same time (Steele, 2012). The narrative in Chapter 5 highlights internal struggles that I encountered in this collaborative inquiry with my colleagues.

In his response to a theme issue of the *Educational Researcher,* titled *Research for Doctoral Students in Education,* Anderson (2002) argued for a research continuum for doctoral education that includes practitioner research. He concluded with a "plea to education faculty who teach doctoral research methods to consider the unique dilemmas of the practitioner research" (p. 25). The fourth chapter in this thesis has shown some of the internal dilemmas that can arise from efforts to lead, learn, and conduct research with colleagues in a professional learning and research collaboration. Unlike Steele (2012), who took responsibility for facilitating a collaborative action research project with colleagues for her doctoral study and found herself providing more direction than she would have liked, project leadership was shared in this inquiry (see Chapter 4) and I experienced opportunities to step back and reflect on what was happening before responding. With coaches focusing on facilitating our meetings, I seemed to experience more opportunities to engage in ongoing assessment of our learning. Even though the narrative in Chapter 5 shows that it was sometimes uncomfortable for me, relinquishing control for project leadership appeared to help mitigate some of the internal tensions that arose as I aimed to conduct research and at the same time promote shared responsibility for our learning.

Ongoing assessment of the inquiry and research activities appeared to be important for informing my decisions as a researcher and project co-leader in this collaborative inquiry. The importance of formative assessment for student learning has been well established (Black & Wiliam, 1998). More recently, drawing on evidence-based research literature, Wiliam (2016) has also considered strategies for integrating formative assessment into teacher evaluation. Wiliam proposed that three processes can be used for formative evaluation of teacher learning: (i) the goal for teacher's learning, (ii) his or her current level of performance, (iii) steps needed to reach the goal (p. 235). He suggested that "the process of formative assessment, so clearly effective for students, can provide a powerful framework for supporting teachers" (p. 240). Findings from my personal inquiry in this study suggest that when it comes to facilitating a collaborative inquiry, ongoing (formative) assessment can be valuable for a project leader and/or researcher, particularly when it comes to adapting plans and to deciding how to respond to participant contributions. Avgitidou (2009), who described roles, participation, and processes in a collaborative action research project, has demonstrated that the facilitator of this kind of project needs to be flexible and sensitive to the context. From the analysis of my experiences in this inquiry, it appears that this flexibility and sensitivity might be supported by using assessment *for* learning.

Limitations

There are three main limitations to the findings from this study. First, the study of what was learned may be limited by participants' contributions to the inquiry. Second, the study of how our learning was supported focuses on teachers' reports on how their learning was facilitated and on how coaches shared particular leadership roles and responsibilities (Bruce, Jarvis, Flynn, & Brock, 2011). Finally, the personal inquiry into how I navigated internal tensions of multimembership is based on my own experiences in this community. This study provides insight into possibilities and considerations for using technology in assessment and for supporting a technology-focused collaborative inquiry. It does not show how technology *should* be used nor how this kind of an inquiry *should* be facilitated.

The study of *what* was learned about using technology in assessment (Chapter 3) draws on participants' contributions to our face-to-face meetings and to our online communications and is therefore limited to describing what was learned from these contributions. Further study, using individual interviews with teachers and classroom observations, for example, would be required to describe individual teacher understandings and/or classroom practices. In addition, even though some teachers shared classroom evidence (e.g., videos of students working with technology) with the inquiry group, this evidence was not analyzed. Therefore, it is important to note that while this study shows that the inquiry group found opportunities for using technology to develop their assessment practices, further study would be required to examine shifts in individual teacher understandings and to determine the impact of technology on student learning.

The study of how our learning was supported (Chapter 4) is limited to the focus on teachers' perspectives and on coaches' roles and responsibilities as project leaders. The analysis in this thesis focuses on how teachers, coaches, and technology supported the collaborative inquiry. In this case, teachers expressed their appreciation for opportunities to meet and share ideas and, given the underlying complexity theory perspective (Davis & Simmt, 2003), these interactions were considered to be essential to promoting our learning. Further study would be required, using interaction analysis of the transcripts for instance (see Fisher, 1980; Roulet, Khan, 2008), to examine the actual interactions that took shape between participants.

Overall, this study of *what* was learned and of *how* our learning was supported in a technology in assessment focused inquiry provides insight into possibilities and considerations for educators, project leaders, and researchers. Since each inquiry community and learning journey will be unique, the findings do not aim to show how technology *should* be used in assessment, nor how a technology-focused inquiry *should* be supported. Another inquiry community, for instance, may or may not have the means to bring together teachers from different schools, or to include instructional coaches, technology coaches, and/or a graduate student researcher. With different people, perspectives, technologies, and assessment policies, the learning that takes shape in other inquiries will almost certainly look different from the learning that emerged in this context.

Research Contributions

This study contributes to three domains of research in mathematics education. Firstly, the study of what was learned about using technology in mathematics classroom assessment contributes educators' insights into some of the considerations for teachers who wish to incorporate technology into their practices. This study contributes to prior research that has highlighted implications of technology for mathematics classroom assessment (Stacey & Wiliam, 2013), and particularly for formative assessment (Clark-Wilson, 2010; Panero & Aldon, 2016). With the focus here being on themes in participants' contributions, however, further study is needed to describe classroom environments and student use of technology in assessment. More specifically, How can technology-enhanced assessment strategies directly impact student learning? What are students experiences with using technology to support their learning (in assessment *as* learning)? How can students use technology to demonstrate their learning (assessment *of* learning)? How can teachers use technology to support assessment *for* learning in their classrooms? Prior research has highlighted some possibilities for using particular technologies to support formative assessment practices (e.g., see Clark-Wilson, 2016; Panero & Alson, 2016). Further study—and perhaps professional inquiry—is needed, however, to better understand classroom environments in which teachers and students use the tools that are available to them (e.g., personal electronic devices) in assessment.

Secondly, the findings from this study contribute to research that provides insight into collaborative inquiry processes, particularly in a technology-focused collaborative inquiry. More specifically, this study contributes to research that shows:

- what leadership roles and responsibilities can look like (Bruce, Jarvis, Flynn, & Brock, 2011), particularly in a technology-focused inquiry;
- how, despite challenges, online communications can support a professional learning community (Prenger, Poortman, & Handelzalts, 2018);
- how a project leader and researcher can experience tensions of multimembership in a collaborative inquiry (Wenger, 1998; Wenger-Trayner, Fenton-O'Creevy, Hutchinson, Kubiak, & Wenger-Trayner, 2014);
- how ongoing formative assessment might help to support professional learning (Wiliam, 2015) and inquiry/research processes.

Although this study has shown that teachers appreciated opportunities to interact with one another, and that online communications appeared to help enable these interactions, further research is needed to better understand the interactions that can take shape in a collaborative inquiry and the ways online communications can support collaboration and professional learning.

For instance, building on the ways Fisher (1980) and Roulet, Khan, and Lazarus (2008) used interaction analysis, further study might explore, How do participants' contributions to a collaborative inquiry reflect diversity? Do participants tend to agree with leaders, thus reducing diversity? What kinds of "social structuring prompts" do project leaders use to help enable sharing? Avgitidou (2009) found that it can take time to build trust, and therefore collaboration. What kinds of prompts can help to establish a sense of community? And how can trust be developed in a blended, or perhaps even strictly online, inquiry community?

Finally, with respect to the contributions to understanding learning systems in mathematics education, this study contributes to Davis and Simmt's (2003) findings by showing the application of principles of complex systems to a collaborative inquiry. In this case, the inquiry was designed to reflect the perspective that teachers' interactions are essential to the emergence of new (to this community) ideas and creative insights into the use of technology in mathematics classroom assessment and that the conditions for learning—internal diversity, redundancy, neighbour interactions, organized randomness, and decentralized control—can help to prompt, bound, and nurture this emergence in this community (Davis & Simmt, 2003). In addition to showing how this inquiry was designed to embrace these conditions, my analysis of *how* the inquiry was supported (Chapter 4) shows that teachers felt that our interactions were valuable to their learning. This same analysis contributes to the findings from Bruce, Jarvis, Flynn, and Brock's (2011) study of lead teachers' perspectives on their roles and responsibilities in collaborative action research by showing that project leaders can share these responsibilities to support a technology-focused collaborative inquiry.

In addition to showing *what* was learned in this community, the first article in this thesis (Chapter 3) contributes to Kieren, Davis, and Mason's (1996) description of how the parameters of a classroom activity (Fraction Flags) can be negotiated and refined. Kieren, Davis, and Mason showed that through conversations that emerged in the Fractions Flags activity, the teacher was able to respond and adapt learning activities "that are in harmony with students' knowledge and interests" (p. 19). Davis and Simmt (2003) suggested that sometimes adapting these activities involves relaxing parameters, at other times it can involve being more rigid, and that there can times when parameters need to be abandoned in favour of student interests. Likewise, this study revealed that there were times when parameters needed to be relaxed, such as when some teachers expressed that they were feeling overwhelmed by the possibilities. At other times, there seemed to be a need to be more rigid, such as when some teachers seemed to need to narrow their focus. There also appeared to be times when parameters needed to be abandoned in favour of teachers' interests and needs, such as when participants expressed a need to focus more closely on formative assessment. By negotiating and refining a shared inquiry focus throughout, the intention was to enable the *liberating constraints* (Davis & Simmt, 2003; Davis, Sumara, & Luce-Kapler, 2000) that are necessary for balancing *diversity* in teachers' interests, experiences, and comfort with technology, with the *redundancy* of a shared focus on using technology in assessment.

Findings from the personal inquiry into my own experiences as part of this collective show that it can be challenging to lead, learn, and conduct research simultaneously in a collaborative inquiry, and that there may be parallels between purposes of classroom assessment and purposes of assessment in a collaborative inquiry. Even though it felt uncomfortable at times to release control for our learning, doing so appeared to present opportunities for me to assess my own learning, my interpretations of the group's learning, and participants' contributions. From this study, it appears that formative assessment might be just as important to supporting professional learning and research as it is to supporting student learning. Further research is needed, however, to better understand the purposes of assessment in supporting professional learning and research. In particular, how can a project leader use formative assessment to support teacher learning? How can a researcher use formative assessment to support his or her own learning and/or participants' learning?

Recommendations for Further Study

Several recommendations for further study arise from this research. First, with respect to what was learned, further study is needed to look at student use of technology in assessment, and at individual teacher learning and changes in confidence with technology. Second, in terms of how learning was supported, further study is needed to provide insight into the purposes of assessment and the interactions between participants in a collaborative inquiry. Recommendations are displayed in Table 5.

Table 5. **Recommendations for Further Study**

Using Technology in Mathematics Classroom Assessment	Further study of student use of technology in assessment *as* learning. How do students use technology to self-assess their learning in mathematics? How does this use impact their learning? Further study of student use of technology in assessment *of* learning. How do students use technology to demonstrate their learning in mathematics? Further study of technology-rich mathematics classrooms to describe how teachers can leverage technology to support assessment *for* learning. How can teachers integrate technology to help inform their teaching and to support student learning? How can technology-enhanced assessment strategies impact student learning?
Supporting a Technology-Focused Collaborative Inquiry	Study of changes in individual teacher learning and confidence with technology that can arise from participation in a collaborative inquiry. How can teacher participation in a collaborative inquiry impact teacher learning and confidence with integrating technology into their practices? Study of the ways that online communications can support professional learning (and research) collaborations. Study of the purposes of assessment in a professional learning and/or research collaboration. How can project leaders and researchers use formative assessment to support teacher learning and research in a collaborative inquiry? Interaction analysis to examine the interactions that take shape in a collaborative inquiry. Do the interactions reflect diversity and redundancy? Do participants tend to agree with 'leaders'? What kinds of prompts can project leaders use to facilitate sharing?

Conclusions

In this thesis I studied the learning that emerged from a collaborative inquiry into the use of technology in mathematics classroom assessment. The findings show that the team generated ideas for using the functionalities of different technologies that were accessible in schools at this time, to enhance and possibly even transform assessment *as, for,* and *of* learning. My analysis of how our learning was supported shows that project leaders, particularly the instructional coaches and technology coaches who were in teacher-support roles, helped to facilitate professional learning and inquiry processes by sharing leadership roles and responsibilities (managing, mediating, motivating, and modelling) (Bruce, Jarvis, Flynn, & Brock, 2011) and by mediating technical demands on teachers. Teachers shared responsibility for our learning by contributing their ideas, resources, and experiences. By blending this collaboration with both face-to-face and online communications, we were able to interact more frequently and dynamically. The findings also suggest that an insider-outsider researcher and/or project leader might encounter tensions in responding to unanticipated contributions from participants and in adapting research and / or inquiry plans along the way. Facilitators could prepare themselves to work through these tensions by listening to understand (rather than speaking to provide answers) and maintaining a collaborative approach to inquiry. Deliberate and ongoing reflection on (or assessment *for*) professional learning and research can also support facilitators in navigating the tensions that will likely emerge in a collaborative inquiry project. Ultimately, this approach supports the assumption that learning can be prompted, bounded, and nurtured in a collaborative inquiry (Davis & Simmt, 2003).

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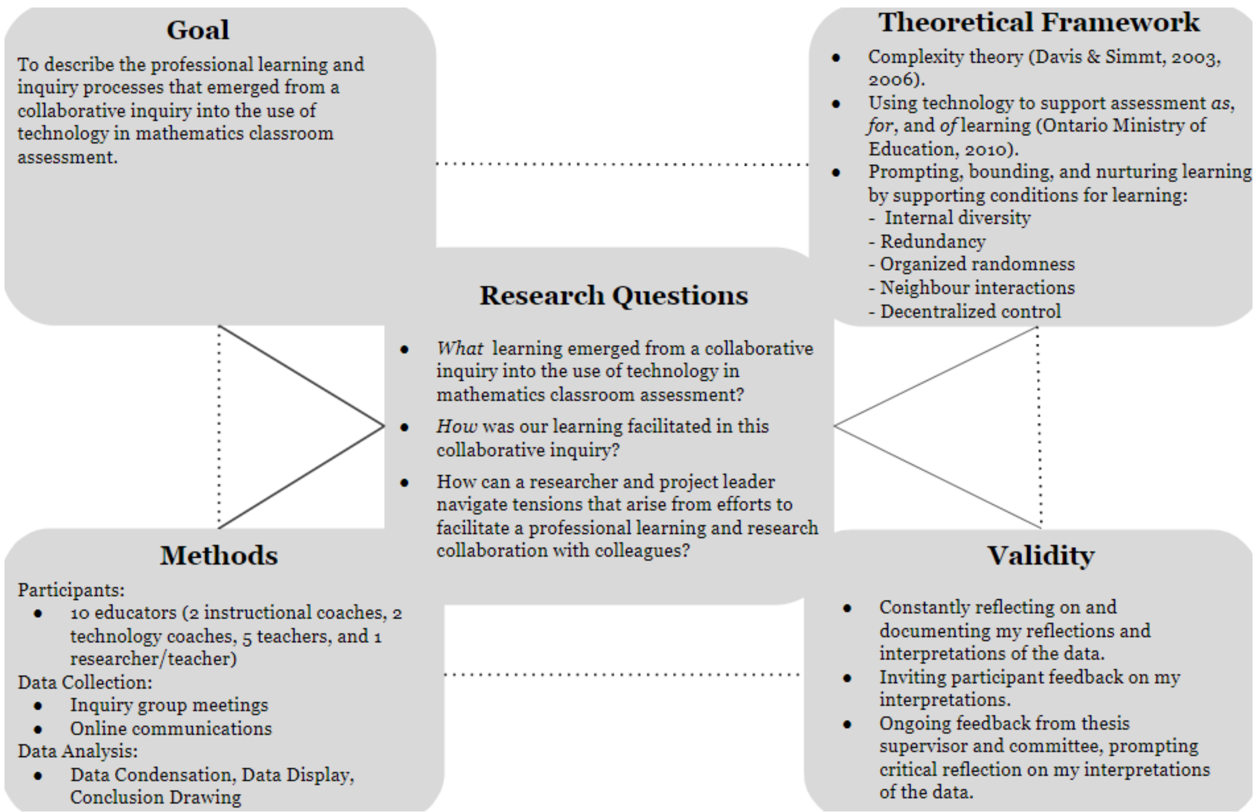
APPENDIX A: Research Design and Summary of Articles

Interactive Research Design

The image below summarizes the conceptual (goals and theoretical framework) and procedural aspects (methods and validity) of the interactive research design that is reflected in this study. This model was adapted from Maxwell's (2013) "Interactive Model of Research Design" (p. 5).



Linking Research Questions and Data in Three Articles

Title	Research Question	Data collected to address research questions	Data Analysis	Key Findings
Using technology in mathematics classroom assessment: Findings from a collaborative inquiry	What was learned about the use of technology in mathematics classroom assessment through a collaborative inquiry?	Analysis of what ideas and insights (e.g., problems, possible solutions, classroom strategies, resources) emerged in: Audio-recordings from 3 face-to-face group meetings and 1 virtual group meeting; and researcher notes (observations and reflections) from 1 virtual group meeting. Online communications between participants (e.g., contributions to a shared platform, project-related emails) and resources (e.g., sample assessment materials, participant-created meeting summaries) that were shared at and between meetings using an online platform (e.g., Google Drive, Padlet). Observations and reflections documented in my researcher journal during all group meetings, subgroup meetings, and individual meetings. Artefacts developed by the inquiry group (e.g., website created for the project, presentation slides, co-constructed assessment and technology in assessment frameworks)	Group members helped to condense our focus and therefore my data by contributing to a collectively constructed technology in assessment framework to bound our focus and to a presentation of our findings. Coaches (Patricia, Shelly, Sarah) and I also developed a website to share our findings with other technology project teams in the district. I further condensed these data by using coding, categorizing, and connecting strategies (Miles & Huberman, 1994). I displayed my data using matrices (including direct quotations and summaries of codes) and network representations to represent connections between ideas. I drew conclusions and verified conclusions that connected to the use of technology in assessment with participants (e.g., individual meetings with Shelly, an instructional coach at my school, with project leaders when we planned for meetings, and with participants when we planned for a presentation of our findings).	Teachers found opportunities to enrich their practices with respect to the use of technology in assessment *as, for,* and *of* learning in mathematics: - that technologies helped to improve the immediacy of feedback to students and teachers; - that technology can change the ways students demonstrate their learning in mathematics.

Supporting a technology-focused collaborative inquiry: A case study	How can learning be supported in a technology-focused collaborative inquiry?	Analysis of data collected to address the first research question but focusing on how our learning was facilitated.	Coded teachers perspectives on how our learning was facilitated (coded as "perspectives on how to support professional learning/collaboration"). Found that teachers appreciated opportunities to interact with one another and "bounce ideas" but they experienced time constraints. Teachers reported that the "pros" of blending our activities with synchronous and asynchronous communications outweighed the "cons." Analyzed project leader (coaches) roles and responsibilities using Bruce et al.'s (2011) framework.	I set up this inquiry project to support conditions for learning in a complex system (Davis & Simmt, 2003, 2006). Teachers emphasized the importance of opportunities to "bump ideas" with colleagues. Online communication facilitated more frequent sharing. Project leaders (instructional coaches and technology coaches) helped to facilitate inquiry activities by being available to support teachers in their classrooms and by mediating some of the technical demands on teachers.
Leading and Learning in a Collaborative Inquiry: A narrative of my experiences as a researcher and project leader	How can a researcher and/or project leader navigate internal tensions that can arise in a professional learning and research collaboration with colleagues?	Analysis of reflections documented in meeting transcripts, my observation notes, and in my researcher journal.	I read and re-read these data and my reflections, and highlighted my personal wonderings and internal tensions, and I documented themes that I observed throughout. Through this process, I engaged in a form of self-analysis or self-assessment (i.e., of the moves that I was making and how I was influencing the inquiry) and I explored themes that emerged with respect to the process of learning to be in this community.	I experienced internal tensions in navigating nexus of multimembership (Wenger, 1998) as a leader and a learner and in supporting equilibrium in the inquiry and research relationships. Distributing leadership responsibilities and using ongoing assessment of our activities helped to navigate these tensions.

APPENDIX B: Consent Form

uOttawa

Title of study: Technology in Mathematics Classroom Assessment: A Collaborative Practitioner Inquiry

Researcher:
Jill N. Lazarus
Graduate Student
Mathematics Education
University of Ottawa

Supervisor:
Dr. Christine Suurtamm
Associate Professor
Mathematics Education
University of Ottawa

Invitation to Participate: I am invited to participate in the abovementioned research study conducted by Jill Lazarus, supervised by Dr. Christine Suurtamm.

Purpose of the study: I understand that the purpose of the study is to gain a deeper understanding of the use of technology in mathematics classroom assessment in a collaborative practitioner inquiry that will involve four or five high school teachers, and possibly one mathematics instructional coach who is in a teacher support role.

Participation: I am aware that my participation will involve attending approximately six face-to-face audio-recorded group meetings, communicating and sharing resources using an online platform (e.g., Google Drive or a wiki), collaborating with the group to develop a goal to support in my own classroom teaching, collaboratively developing a plan for supporting this goal in practice, implementing this plan in the classroom and sharing my findings with the research group.

I understand that this research will take place over the course of approximately six months, beginning this fall semester, 2015. I have been informed that group meetings will be approximately 2 hours in length, unless all participants agree that a longer or shorter meeting is appropriate. I understand that I am expected to share ideas and classroom activities that I feel are appropriate for the project, both online and at inquiry group meetings.

Risks: I understand that there are no known risks associated with participation in this study. I understand that confidentiality will be protected by appropriate storage of and access to data and by the use of pseudonyms.

Benefits: I understand that through my participation in this study I will benefit from the opportunity to reflect on my current teaching practices and to investigate new ideas for enhancing my teaching with respect to the use of technology in mathematics classroom assessment.

Confidentiality and anonymity: I have received assurance from the researcher that the information I share will remain strictly confidential. I understand that the contents will be used only for better understanding professional learning and the use of technology in mathematics classroom assessment. I understand that my confidentiality will be protected and school and participant names will not be revealed. Pseudonyms will replace my name and school name and any identifying information on all data that I provide and in any publication that is created as a result of this research. I recognize that there are limits to the extent to which confidentiality can be guaranteed, and that the other teachers at group meetings may refer to something I say outside the sessions. The researcher will review expectations of confidentiality with each participant and ask that they maintain confidentiality.

Conservation of Data: I understand that the data collected, including all hard copies and electronic copies of audio recordings, transcripts, and artefacts that I contribute, will be kept in a secure manner. All electronic copies of data will be stored on a password protected hard drive and all hard copies of data will be in a locked file cabinet for 5 years after the study is complete. Only the researcher and her supervisor will have access to this data.

Voluntary Participation: I have been notified that I am under no obligation to participate and if I choose to participate, I can withdraw from the study at any time and/or refuse to answer any questions, without suffering negative consequences. If I choose to withdraw, I may request removal of all or part of my data, without suffering any negative consequences. Since data from group meetings involving other research participants are highly dependent on overall group discussions, I understand that these data sources will not be destroyed. However, my contributions will not be quoted directly and will be omitted from all excerpts of data that are quoted.

Acceptance: I, ____, agree to participate in the above research study conducted by Jill Lazarus of the Faculty of Education at the University of Ottawa, whose research is under the supervision of Dr. Christine Suurtamm.

If I have any questions about the study, I may contact the researcher or her supervisor.

If I have any questions regarding the ethical conduct of this study, I may contact the Protocol Officer for Ethics in Research, University of Ottawa.

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

Participant's signature: ______________________ Date: _____________

Researcher's signature: ______________________ Date: ___________

APPENDIX C: Summary of Meeting Activities and Data

Participant Pseudonyms and Initials

Initials	Pseudonym	Role
PA	Patricia	Instructional Coach
CH	Christine	Mathematics Teacher
BR	Brent	Technology Coach
BE	Ben	Mathematics Teacher
KE	Kelly	Mathematics Teacher
SA	Sarah	Technology Coach
SH	Shelly	Instructional Coach
LI	Liz	Mathematics Teacher
JE	Jennifer	Mathematics Teacher
JI	Jill	Researcher/Teacher

Data Source Codes

TRANS Transcript
EMA Email
JRNL Researcher journal/field notes
DOC Documents (e.g., meeting notes/agendas, shared materials, presentation slides)
AGENDA Meeting agenda
COLAB Group collaborative platform (Padlet page)
WEB Website created for district project

Activity/Event Codes

GRP Inquiry group meeting
IND Individual meeting
SUB Subgroup meeting
INF Informal meeting
PRES Presentation
BRD Meeting with other board (district) project teams

In-Text References to Data

In-text references to data are identified by participant pseudonym, data source (e.g., email, transcript, document), event/activity (e.g., group meeting, individual meeting), and transcript page number (when applicable). For example, a quote from Patricia at our first group meeting would be identified as (Patricia, Trans, GRP_{OCT}, p. 2).

Data Collected from Inquiry Group Meetings

Date	**Event and Data Sources**	
Oct. 28	**Group Meeting # 1 (Face-to-Face)**	
	Audio Recordings	File 1: 69 mins and 14 sec File 2: 27 mins and 58 sec File 3: 109 mins and 8 sec
	Transcript	26 pages (1304 lines)
	Documents	Observations and reflections in researcher journal "Meeting#1" folder in shared online, includes "Assessment *for, as, of*" and "Technology in Assessment *for, as, of"* documents, agenda, individual project goals, meeting notes created by Shelly and Sarah, and "Examples" folder.
Nov. 25	**Group Meeting # 2 (Online)**	
	Audio Recording	File 1: 49 mins and 15 sec
	Transcript	7 pages (301 lines)
	Documents	Observations and reflections in researcher journal. "Meeting#2" folder in shared online folder, includes meeting agenda document and participant-created meeting notes.
Feb. 12	**Group Meeting # 3 (Face-to-Face)**	
	Audio Recording	File 1 of 3: 66 mins and 57 sec File 2 of 3: 52 mins and 1 sec File 3 of 3: 39 mins and 10 sec
	Transcript	24 pages (1039 lines)
	Documents	Observations and reflections in researcher journal. "Meeting#3" folder in shared online folder, includes meeting agenda, Sarah's "Math & SAMR" presentation slides, and a copy of slides drafted for provincial math presentation, link to group Padlet page.
April 8	**Group Meeting # 4 (Online)**	
	Audio Recording	Not audio recorded (this was a more informal check-in). Agenda sent by email (from Patricia) on April 6.
	Documents	Observations and reflections in researcher journal (I experienced technical issues and was unable to audio-record this meeting).
May 5	Group Meeting # 4 (Face-to-Face)	
	Audio Recording	File 1: 71 mins and 17 sec
	Transcript	15 pages (620 lines)
	Documents	Observations and reflections in researcher journal. "Claims and Evidence" document created by Shelly to summarize ideas.

Data Collection Log

The following table outlines data collection activities, including a description of the activities and data that were collected. Rows that include group meeting activities are highlighted grey in this table.

Event Code / Date	Event	Description of the activities	Description of the data that were collected
SUB_{SEPT} Sept. 22	District project planning meeting	Jill, Patricia, Shelly, Sarah, and Brent met face-to-face to plan for the district technology project. This meeting took place prior to the data collection period.	Sarah shared meeting notes that she created in a Google Drive folder that was accessible over the duration of the entire project.
EMA_{SEPT} Sept. 22	Email invitation	An email inviting potential participants to join the innovation project was sent to potential participants prior before this research started.	A copy of this email was included in the online document that Sarah created and shared at this meeting.
EMA_{OCT} Oct. 14	Email information for first group meeting	Jill sent an email to everyone with information for the meeting (e.g., meeting time, information for arranging supply teachers, overview of the plan, description of technology resources that would be available, invitation for suggestions or questions from participants)	Copy of email.
GRP_{OCT} Oct. 28	Inquiry group Meeting #1 (Face-to-Face)	The inquiry group came together for their first full day face-to-face meeting at a central location. All members were present (Jill, Patricia, Shelly, Sarah, Brent, Kelly, Liz, Christine, Jennifer, Ben).	Everyone signed a copy of a consent form to give permission to audio record this meeting for the district project purposes. Once university ethics approval was received, this recording, my field notes, and materials that were shared in the online folder (which was available for the duration of the project) were included as data for this study.
EMA_{NOV} Nov. 17	Email from Shelly to Jill	Shelly shared a blog that she thought "clarified some of [her] thinking about Nearpod, etc. in terms of gathering class sets of data. http://mathmistakes.org/how-sets-of-class-work-change-the-conversation/	Copy of email.
PRE_{NOV} Nov. 17	Presentation to school district trustees	Jill and Shelly presented project plans and description documents that were created at the first group meeting (assessment and technology in assessment frameworks).	Field notes.
SUB_{NOV}	Coaches	Patricia and Shelly met online using	No data collected.

Nov. 23	meeting	(Google Hangout) to plan for the next inquiry group meeting.	
IND_{NOV} Nov. 23	Individual meeting with Shelly	Shelly and Jill met face-to-face. Shelly shared the meeting plan that she and Patricia created and Shelly and Jill drafted an email to share this plan with the group.	Field notes.
EMA_{NOV} Nov. 23	Email with agenda	The agenda for the next group meeting was sent to participants.	Copy of email.
GRP_{NOV} Nov. 25	Inquiry group meeting # 2 (Google Hangout)	The inquiry group met for approximately one hour using an online platform (Google Hangouts) to connect teachers from different schools. Patricia was with Ben at one school, Brent was with Christine at another school, Shelly was with Kelly at another school, Shelly was with Jennifer at a different school, and Liz was with Jill at another school.	This meeting was audio recorded and Shelly took notes in a shared online document.
SUB_{DEC} Dec. 10	Meeting with coaches	Jill, Shelly, Patricia, and Sarah met to discuss the project and next steps.	This meeting was audio-recorded and notes were taken in a shared online document. I also took my own field notes.
IND_{JAN} Jan. 26	Meeting with Shelly.	Shelly and I reviewed transcripts and discussed plans for the next group meeting.	This meeting was audio-recorded and notes were taken in a shared online document. I also took my own field notes.
BRD_{FEB} Feb. 4	District project "launch" meeting	Technology project teams from across the board came together to share their plans for second semester of the school year. Because of strike action, elementary teams were beginning their work at this time. Shelly, Patricia, and I attended this meeting on behalf of the group.	Shelly, Patricia, and I recorded notes, including ideas that were presented at the meeting and our own ideas, in a document that was shared in the team folder.
GRP_{FEB} Feb 12	Inquiry group meeting # 3 (Face-to-Face)	The group met for a full day face-to-face meeting at a central location. Brent and Sarah were present for the morning. Shelly, Patricia, Jill, Liz, Kelly, Jennifer, and Christine were present for the entire meeting.	This meeting was audio recorded and Sarah took notes in a shared online document. I also kept field notes. Documents that were shared in the online folder and a Padlet page that was created were included in the research data.
INF_{MAR} Mar. 4	Informal face-to-face meeting with Shelly	Jill and Shelly met briefly and informally. During this meeting, we discussed some observations.	Field notes.
EMA_{APR} April 6	Email from Patricia	Patricia sent an email to everyone in the group to address goals for the next meeting (e.g., for everyone to share what	Copy of email.

		they have been doing and their next steps, to consider what will be included in the provincial conference presentation, and to consider evidence to collect to show our learning for the district project purposes).	
GRP_{APR} Apr. 8	Inquiry group meeting # 3 (Google Hangout)	The group met online (using Google Hangouts) for approximately one hour to share what they had been working on. Patricia, Shelly, Christine, and Jennifer were present (Li was unable to attend). This was a more informal sharing meeting, with no formal notes being taken or documents being shared.	Researcher field notes.
EMA_{APR2} Apr. 26	Email from Patricia and Jill	Patricia and Jill sent an email to the group suggesting a meeting time for the final meeting, to "consolidate all the learning."	Copy of email.
DOC_{MAY} May 3	Classroom materials	Kelly shared sample problem to use for the provincial conference presentation.	Copy of the assessment material shared in online folder.
$PRES_{MAY}$ May 5	Conference presentation	Jill and Kelly led a session on the technology and mathematics classroom assessment where we shared findings from the inquiry. Shelly attended and helped to facilitate this presentation.	Copy of the presentation slides and materials (e.g., sample assessment materials, a Padlet page that was used for the presentation) were shared in the online folder. I also recorded field notes after the presentation.
GRP_{MAY} May 5	Final group meeting.	Shelly, Patricia, Jill, Christine, Liz, Kelly (Jennifer, Sarah, and Brent did not attend the conference) met after our conference presentation for a final wrap up meeting.	This meeting was audio recorded. Shelly recorded meeting notes in a shared online document and I recorded field notes.
SUB_{JUN} June 1	Planning meeting	Shelly, Patricia, and Jill met to develop a website for the school district project. Creating this website to share our findings was part of the district project requirements.	This meeting was audio recorded and I kept field notes. The website that we created was also included as data for this study.
BRD_{JUN} June 9	District project "wrap" meeting with all team leads.	Patricia and Jill attended a full day face-to-face meeting at the board office where we presented the project website and our findings. Other project teams shared their findings.	I kept field notes to document my own reflections. Our website was also considered for data collection.

APPENDIX D: Assessment and Technology in Assessment Frameworks

Collectively Developed Assessment Framework

Participants recorded key ideas from assessment policy (Ontario Ministry of Education, 2010) and literature (Earl, 2013) in the following document at our first meeting in October. This document was included in the shared online folder that everyone in the group had access to.

Assessment	Key Ideas
As *"Assessment as learning focuses on the explicit fostering of students' capacity over time to **be their own best assessors**, but teachers need to start by presenting and modelling external, structured **opportunities for students to assess themselves**."* *(Western and Northern Canadian Protocol, p. 42)*	• students [develop into] independent, autonomous learners • students set goals, monitor their own progress, determine next steps, reflect • teachers need to plan assessment throughout learning cycle • "teachers need to present & model external, structured opportunities for students to assess themselves" • the teacher is the 'lead learner' while gradually releasing responsibility to students as they develop skills & knowledge • students use info to give feedback to peers and to progress towards their own learning goals (peer and self-assessment) • occurs frequently in an ongoing matter • students as "learning resources for one another" • teachers help students develop their self-assessment skills • a common understanding of learning goals and success criteria is essential for students and teacher • group work provides opportunities for this to take place
For *"Assessment for learning is the process of seeking and interpreting evidence for use by learners and their teachers to decide **where the learners are** in their learning, **where they need to go**, and **how best to get there**."* *(Assessment Reform Group, 2002, p. 2)*	• descriptive feedback (timely & specific) p.28 • coaching for improvement p.28 • assessment intertwined with instruction p.28 • requires learning goals & success criteria p.28 • assess student learning before, during & after instruction p.28 • assessment informs instruction, goal setting, progress p.28 • typically involves *diagnostic* & *formative* assessment p.31 • both teacher and student involved • evidence gathered through a variety of tools (triangulation) • Happens in the middle of learning • Focused on the student and student using this feedback; teachers use feedback from students to adapt instruction • Conversations, observations • **"Two-way street":** Student needs to adapt based on feedback from teacher and teacher needs to adapt based

	on feedback from students • requires a collaborative culture between student-teacher and student-student • helps with decisions around differentiation and individual needs • Information for teachers' instructional decisions

Of
 	
*"Assessment of learning is the assessment that **becomes public** and results in statements or symbols about **how well students are learning**. It often contributes to pivotal decisions that will affect students' futures."*
 	
(Western and Northern Canadian Protocol, p. 55)
	• Typically done at the end of a period of learning
	  ○ summarize learning at a given time
	  ○ judgements about the quality of student learning on the basis of established criteria
	• summative
	• usually takes the form of tests, tasks, exams (typical of high school)
	• Teachers make judgment about students' understanding/skills related to the overall expectations after having offered several opportunities to improve their learning
	• **reference point - criterion-referenced NOT norm-referenced p. 19

Technology in Assessment Framework

After creating an assessment framework, the group considered different technologies and discussed strategies for using each tool to support different purposes of assessment. Sarah and Shelly recorded the following notes during our discussion. These notes were also shared in the online folder.

	Technology					
	Plickers	**Desmos**	**MyScript Calculaor**	**Padlet**	**Kahoot**	**Nearpod**
As		- students can self check their work or peers (using comments)	- in some ways it's replacing the answer key (not higher order thinking)			
For	- beginning as a diagnostic - quick check on learning - more about group understanding vs individual understanding	- students are investing on their own (i.e. relationships) and use AirPlay to share				-beginning as a diagnostic -quick check on learning -to gather individual and group data (by student and by item)
Of		- can print screen and use graphs for assessments of learning				
			does not lend itself to assessment as much as it is an instructional tool			
Overview:	www.plickers.com	www.desmos.com		www.padlet.com	www.kahootit.com to play www.getkahoot.com to make	
	- app (information on website)	- app but also web based	- app	- web based & app		
	- simple tool to collect real-time assessment data	- free online graphing calculator	-handwriting calculator	- a collaborative space to share resources or thinking	-can highlight individual solutions	
		- does not need to be y=mx+b format				

APPENDIX E: Sample Inquiry Group Meeting Summary

This is a summary of the first face-to-face inquiry group meeting. This summary was prepared after transcription and prior to the second meeting with participants. As shown below, in addition to keeping a journal in which I recorded field notes, I also highlighted parts of the summary and noted some of my thoughts (e.g., questions, ideas for subsequent activities) within the summary.

AGENDA
The agenda below was shared by email with the team prior to the meeting:

Goal: Accessing prior knowledge & setting group/individual goals. Each person leaves with a plan for using technology in math assessment

1. Overview of the research and Innovation Project
2. Introductions
   - What courses are we teaching?
   - What resources are available (e.g., Chromebooks, iPads)?
   - What issues do we face with respect to the use of technology in mathematics classroom assessment?
   - What kinds of things are we doing and/or interested in doing?

3. See, Think, Wonder
   What are we seeing at the moment with respect to the use of technology in mathematics assessment?

4. Assessment *as*, *for*, and *of* learning
   Key ideas and examples of how technology may be used to support each of these

5. Some different technologies
   - Padlet, QR codes, & Google Classroom (Jill & Shelly)
   - Plickers (Jill)
   - Desmos (Jill)
   - Nearpod (Jill & Shelly)
   - Kahoot (Jill & Liz) [Liz agreed prior to the meeting to share]
   - Google (Docs & Google Classroom) (Shelly)
   - Explain Everything (Sarah or Shelly)
   - Others?

6. Classroom Inquiry Goals

7. Planning Time

8. Next meeting (date, location, time, focus, wants & needs)

Meeting Summary

Roundtable (approx. 20 mins)

Participants take turns sharing what technology is available at their schools (e.g., iPads, Chromebooks) and how easy it is to access this technology. There is a wide range of access across schools. One school has access for each class (Ben), another department has one shared iPad cart (Christine) which gets a lot of use, another school has iPad carts in the library but on a different floor (Kelly). This cart is eventually moved upstairs to support this teacher. Another school has one iPad cart for the entire school (Liz & Jill). At this time, this iPad cart was not getting a lot of use so Jill was able to use it quite regularly. Schools also have access to Chromebooks.

Most of this discussion is technical (e.g., how to connect with IT support if there are issues, where to plug in an iPad cart, a new version of Smart Notebook is available, is the new version of Smart Notebook compatible with GeoGebra, updating apps). Shelly is recording notes during this conversation.

At one point, Brent mentions another thing "that might be of note" is how the Board is interested in exploring how to use technology collaborate across schools:

> [...] but the other things that might be of note and I think they're still running are going to be collaborative, like how to be collaborative amongst people from other school online. Like how to use Google Hangouts to stay connected. That might be stuff that comes up through these meetings anyways. But we were planning on hosting some how to's on that. Plus, how to develop a professional learning community. So how to use things like Twitter and all that kind of stuff that's out there, social media, to build your kind of math group. Or whatever department, to find resources like interest or something I don't know. So that was something that's on the go to. So keep an eye out for those things if you think they might fit. (Brent, lines 87-91).

See, Think, Wonder (approx. 46 mins)

Patricia explains how to do the See, Think, Wonder with respect to the use of technology:

> Do you want to go to the "See, Think, Wonder?" And then we'll come back. Get people thinking. Do you have something to write on, everybody? [...]. If you divide your page into three columns [...] and put the See on top of one column, and Think, and then Wonder. And what we'd like you to do is, What are you seeing in your school at the moment, maybe in your classroom or in other classrooms? What are you seeing with respect to the use of technology in math classrooms? That's what are you seeing. And then, what do you think about what you're seeing? And then what are you wondering about? What questions do you have? Is that clear? So what are you seeing? What do you think about what you're seeing? What are you wondering about? (Patricia, lines 155-163)

Individual Thinking Time (approx. 5 mins)

Everyone writes individual responses.

Pair sharing (approx. 15 mins)

Everyone shares with a partner. Patricia with Shelly and Liz; Jill with Christine; Brent and Jennifer; Ben and Kelly. Lots of discussion happening.

Sharing with team (approx. 26 mins)

Patricia asks everyone to share:

> [...] Anyway, so let's go around and just sort of one thing that you'd like, one or two things that you'd like to share, that you've just been talking about [...]. (Patricia, lines 173-174)

Christine shares what she and Jill discussed (increased comfort level with students who have apps on their phones.). Jennifer makes an important observation that technology is being used more in the learning/infestations as opposed to for demonstrating learning and if we want to use technology for summatives then we need to design activities that are not going to be compromised:

> [...] We talked about quite a few things but observation-wise, technology being used more for investigations and like the learning ["the learning" is stressed"] as opposed to the demonstration of your learning, which is what, you know... it's all the way along, embedded, but for the final part. Um, so I was talking about this activity that I did with my 3M's. I actually stole it out of the 2D but we had to do the biting on the paper and then making their parabolic dental arcade [...]. But I had them just use Desmos for that and enter their.... And I used it as an assessment but we were talking about the struggle with, okay if you are going to use it for that summative piece then we have to be designing things that are... activities that are not going to be compromised. The integrity of it won't be compromised if they have access to whatever they want to have access too, right? So it's a shift in the type of questions that we're asking or what we're having them do I think is the big piece. And how to get around that. (Jennifer, lines 185-196).

The next person does not interact with this idea. The idea gets dropped for a bit. Kelly shares what she and Ben talked about right away. She explains that "Ben's at one end of the spectrum and I'm kind of at the other end but we're similar" in that they agree that students are more comfortable with actual manipulatives than with the technology. Kelly adds that Ben is a new teacher who needs to first become comfortable with the course itself before adding too much of the technology and she is comfortable with the course but needs to get more comfortable with the technology, "so it's kind of learning it and interjecting it" (lines 197-209). Ben adds later in the conversation (line 424) that if he would have integrated technology on a more regular basis from the start, his students would probably be more comfortable with it. Kelly's comments highlight the importance of teacher comfort and student comfort. Shelly asks what kind of technology they are referring to and this leads to further conversation about this. Shelly makes a point about how she wonders if, "like with anything else, when we're teaching the new skills and the technology's the new skill, if we make the cognitive demand very little while we're teaching the skill of using the technology [...] (lines 236-240). With respect to using the algebra tiles app, Patricia adds that this may be an example of "using [technology] for the sake of it" (line 244). There is discussion about the value of a manipulatives app.

Kelly adds that she learned about Desmos before but it used to be on the computer. Now that it is more accessible with the iPads she is trying to learn it. She tried it with her class yesterday an says that it's "baby steps" (lines 281-286).

Another important question arose when SK asked JB what she shared earlier since she did not get to record it yet in the Google Doc. This brings up the issue of integrity of assessments of learning (using technology to demonstrate understanding) and how it really depends on the curriculum expectation:

> **Shelly:** JB, I forget what your point was. And I'm sorry but I didn't write it down. Just remind me.
> **Jennifer:** Oh like what we talked about?
> **Shelly:** Yeah.
> **Jennifer:** Well I think the biggest one was the, preserving the integrity.
> **Shelly:** Oh yes, assessments are changing.
> **Jennifer:** Figuring out how to ask the right question that it doesn't matter that they have access to whatever they want to have access to. That they can't really cheat with open book. Open world. [love this statement - issue... Open book, open world... can't really cheat] [...]
> **Jill:** That was one of my big questions too. Like they have that photo math app now and they were working on quadratic, solving quadratic equations or something, and STUDENTNAME pulls out this photo app and he's like scanning questions in the textbook. He's like, "This thing will tell me the solution." I'm like, "That's cool but...." [others laugh] Now what do I do?
> **Jennifer:** So turn your back while they're writing their test and how do you know what....
> **Jill:** It's really neat but...
> **Christine:** Yeah, a kid was just telling me the other day how he was... some university person was saying now with the Apple watches that people are cheating off these Apple watches because you can put I guess pictures and things into there. And like yeah, things that you don't even think about. Like so much for just looking off your partner. But now it's....
> **Shelly:** Is it cheating if they leave school and they're going to use that in their life? I'm just throwing that out there. I'm not saying that it is. I'm asking the question.
> **Jennifer:** Well it depends what you're asking them to do. Like we were also talking about like, in the curriculum, they have to be able to graph without technology.
> **Christine:** That's right. Exactly.
> **Jennifer:** So if they're using it to check their answer while they're supposed to be doing it out of their heads then yes that's cheating. Right? It's like what's the expectation that you're evaluating?
> **Christine:** That's right. I think that's right.
> **Shelly:** So how do we limit their use of that to test that.... Yeah, that's your big question. (lines 289-316)

Jennifer questioned whether or not using technology is cheating or not depends on the curriculum expectation. So we may not need to limit student use. In a future meeting, we should experiment with designing assessments that may use technology. This conversation turns into a discussion about how technology (calculators, personal devices) are not allowed in university mathematics courses and how students need to develop their mental math skills. Jennifer describes how a teacher used the College Math assessment and students had a fit since they were not allowed to use calculators. An issue seems to be that they punch things into their calculators without thinking. At one point Patricia suggests that maybe our teaching needs to change with the use of technology to "have more emphasis on estimating and the reasonableness of answers" (lines 389-390). Christine adds that the technology could help with this (e.g., using technology to verify that a solution to a quadratic equation is reasonable) and PM adds, "And making all those connections" (line 399). This conversation lasts until Ben is asked to share (414).

One frustration related to first introducing technology in Grade 11 (line 436-439) emerges.

Liz was wondering if maybe Applied students learn better with the technology (lines 441-449). Liz and Shelly talk about how access to technology and familiarity are issues at this school. Familiarity seems to be an important theme. Once teachers were familiar with tools, they seemed to really integrate them more than I expected.

The team discusses how iPads are allowed on EQAO (lines 454-482).

Jill brings up issue of keeping the focus on the math and not the tool (lines 496-506) and the issue of introducing technology in senior years comes up again (line 501). SN adds that students are becoming more and more familiar with technology so this will likely be less of an issue. This ends with the discussion about tools becoming more user-friendly.

Lunch

Question for the Group (approx. 4 mins)

The team discusses why they think there has been a change from formative/summative to assessment for, as, and of learning. Jennifer offers one idea but most of this is Patricia and Shelly sharing.

Assessment for, as, and of learning - 'expert group' analysing policy (approx. 17 mins)

The team divides into three groups, each group focusing on one type of assessment, dissecting the policy document and Earl literature. Each subgroup is sharing on a shared Google Doc that everyone can see at the same time.

Whole group sharing findings (approx. 10 mins)

Patricia invites the "as" people to share first. Shelly summarizes and Patricia asks what it (as learning) means. Sarah responds but this sharing is mainly the coaches (seen as 'experts' I wonder?):

> **Shelly:** So, assessment as, lots of different ideas. Students develop... so students, the focus is on students developing into independent autonomous learners is kind of a big piece. They set goals, monitor their own progress, and determine next steps and reflect. The teachers role in this is planning the assessment throughout that learning cycle. So opportunities for that to take place. And then there's just more specific about the how to. They need to present and model external structured opportunities for students to assess themselves.
> **Patricia:** Okay what does that mean?
> **Shelly:** Um, I think.... And it didn't really....
> **Patricia:** What's that mean in real language?
> **Shelly:** So what does that mean, ladies?
> **Sarah:** To me it meant that before you expect the student, right, to be self-assessing, they need somebody to guide them of what that looks like. So, and this is just my interpretation, is that the teacher's the one whose modelling, you know, what assessment, what reflection looks like as a lead learner in the classroom. With the goal that over time, right, the

> students are going to naturally do that on their own without me stepping in to say, "Okay, now we're going to reflect on, you know, what we learned, consolidate our thinking. Right? That's going to happen more automatically instead of me being the one to direct it.
> **Shelly:** And actually BC it kind of links to our earlier conversation around, is the technology something that the kids just don't like or something they're not familiar with? And so teaching those little skills. I see it kind of the same way. We have to teach them and model it before they can actually do it so. Um, feedback is important. So students giving feedback to peers and to monitor their progress toward their own learning goals so that peer and self-assessment piece. It's frequent and ongoing. The students are learning resources for each other. And to, well I guess that's kind of repetition, the teachers are helping the students develop their self-assessment skills. Really important to have a common understanding of the learning goals and the success criteria because they can't evaluate, assess themselves, if they don't know what they're aiming for and what success looks like. And group work provides an opportunity for this to take place. So if we don't create the environment for it, I feel that it's going to be difficult for them to peer-assess as well. Anything else?
> **Patricia:** [Summed it up nicely?]
> **Shelly:** Done. (lines 585-614)

Patricia suggests moving on to the 'for learning' group, which she was part of, and she summarizes some of the ideas that are included in the Google Doc:

> **Patricia:** Okay so our for one goes on a bit forever because [...]. Someone want to present this? What we were thinking? [...]. Alright, so the [inaudible] it said the Growing Success quotes, the descriptive feedback, the coaching for improvement. And it's very, it's just very much this two-way involvement and I think we've got that several times through here, that it's.... Whereas the as tends to be directed by teachers but it's student to student [?]. The for is very much student with teacher. Teacher with student and a little bit of student to student as well. So it's very two-way but it's, it's just the big emphasis of change for us as teachers. It's to inform instruction, our instruction, in many different ways and that also means that it gives you your next steps. It helps you with differentiating the instruction for different kids. So it's far more precise than just using like formative assessment. It's kind of that whole idea of do kids have to do it? That's why they changed the name. It's gathered through a variety of different ways so it's not just for paper and pencil testing. We need to look at that big T word down there, triangulation. But we do need to... it doesn't have to be formal assessment. It could be, you're having a conversation with a student. You notice something that they're doing while they're explaining something to you. And you think, "Oh, that kid doesn't get this bit. I need to do this with them." So it doesn't have to be a formal assessment. It can be sort of ongoing casual type of assessment. What else do we have in there? What's that.... reference point JL that you put in there? (lines 615-629)

Jill explains she included this because the 'assessment of learning' group referred to a reference point [in the Earl document]. Jennifer explains that this literature referred to other students as a reference point, which she considered contradictory to what we are learning in other PD in the Board [criterion- versus norm-referencing]. This leads to some discussion about what this might mean, if not norm-referencing. Shelly says that this literature is not the policy so we will stick with Growing Success, which is against norm-referencing.

Patricia then adds that for 'assessment for learning' another thing that is required is to develop a collaborative culture in the classroom, which doesn't come automatically. Then she invites the 'of' group to share (line 671).

The 'of' group discusses the reference point idea again and how stunned they are and Jennifer offers to remove this from the Doc. Otherwise, there is no conversation about 'of learning'.

Technology in Assessment As, For, and Of Learning - Table (Approx. 6 mins)

Then Patricia says that in the afternoon we will build up the table of assessment as, for, and of learning:

> **Patricia:** Okay. So we're going to build this table up as we go through this, this afternoon as we go through different ideas of assessment [of?] technology. Then we're going to kind of build up this table of where we think we can use it for assessment as, for, or of is the idea.
>
> **Jill:** Yeah. And part of the reason, like when I said I'm interested in technology and assessment and I tell different people that, there's different assumptions about what that means. So some people will say, "Well you must be interested in clickers and finding out how much students know." But you could actually use technology in different ways to support student learning instead of just to see how much they know. So it's kind of a framework to think about. [32:00] (lines 683-690)

Sarah, Shelly, Jill, and Jennifer suggest that the tools will not necessarily fit in all of the categories--as, for, and of. Jill gives Plickers as an example of how Plickers may fit with assessment for learning but if we tweak the way we use it, it could turn into assessment as learning. SK summarizes the technologies we will look at and asks if anyone has used them. I say that I volunteered to share so that nobody was put on the spot but that I would be happy to have others jump in and that what I will share is not perfect:

> **Shelly:** [...]. How many people have worked with, used any of those things in the past? So how many people have used [...] [Goes through each technology].
>
> **Jill:** So if you have used anything and you want to share, after lunch we're sharing. My name's up there a lot only because I didn't want to put anybody on the spot. I'm happy not to share. Like I'll share some of the things that I'm doing and obviously like, I always think of things that I could improve. So it's not perfect but it's, I thought something that I could at least show you what it can do. (lines 709-716).

Just before lunch, Brent says that the table will be helpful to summarizes the different tools so that teachers may go back and see the ideas.

> **Brent:** But I think it will be helpful to, like because I always end up having these like, "Oh I'm going to store that for some day." But if I know that this is in the chart and it says like here's... if I'm doing this and I can pull these ones in. That would be helpful to go back to.
>
> **Jill:** And we should have time at the end to kind of like plan, like where you think that things might fit with your class and actually... so not just leave here with the idea that I want to try it but leave here hopefully with an idea of how you're going to try it in your class. (lines 709-730)

Introducing Technologies (approx. 1 hour and 8 mins)

Plickers is the first tool introduced (lines 737-782). When asked if this could fit in 'as', 'for', or 'of' learning, Liz suggests it could work for all three and Jill agrees. Liz suggests using it at the beginning, before starting something new. Jennifer says it could work well for as and for but that she does not like multiple choice for of learning. Jill asks how she would use it for as learning and Jennifer explains what she would do (lines 750 - 755) to encourage self-assessment. Patricia asks if it is possible to see individual scores because students are not going to be able to self-assess unless they know if they got something right or wrong. They decide that Plickers might not be best and Sarah summarizes that "I think that's where it's challenging, right, is you really need to think about what your purpose is for focusing the tool to pick which tool's best because sometimes it... like as you said, like Kahoot's much better for that purpose, right? Depending on what you want to do" (lines 761-763). I attempt to connect this to what Jennifer said earlier with respect to questioning and the different purposes of assessment:

> **Jill:** Yeah this one's if you don't need a visual so much, you just want a conversation. Like you [Jennifer] talked earlier about the importance of questions. Like the integrity of a test for example. If you're trying to get at assessment for learning with this type of a tool then you'd want to think carefully about the kinds of questions I think and model, I guess, assessment for learning. Like why would someone do this? Or what was this person maybe thinking? I think the conversation would be the assessment as learning part. Because it's not like Kahoot which may be better documenting part. (lines 764-770).

Next we look at Desmos (lines 783-1029). Jill shows how she used it with her current Grade 10 Applied class to investigate slope and y-intercept. One misconception that Desmos is good for bringing out is with respect to scale and students counting squares (Jennifer, line 845). This gets into talking about how multiple choice questions on EQAO are scored, all or nothing. Shelly shares something another teacher in the Board has done and asked about a place for assessment as learning (line 864) and what does it look like? How do you get it so that students are peer assessing as opposed to just posting? (this example was combining tools so students could respond). An important piece is "accountability." which Jennifer says students take more seriously when they peer edit in English class and their work is public (line 884). This is something I noticed when using Nearpod to share. Desmos as "self-checking" (line 891) is recorded as assessment as learning. SK adds that it could be self- and peer- depending on how a task is designed and maybe combining with a tool that allows for commenting (line 892). Patricia asks how Desmos could be used as assessment for learning and Jennifer suggests that is the investigation piece (lines 898-901) and Patricia adds that airdropping could be used to show what other students are doing. Jennifer explains how she used Desmos in her Grade 11 class to make art. Some chose to do it by hand. She didn't care if they used Desmos because they had to explain why they chose a particular type of function (lines 922-931). This is a great example of assessment of learning!

Next we discuss MyScript (line 947). Shelly throws the question out there, are we letting MyScript do the thinking now? She and Patricia discuss the question a bit but there is very little discussion. Jennifer sees this as a tool just to check answers (line 967). Shelly adds it could be used in a task where students might get stuck on the algebra. Christine says, "I think it depends on what you're assessing. Like if I was doing a Thinking question and the kid [...] was doing everything right and just making some calculation error. Okay well that's where it would be appropriate to go to this [...] you can still see their thinking (lines 973-976). There seems to be agreement that MyScript is more for answer checking (lines 1000-1009) and then talk about whether the tool allows students to move their thinking further.

Padlet is discussed next (line 1029). Jill shows a couple of Padlet examples. Brent adds that this is an extension that allows for collaboration outside of the classroom.

Patricia asks who would like planning time or if the team would prefer to continue looking at technology. Jennifer asks to look at Kahoot and Brent adds this is something he is interested in too (lines 1065) so Liz shows how to use Kahoot. The team seems to agree it is fun and Brent suggests maybe using it for an exit card.

Patricia prompts again for planning time:

> **Patricia:** Alright, so I think since we're running short on time that it will be a good idea for you to think about what your goal is in a classroom and think about how you're going to use a piece of a technology and how you would use it... whether you're going to use it as assessment as, assessment for, assessment of, and just spend some time planning and we've got people to talk to. We've got SN or BR here that can answer more techy questions and let's get something so that when we come back next time we'll be able to say, "I've tried this. This works quite well but this didn't work." (lines 1139 - 1144).

Kelly has a question about technology though. She wants to know about Nearpod so the team discusses her question, "for math is it better?" Shelly says it depends on the type of questions (lines 1159) and then the team discusses how to use Nearpod.

Recording Goals & Planning Time (Approx. 20 mins)

Patricia prompts again for planning time: "So are we good to go? Planning, figure out what you're going to bring back next time" (line 1217). Brent asks if they should use one tool/one class or more and they decide it is best to focus on one thing in one class so it is not overwhelming.

* Aside conversation - Shelly asks if we should create a Google Classroom for the group. I think this is something we maybe should have pursued for documenting our learning. Google Drive has not been well used.

Recording Goals

Patricia invites participants to record their goals in Google Drive:

> **Patricia** [1:28:40]: So we have about 15 minutes to go. Before you leave, could you make sure that you fill out this form here. It's been shared with you in that folder [...] and just put your name and what you're hoping to do. The evidence, if you haven't really thought about that, that's something that we can think about next time. But in all things, if you're trying something, you need to try and work out what sort of evidence you're going to gather to show whether what you used was efficient and useful and helped the students [...] and what resources you might need. (lines 1256-1261)

Jill reminds everyone there is support if they want someone to come into the classroom or if they want to go into someone else's classroom. Jill also invites to share in Resources if there is anything they are willing to help with (e.g., Nearpod, Kahoot) at the next meeting. Brent asks if they should say specifically what type of assessment they are using the tool for (e.g., this tool for this type of assessment) or if that is too specific.

The following goals were recorded by each participant in a shared Google Drive document:

> Jill: To use technology (e.g., Nearpod, screencasting, Kahoot) to get students more involved in assessing their own learning
>
> Ben: Use technology on a more regular basis in class and become comfortable with using Kahoot and Nearpod for quizzes and review (assessment for and as). Use Airplay to share students' work with the class and explain/demonstrate their thinking.
>
> Jennifer: To use technology (kahoot and/or nearpod) for diagnostic, minds-on, review, exit cards to inform students and myself regarding general comprehension. By doing so, I hope to increase student engagement and accountability, which will help them achieve to their potential by self-assessing and setting goals.
>
> Liz: to use Desmos to discover the roles of “a”, “h” and “k” in vertex form, to visually confirm our graphs
>
> Christine: Try padlet in conjunction with screen casting and flipped classroom as an interface for students to post questions and comments about explain everything video lessons.
>
> Kelly: Make use of ipads on a regular basis with the specific use of Desmos and padlet (or nearpod)

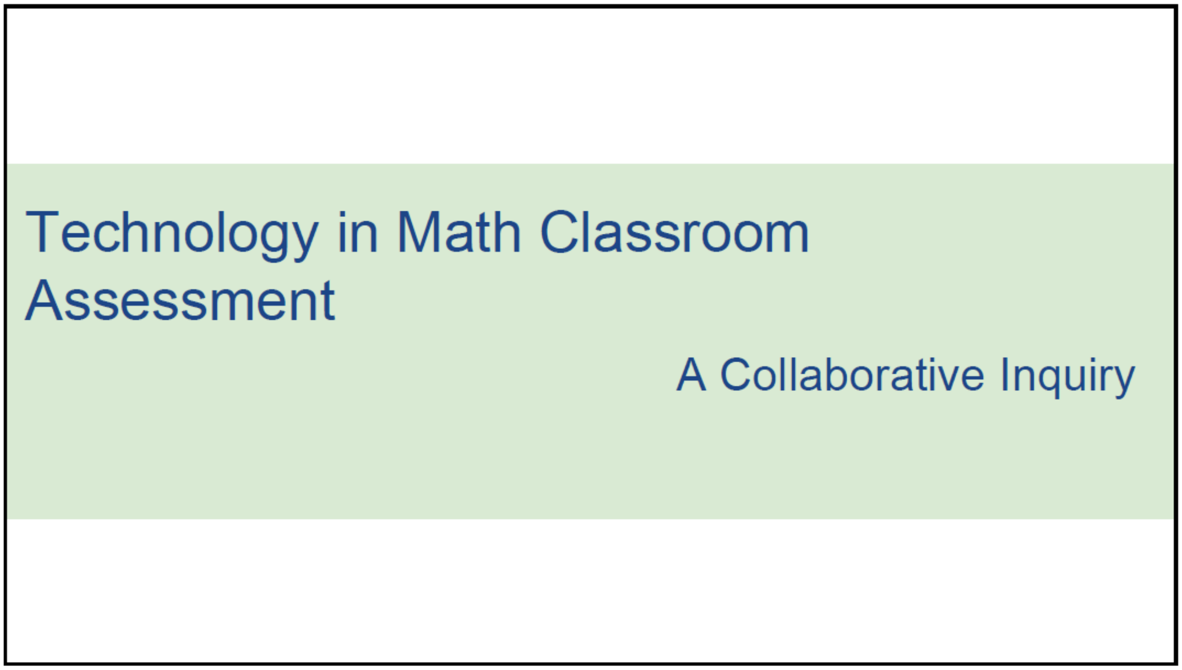
Next Steps (Approx. 10 mins)

The team chooses a date for the next one period Google Hangout (with support) where they will "check-in to see how everyone's doing...."

APPENDIX F: Conference Presentation Slides

Rough Draft - February

Below is a copy of the slides that were drafted for the provincial conference presentation. This is the rough draft that emerged from a discussion at the third meeting that involved all participants. All identifying information has been removed from the slides.



Some Challenges and Opportunities

- Context (e.g., Applied, Academic)
- Teacher Comfort and Student Comfort
- Everything is changing
  - Coming up with new ideas
  - Time to learn (tech before fit w assessment?)

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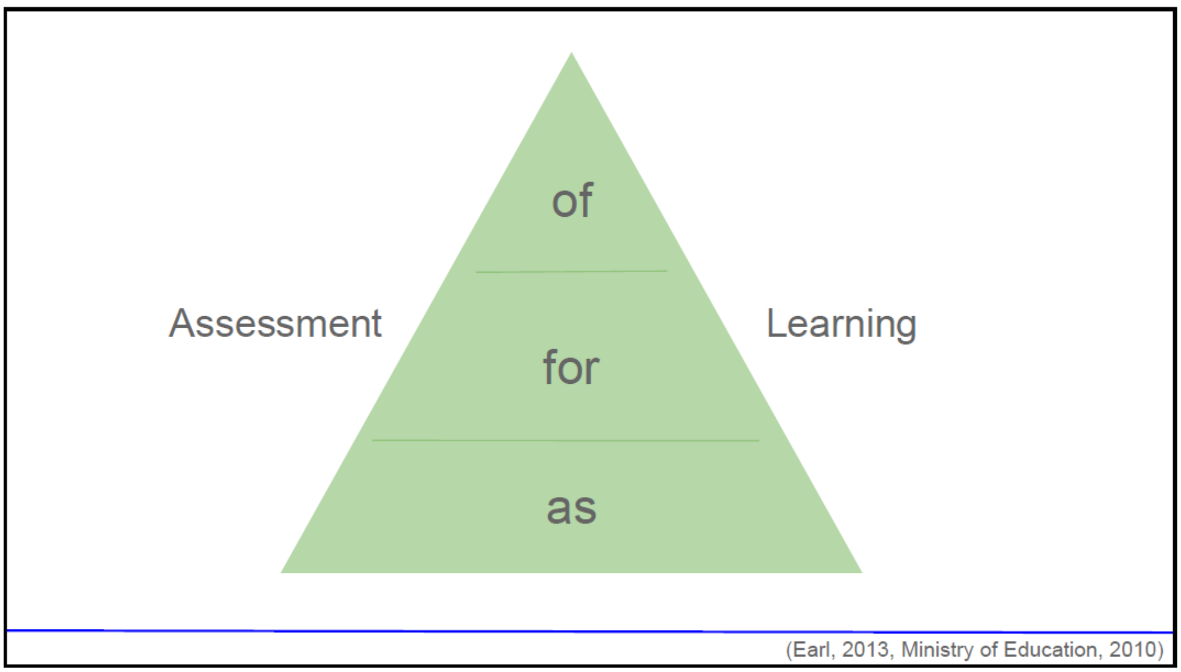
Collaborative Inquiry

- Face-to Face & Google Hangout Meetings:
  - 6 High School Math Teachers
  - 2 High School Instructional Coaches
  - 2 ICT Coaches



Challenges & Opportunities for demonstrating Learning: Assessment OF Learning

- Technology to "up the anti" or add something more!
- Padlet to up the anti? As a redefinition (see p. 17)
- Integrity of Questions (demonstrating learning)
- Transitions (previous grades; universities not allowing technology)
- Procedural vs. Conceptual - role of skills questions (e.g., graphing by hand, manipulating algebraic expressions, solving equations)
- Alternative assessments?
  - Connect to expectations (e.g., [Jennifer's] Desmos graphing activity)

"Assessment of learning is the assessment that becomes public and results in statements or symbols about how well students are learning. It often contributes to pivotal decisions that will affect students' futures."

Challenges & Opportunities for Improving Learning: Assessment FOR Learning

Anonymity vs. Accountability

Making thinking visible

Accountable Talk

Plickers

Nearpod

Kahoot & Jeopardy

Polleverywhere

"...process of seeking and interpreting evidence for use by learners and their teachers to decide where the learners are in their learning, where they need to go, and how best to get there" (Growing Success)

Challenges & Opportunities for Improving Learning: Assessment AS Learning

Google

Desmos & GeoGebra

Kahoot

Verification strategies (e.g.,different representations, technology)

Nearpod

"Assessment as learning focuses on the explicit fostering of students' capacity over time to be their own best assessors, but teachers need to start by presenting and modelling external, structured opportunities for students to assess themselves." (Growing Success)

Ongoing Learning

What is helpful for supporting our learning

- Instructional and ICT coaches
- Checking in - Hangouts?

What do we want to know more about? ([Conference] participant questions)

Final Version - May

This final draft of the presentation was created in collaboration with Kelly, with some feedback from Shelly. Both participants agreed to be involved in a presentation of the findings at the annual conference. Shelly chose to attend mainly to support myself and Kelly, who expressed that she was nervous about her first conference presentation. Therefore, Kelly and I were involved in the planning and Shelly attended and during the presentation she mainly recorded some of the ideas that emerged on a whiteboard and offered support as needed.

Technology in Math Classroom Assessment

A Collaborative Inquiry

Some of the things we've tried…

plickers clickers, simplified
Poll Everywhere
Explain Everything
Google
MyScript. The Power of Handwriting
AirPlay
AirDrop
padlet
Kahoot!
nearpod
SMART
GeoGebra
desmos

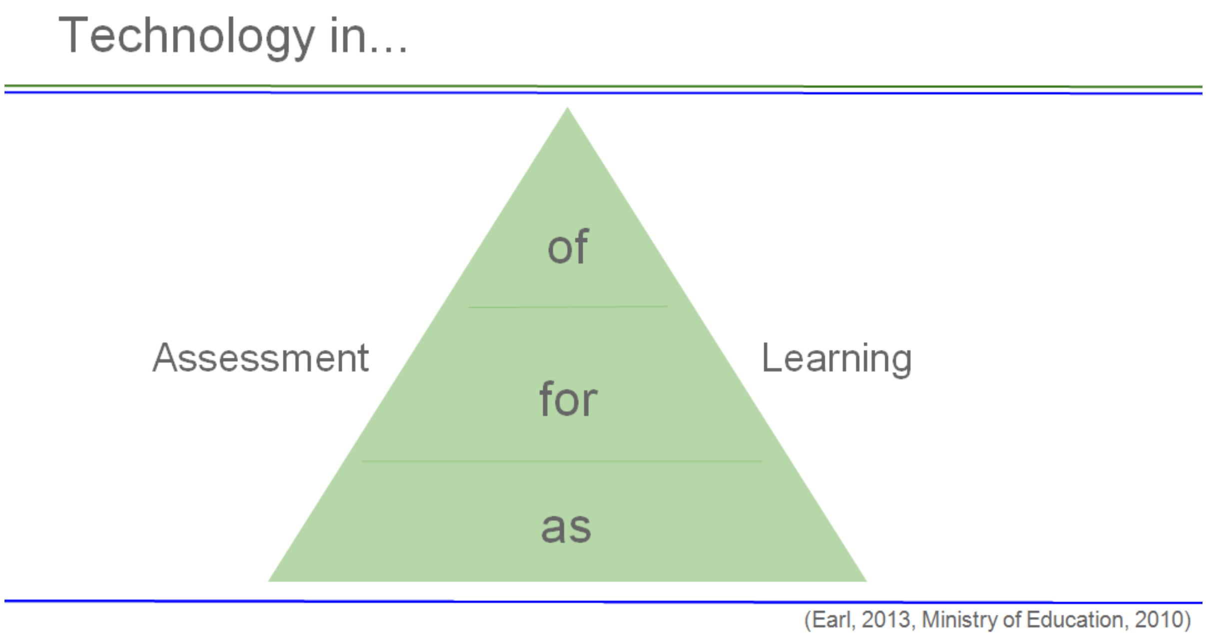
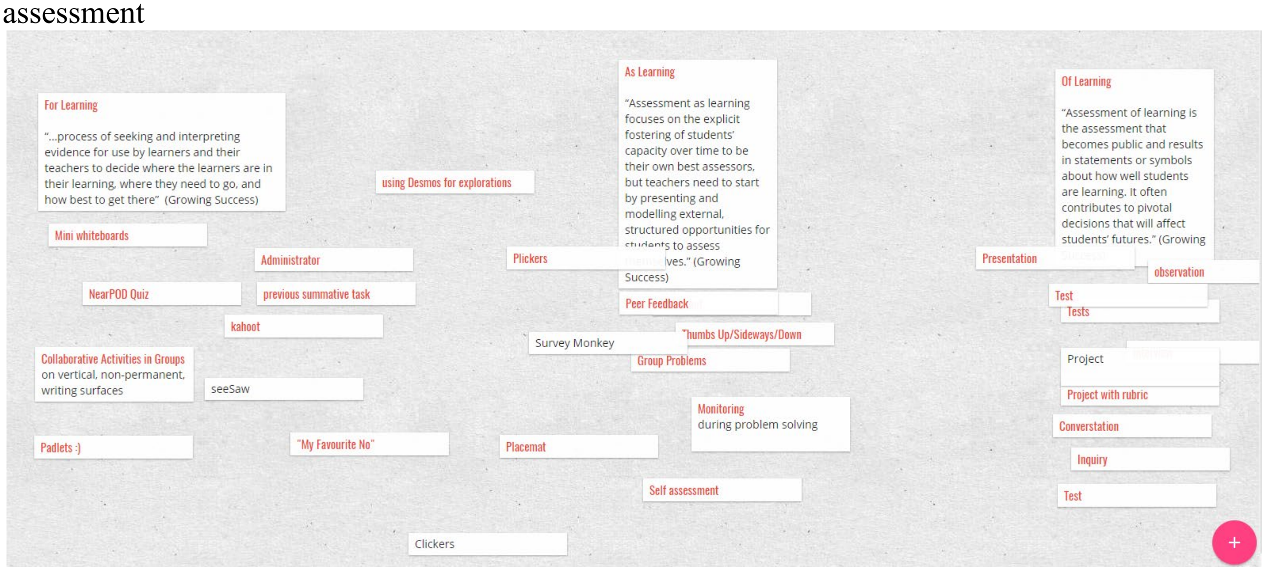
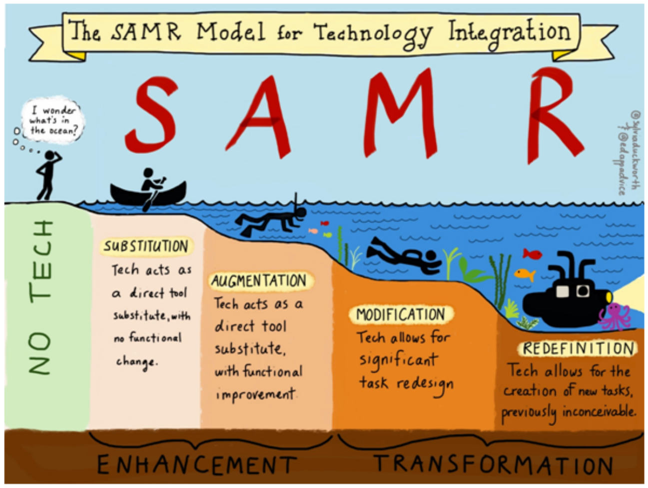


Image of Padlet page created by participants at our session.
Participants were asked to identify tools that could be used to support each purpose of assessment



SAMR



How can different tools be used for Assessment FOR Learning?

Plickers

Polleverywhere

Nearpod

** Anonymity vs. Accountability
** Making thinking visible
** Instructional moves (e.g., misconceptions)

How can different tools be used for Assessment AS Learning

Nearpod

Desmos

Desmos Classroom Activities

How can different tools be used for Assessment OF Learning

Transforming assessment - technology to "Up the ante"

- Procedural vs. conceptual understanding
- Integrity of the questions we ask - depending on the expectation

APPENDIX G: First Cycle Coding with ATLAS.ti

This is a sample transcript with codes applied to segments of the transcript (column on right).

081 **PM:** Do you want to go to the "See, Think, Wonder?" And then we'll come back. Get people thinking. Do you have something to write on, everybody? [JL asks PM an inaudible question and PM says they'll go back to it... skipping the next thing on the agenda]. If you divide your page into three columns [...] and put the See on top of one column, and Think, and then Wonder. And what we'd like you to do is, What are you seeing in your school at the moment, maybe in your classroom or in other classrooms? What are you seeing with respect to the use of technology in math classrooms? That's what are you seeing. And then, what do you think about what you're seeing? And then what are you wondering about? What questions do you have? Is that clear? So what are you seeing? What do you think about what you're seeing? What are you wondering about?

Codes: Managing/Mediating; Questioning/Prompting; Technology

082

083 Pair Sharing (or 3) - Approx. 15 minutes

Codes: Transitions

084 [27:01 - 42:21 everyone sharing with a partner/group of three. PM with SK and LG; JL and CM, BR and JB, BC and KO. Lots of conversation. My conversation with CM is audible here - very interesting conversation but I am more interested in what is shared with the group later. One thing CM is wondering about is curriculum change with respect to the use of technology. *Note: I feel that this pairing up worked pretty well--lots of conversation. Better than the first roundtable with more interaction.*]

085

086 **PM** [26:43]: [...] Everyone finished? Okay. So I'm going to do a, sort of a pair up and just let's swap ideas [pairs people up]. By the way, we're going to share back as a big group too so be [inaudible]

Codes: Managing/Mediating; Questioning/Prompting; Transitions

087

088 Sharing with group - Approx. 26 minutes]

Codes: Transitions

089 [42: 21 - 1:08:25 each pair/person shares their key observations from the see, think, wonder]

090

091 **CM** [was with JL]**:** Sure. We were just mostly talking about the increased comfort level that the kids have with these things and like especially with graphing apps and you know they just kind of automatically go to that now whereas when you used to have to use the graphing calculators. Like a), it just wasn't accessible all the time. It wasn't something that they had at home so I think just their... like it helps their understanding and their comfort levels with being able to solve these problems and a lot of them have it on their own devices that you don't even need to give them anything.

Codes: Comfort with Technology; Describing access to technology; Findings/Observations wrt Technology in Schools; Technology

092 **JB** [was with BR]: We talked about quite a few things but observation-wise, technology being used more for investigations and like the learning ["the learning" is stressed"] as opposed to the demonstration of your learning, which is what, you know... it's all the way along, embedded, but for the final part. Um, so I was talking about this activity that I did with my 3M's. I actually stole it out of the 2D but we had to do the biting on the paper and then making their parabolic dental arcade. I know you feel like you're going to play a video game now [others laugh]. But I had them just use Desmos for that and enter their.... And I used it as an assessment but we were talking about the struggle with, okay if you are going to use it for that summative piece then we have to be designing things that are... activities that are not going to be compromised. The integrity of it won't be compromised if they have access to whatever they want to have access too, right? So it's a shift in the type of questions that we're asking or what we're having them do I think is the big piece. And how to get around that. [I think this is a really key idea/question. The idea is abandoned here though].

Codes: "Integrity" of Assessment; Desmos; Assessment; Changing Assesment; Describing access to technology; Findings/Observations wrt Technology in Schools; Strategy/Activity; Technology; Technology and Assessment; Technology for learning

093 **KO:** BC and I had similar experiences. BC's at one end of the spectrum and I'm kind of at the other end but we're similar in that we're finding that with our 2P's almost the opposite of what has been said in that they like to have manipulatives right in front of them versus the technology. That they're more comfortable with that. As much as we think that maybe they shouldn't, you know, they should want the technology. But, you know, BC's a new teacher with a new course and so, you know, he has to first of all get comfortable with the course, you know the 2P course in itself, before adding in too much of the technology. And for myself, I'm comfortable with the course but the technology, it's not a fight but for me it's...I mean, you know, just an older person you know it's not as at my fingertips. I don't go

Codes: Agreeing; Comfort with Technology; Algebra Tiles / Manipulatives; Technology; Teacher background; Technology "for the sake of it"

APPENDIX H: Data Display

Category Sample 1: Matrix created to organize codes that connected to technology and assessment, including direct quotations and descriptive codes.

TECHNOLOGY IN ASSESSMENT

Time & comfort?

	Challenge	Barrier	Opportunity	Enabler	Summary/Notes	Direct Quotes	Codes
		Time for students to learn new tools			Time for students to get comfortable	Ben: Uh, partially. I think just getting used to it is taking some time. So whenever it's taking time to start they might get frustrated and then kind of get turned off on the app.	"Time"
			Students are already comfortable with some tools and some are more natural, therefore less class time is spent teaching technology - maintain focus on math		Some technologies come more naturally to students and therefore less class time is spent teaching technology.	JL: No, um, we kind of just, yeah we talked about students, things being more natural for them. Like Desmos, going to it, especially in the grade... like when I taught Calculus they were just automatically going to their phones and actually using it for math [someone laughs] and in my Grade 10 Applied they were... with like the MyScript they liked that. They thought they were cheating. Like, "I know you have it." But they were all impressed by that. And then there's other things that aren't used for math but they use in their other classrooms. Like Google Classroom, I don't have to teach them how to use Google Classroom. Like there's a lot of technologies that are being used in other places. So I don't have to spend the time teaching them the technology, which was my big issue a few years ago was I was spending class time to teach the tools, which, you know, it's not worth it. You want the focus to be on the math. So I was wondering about how to kind of build on what they already know. Like keeping the focus on the math. Not the technology.	"Time"
		Teacher and student time to learn technology			Teachers need time to learn and gain comfort with technology; this also relates to "teacher comfort" code" and "student comfort"	Ben: Well and the other part would be like just me starting. I got the job Friday before school started [others laugh]. Christine: Lots of time to prep and get ready for that. Yeah. Ben: So then I started off the course going by what they gave me. Like the workbook and the binder for the course and I didn't have... I wasn't integrating technology right from the start. So I think if I would have started integrating it more and more on a regular basis, they would have been more comfortable with it this entire time but...	"Time"

Category Sample 2: Matrix created to organize codes that connected to technology and assessment, including direct quotations and descriptive codes.

Technology and Assessment

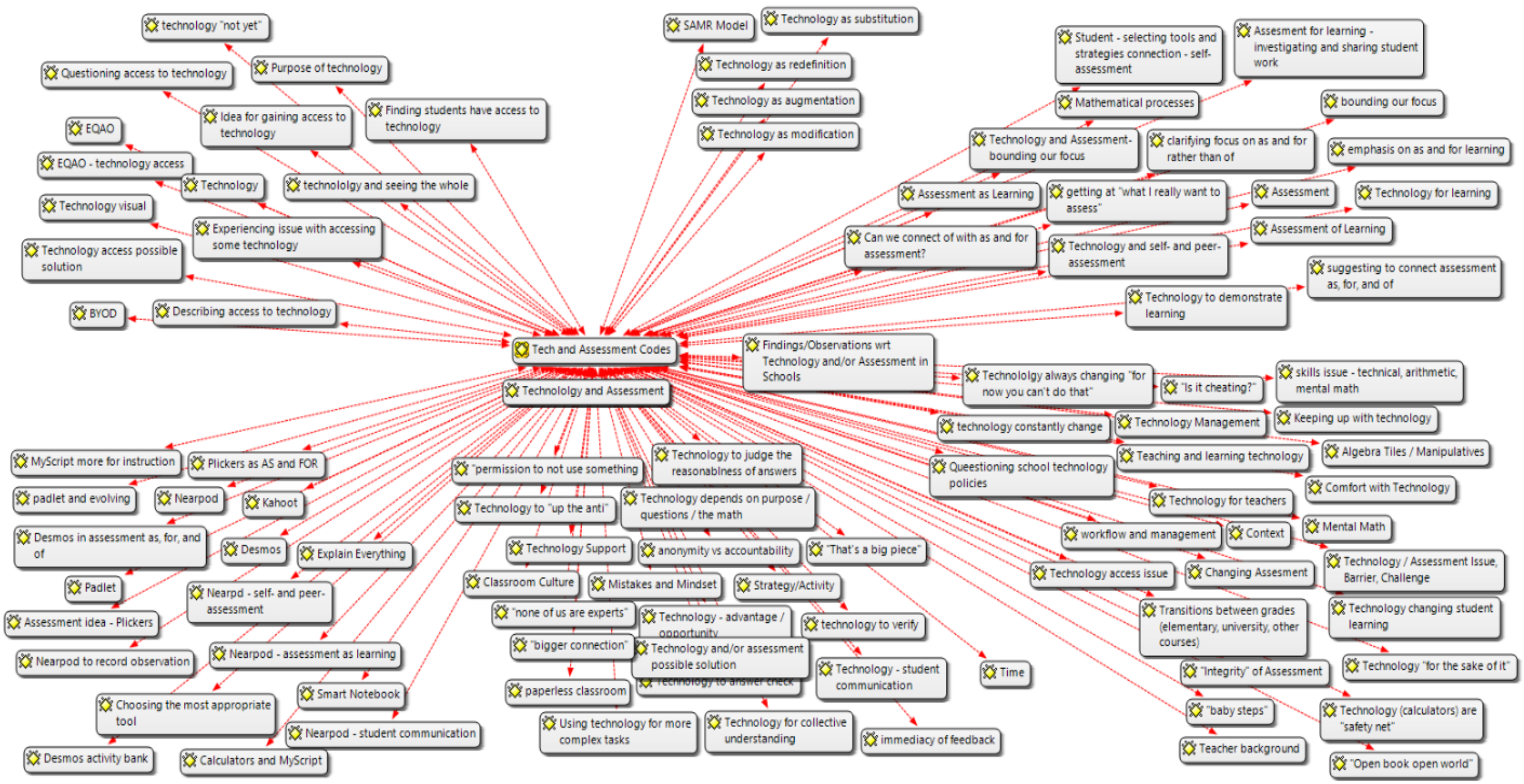
Student comfort	**Christine** [p. 4 line 30] notices increased student comfort especially with graphing apps and accessibility **Ben** says that students might have been more comfortable if he used it right from the start of the semester [p. 9, line 20] Christine is interested in transition and finds it challenging when students have no experience with using technology in math... teaching skills for the first time in Grade 11. Is it worth it? [p. 9, line 22] JL mentions students in general have more experience with apps so less instructional time spend on learning them but questions how much time should be spent in instruction. PM says worth it in long run (depending) [p. 10 line 41]
Technology used for the learning rather than for demonstrating the learning. Need to consider types of questions for integrity.	**Jennifer** [reporting on conversation with Brent]: We talked about quite a few things but observation-wise, technology being used more for investigations and like the learning ["the learning" is stressed"] as opposed to the demonstration of your learning, which is what, you know... it's all the way along, embedded, but for the final part. Um, so I was talking about this activity that I did with my 3M's. I actually stole it out of the 2D but we had to do the biting on the paper and then making their parabolic dental arcade. I know you feel like you're going to play a video game now [others laugh]. But I had them just use Desmos for that and enter their.... And I used it as an assessment but we were talking about the struggle with, okay if you are going to use it for that summative piece then we have to be designing things that are... activities that are not going to be compromised. The integrity of it won't be compromised if they have access to whatever they want to have access too, right? So it's a shift in the type of questions that we're asking or what we're having them do I think is the big piece. And how to get around that. [I think this is a really key idea/question. The idea is abandoned here though]. [p. 4, line 36] **Shelly:** JB, I forget what your point was. And I'm sorry but I didn't write it down. Just remind me. **Jennifer:** Oh like what we talked about? **Shelly:** Yeah. **Jennifer:** Well I think the biggest one was the, preserving the integrity. **Shelly:** Oh yes, assessments are changing

Category Sample 3: Matrix created to organize codes that connected to challenges/barriers and opportunities/enablers connected to technology and assessment.

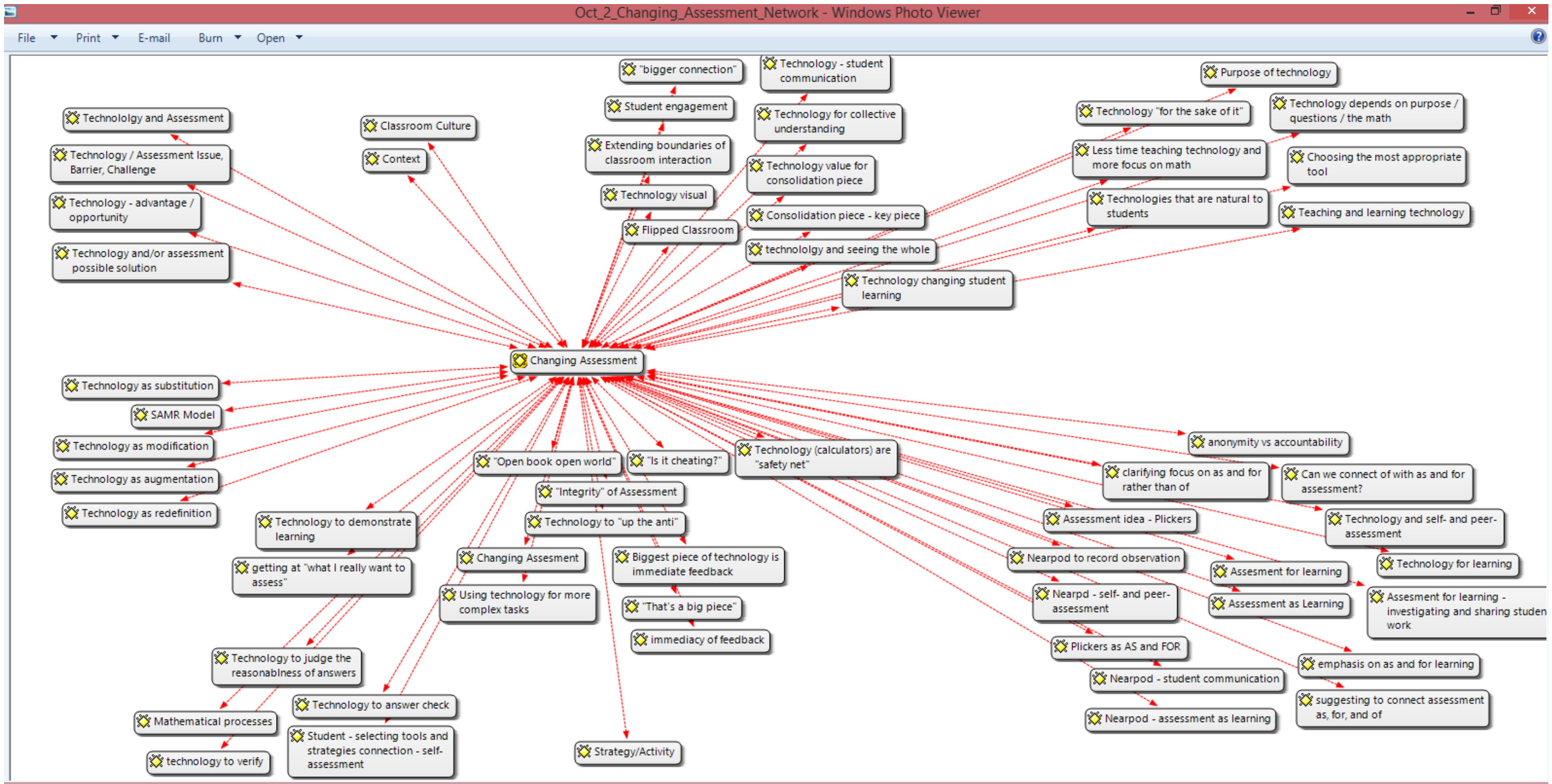
Technology and Assessment

Challenges	Barriers	Opportunities	Enablers
Open book, open world, cheating	Access to technology	Giving quiet kids voice (LG, CM, May 5)	Not one size fits all (know limitations with technology)
Transition	Time to learn and to implement	Immediacy of feedback	Do a little at a time / baby steps
Tech for a purpose - choose most appropriate tool	Teacher awareness (May mtg; OH teacher)	'up the anti' of assessment - more complex tasks; assess different things	Value of time to learn
Mental math skills		Technology to judge the reasonableness of answers / to verify answers	Technology Support
Teacher and student comfort		Anonymity & accountability	PLC for ideas/motivation to try things (tech keeps changing)
Learning technology		Mistakes & mindset	BYOD
Ideas for technology		Paperless classroom	
Technology always changing		Student communication (e.g., Nearpod, Explain Everything)	
Workflow/management			
Integrity of questions/changing assessment		Investigation & sharing student work	
Questioning		Visual	
Context (e.g., LG connects to what KO and BC said about students in Applied being more hands on learners		SAMR & KO task/Padlet idea	
Always changing - "I'm figuring this out on a		Algebra and technology - does this connect to	

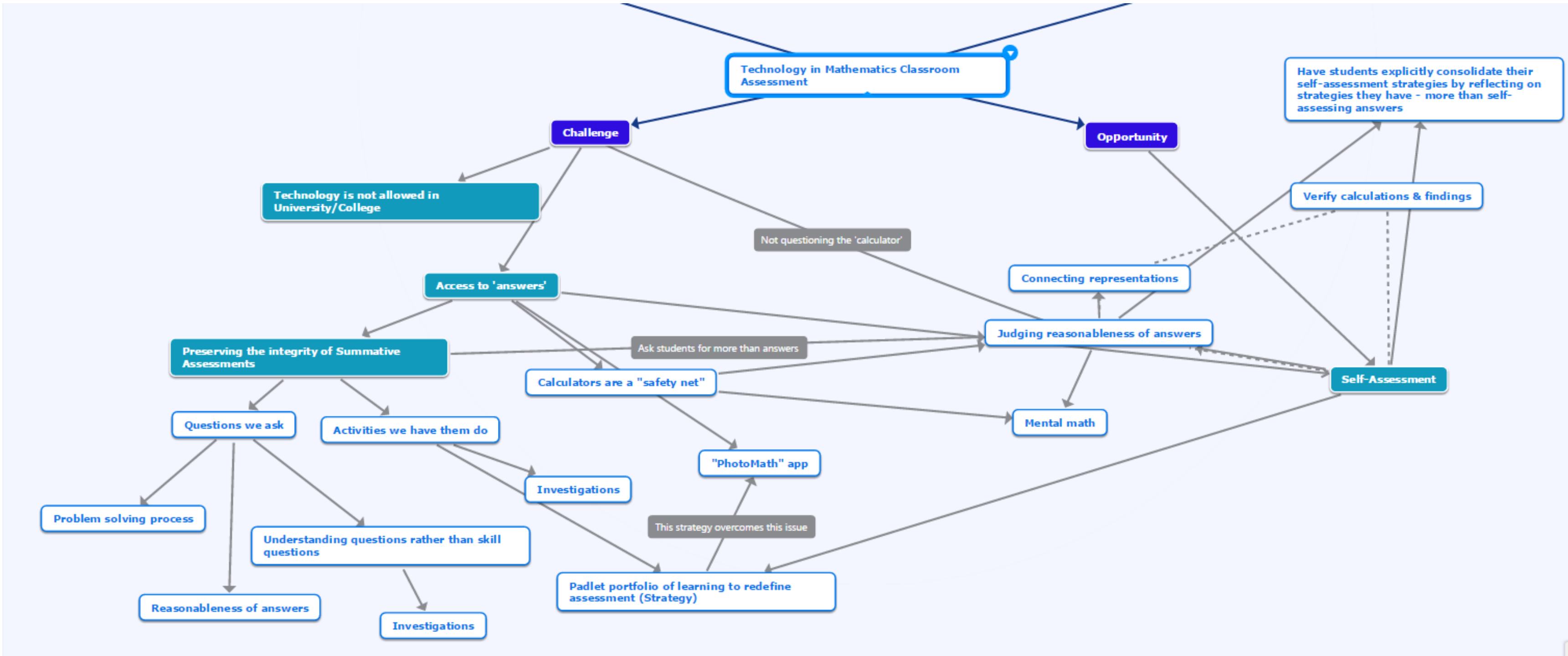
Network/Connecting Sample 1: initial connections in ideas related to technology and assessment represented using ATLAS.ti



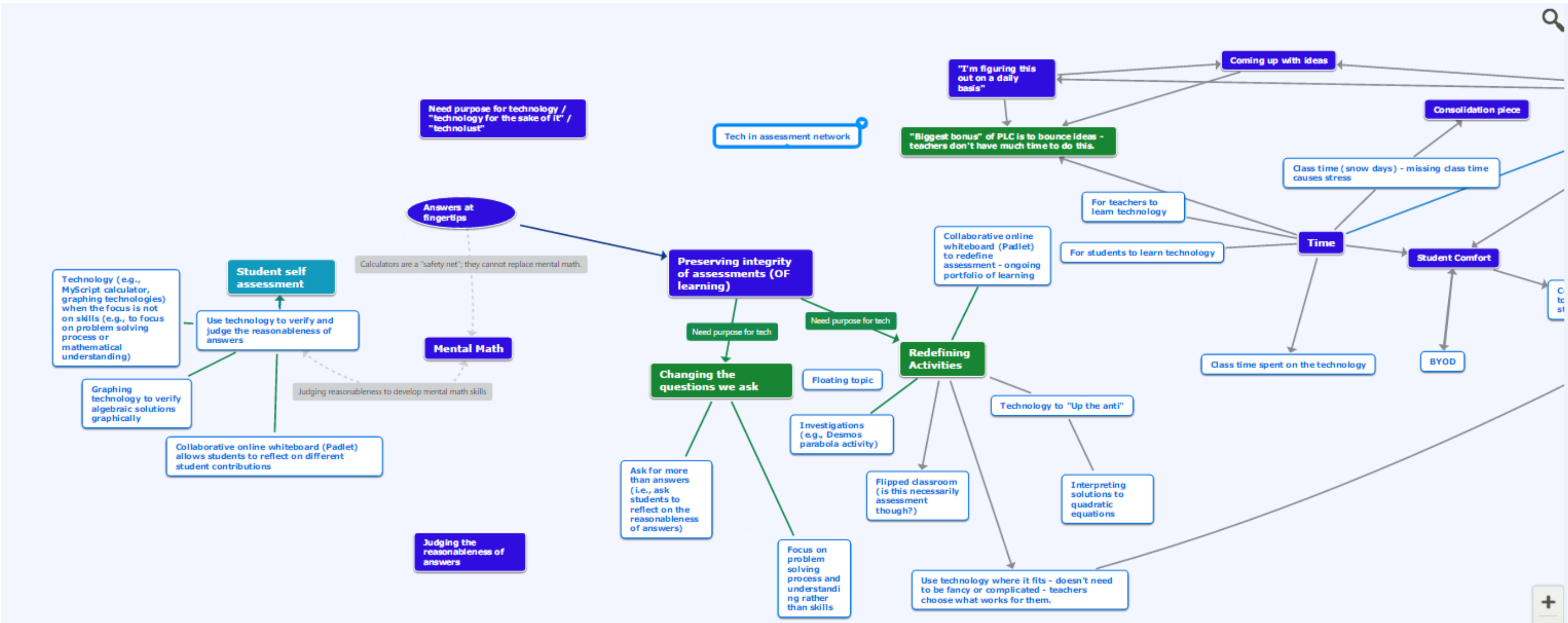
Network/Connecting Sample 2: connections in ideas related to technology and assessment represented using ATLAS.ti



Network/Connecting Sample 3: connections in some organizational categories related to technology and assessment represented using Mindomo.



Network/Connecting Sample 3: connections in some organizational categories related to technology and assessment represented using Mindomo.



APPENDIX I: Coding

Data, including transcripts and artefacts (i.e., online communications, documents shared with the group) were coded to look at *what* knowledge emerged and *how* our learning was facilitated.

What was learned about using technology in assessment
Categories related to what knowledge emerged in the group were coded as ideas, insights, and artefacts, and were coded in connection to the three approaches to assessment (Ontario Ministry of Education, 2010). More specifically, I initially looked at:

Ideas and insights in connection to the use of technology in assessment

- Observation (e.g., of the use of technology in their classroom assessment practices).
- Problem (e.g., with preserving the integrity of summative assessments when students have access to technology).
- Solution (e.g., a proposed solution to a problem related to using technology in assessment).
- Question (e.g., what questions should we be asking when students have access to technology?)

Technology in assessment
Data segments that fell under the umbrella of using technology in assessment were coded according to the more specific focus of the segment. The initial codes included:

- Technology" (when the focus was specifically on technology)
- Assessment
- Technology and Assessment
- Assessment for Learning
- Assessment as Learning
- Assessment of Learning

Codes also emerged in the field (see Appendix H for codes that connected to technology and assessment.

Facilitating Inquiry Processes
I initially coded participants' perspectives on our inquiry/learning processes using the code "perspectives on how to support professional learning/collaboration." Within this code, I observed a pattern in perspectives on the importance of opportunities to interact so I coded perspectives on our interactions and looked for themes within this category.

In order to examine how project leadership roles and responsibilities played out, I coded segments in the transcripts when I found evidence of *managing, mediating, modelling, motivating* (Bruce, Jarvis, Flynn, & Brock, 2011) and I looked for patterns within these categories.

In my personal inquiry to gain insight into the ways I navigated this professional learning and research collaboration with colleagues, I also highlighted instances in the data (transcripts, researcher journal) when I experienced tensions and I looked for patterns in the tensions that I encountered (e.g., in the questions that I was posing to myself).

APPENDIX J: Participant Roles and Attributes

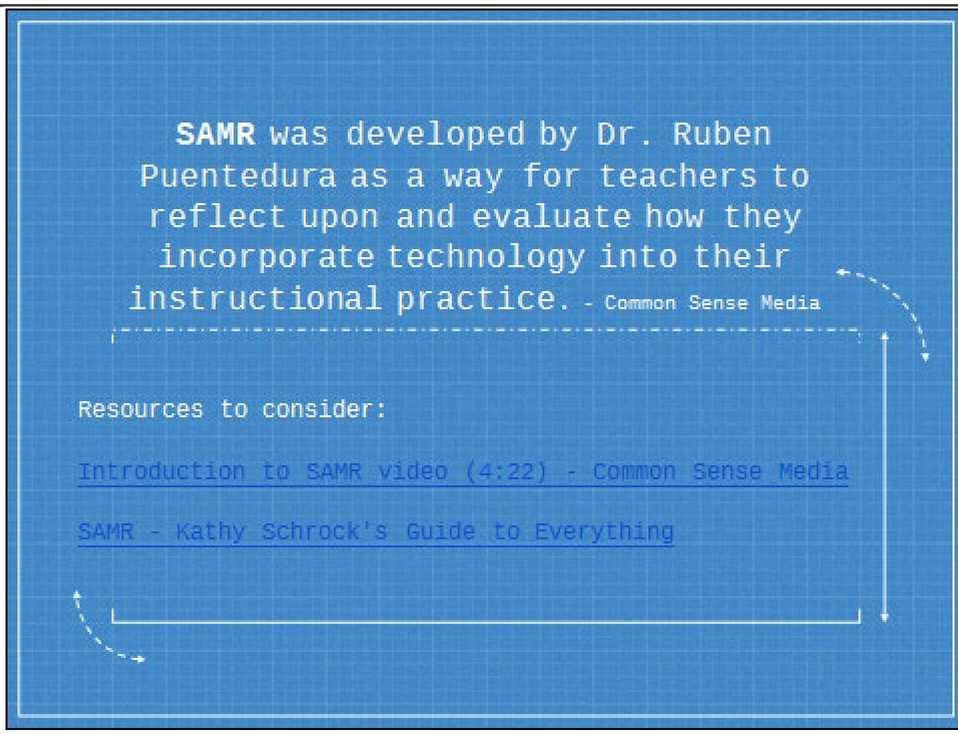
Table 2.
Participant Roles and Attributes

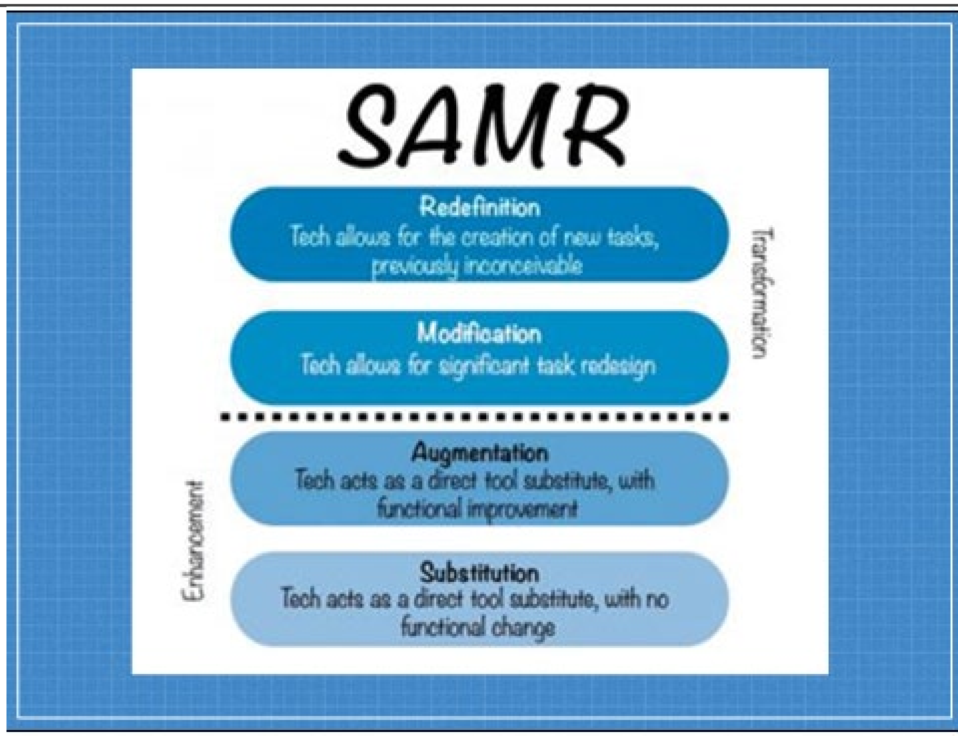
Name & Role	Attributes
Jill Secondary Teacher & Doctoral Student Researcher	District project co-lead, doctoral student researcher, and part-time high school mathematics teacher with approximately 5 years experience. Comfortable with teaching mathematics and with using technology to support practices. Initial teacher inquiry goal was *To use technology (e.g., Nearpod, screencasting, Kahoot) to get students more involved in assessing their own learning* (Doc, GRP_{OCT}).
Patricia Instructional Coach	District project co-lead and high school instructional coach. Supported teachers at three schools in the district. Her role involved supporting teachers' practices, including the use of technology. She worked directly (in schools and classrooms) with Ben first semester and with Kelly second semester.
Shelly Instructional Coach	High school instructional coach at three different schools in the district. Her role involved supporting teachers' practices, including the use of technology. She worked directly (in schools and classrooms) with Liz, Jennifer, and Jill. Even though she was not officially a project co-lead, Shelly was highly involved in supporting all aspects of the inquiry.
Brent Technology Coach	Co-liaison with the Technology Department. Comfortable and experienced with supporting teachers' use of new technologies. He offered a unique understanding of educational technologies and provided in-school support between meetings. He worked directly (in school and classroom) with Christine.
Sarah Technology Coach	Co-liaison with the Technology department. Comfortable and experienced with supporting teachers' use of new technologies. Offered a unique understanding of educational technologies and provided in-school support between meetings. Helped to co-plan for meetings, particularly in the early stages of the project, and shared relevant ideas related to the technology during meetings. Worked directly (in school and classroom) with Kelly.
Ben Secondary Teacher (until January 2016)	First year teacher, teaching one Grade 10 mathematics class. New to teaching mathematics and to using technology to support his practices. Initial inquiry goal was to *Use technology on a more regular basis in class and become comfortable with using Kahoot and Nearpod for quizzes and review (assessment for and as). Use Airplay to share students' work with the class and explain/demonstrate their thinking* (Doc, GRP_{OCT}).

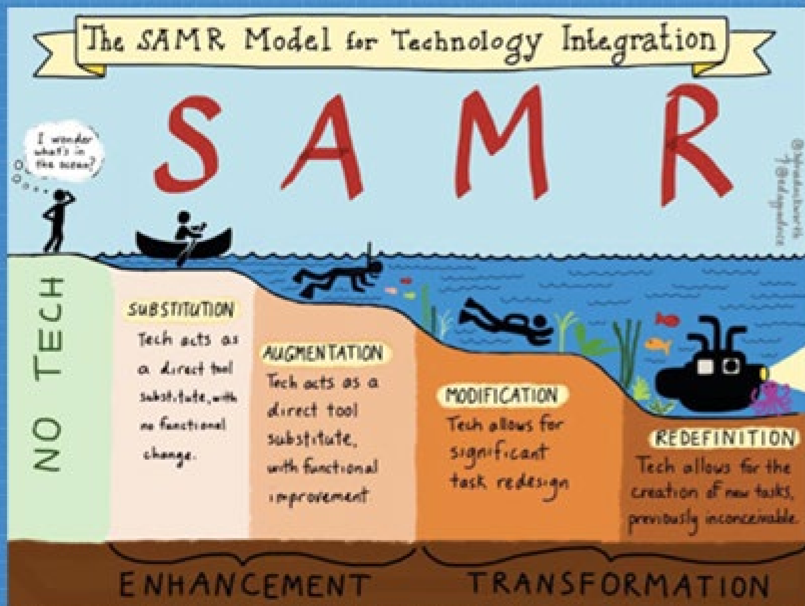
Liz Secondary Teacher	Experienced mathematics teacher, teaching Grade 9, 10, and 11 mathematics classes. Had some experience and comfort with technology prior to joining the project. Initial inquiry goal was *to use Desmos to discover the roles of "a", "h" and "k" in vertex form, to visually confirm our graphs* (Doc, GRP_{OCT}).
Kelly Secondary Teacher	Experienced mathematics teacher, teaching Grade 9, 10, and 11 mathematics classes. Some experience and limited comfort with technology but open to learning. Initial inquiry goal was to *Make use of ipads on a regular basis with the specific use of Desmos and padlet (or nearpod)* (Doc, GRP_{OCT}).
Christine Secondary Teacher	Experienced mathematics teacher. Very comfortable and experienced with technology. Initial inquiry goal was to *Try Padlet in conjunction with screen casting and flipped classroom as an interface for students to post questions and comments about explain everything video lessons* (Doc, GRP_{OCT}).
Jennifer Secondary Teacher	Experienced high school mathematics (and English) teacher. Very comfortable and experienced with using technology. Initial inquiry goal was *To use technology (kahoot and/or nearpod) for diagnostic, minds-on, review, exit cards to inform students and myself regarding general comprehension. By doing so, I hope to increase student engagement and accountability, which will help them achieve to their potential by self-assessing and setting goals* (Doc, GRP_{OCT}).

APPENDIX K: Technology Coach Presentation of Math (Assessment) and SAMR Model

Sarah's presentation of the SAMR Model (Puentedura, 2013)

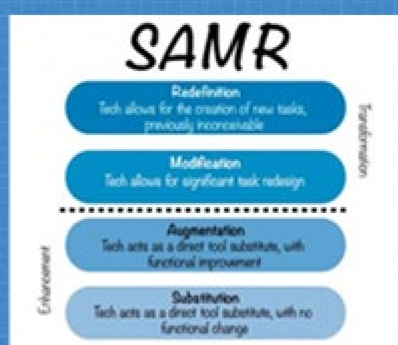




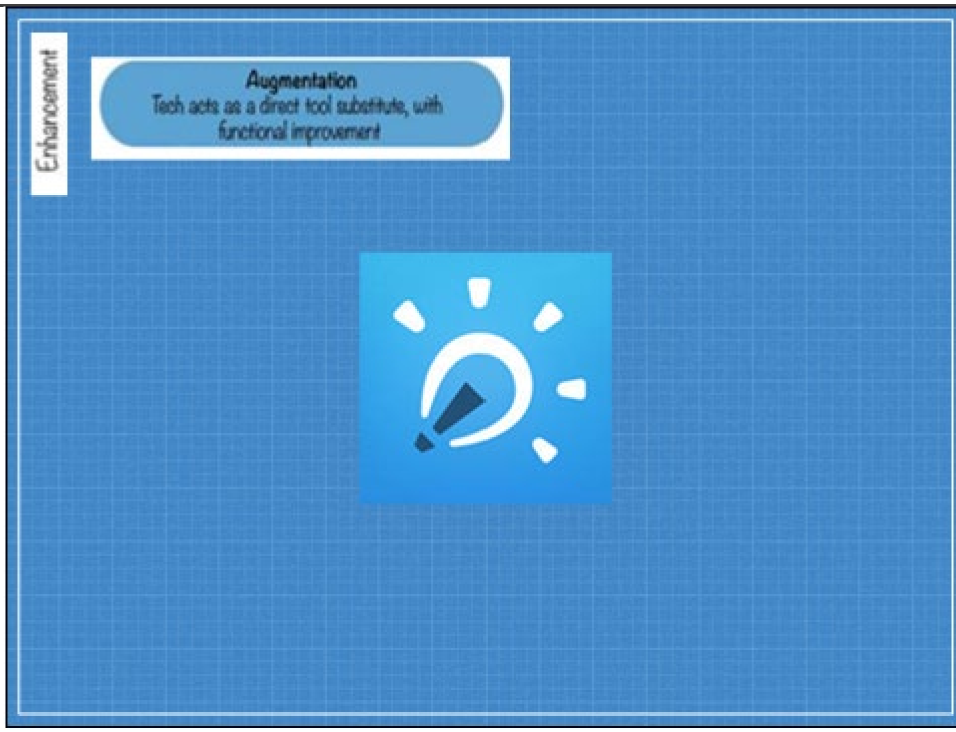


Task:

Considering our focus on assessment in math, how can students communicate their learning?

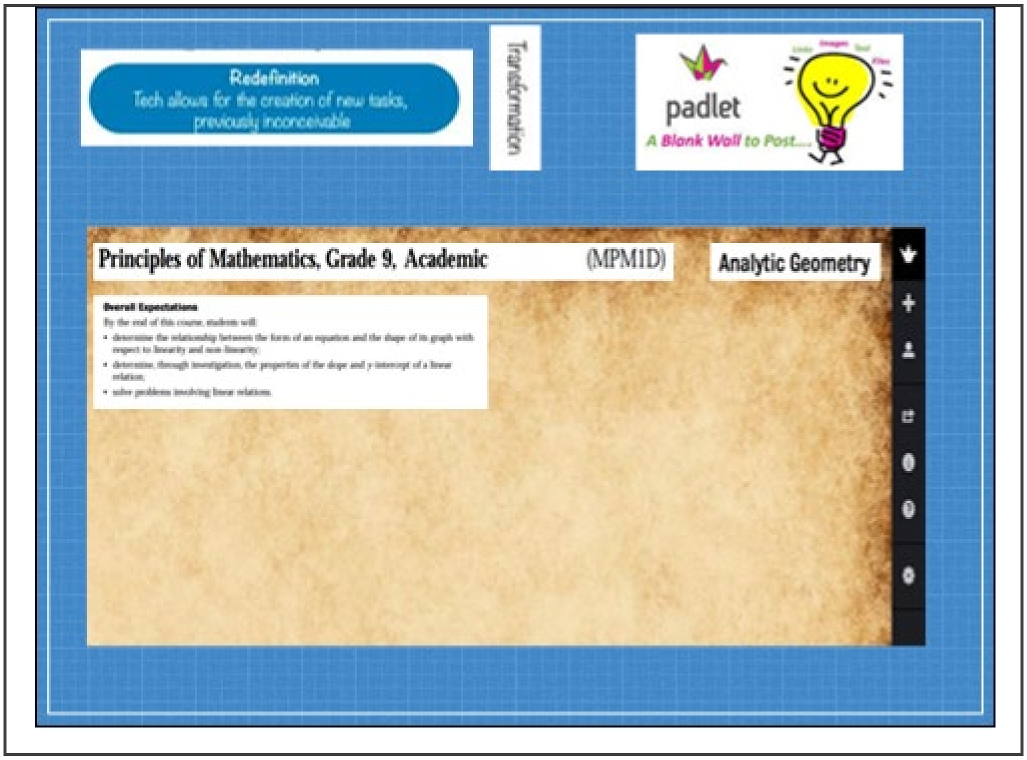



Enhancement
Substitution
Tech acts as a direct tool substitute, with no functional change


Enhancement
Augmentation
Tech acts as a direct tool substitute, with functional improvement


Modification
Tech allows for significant task redesign
Transformation

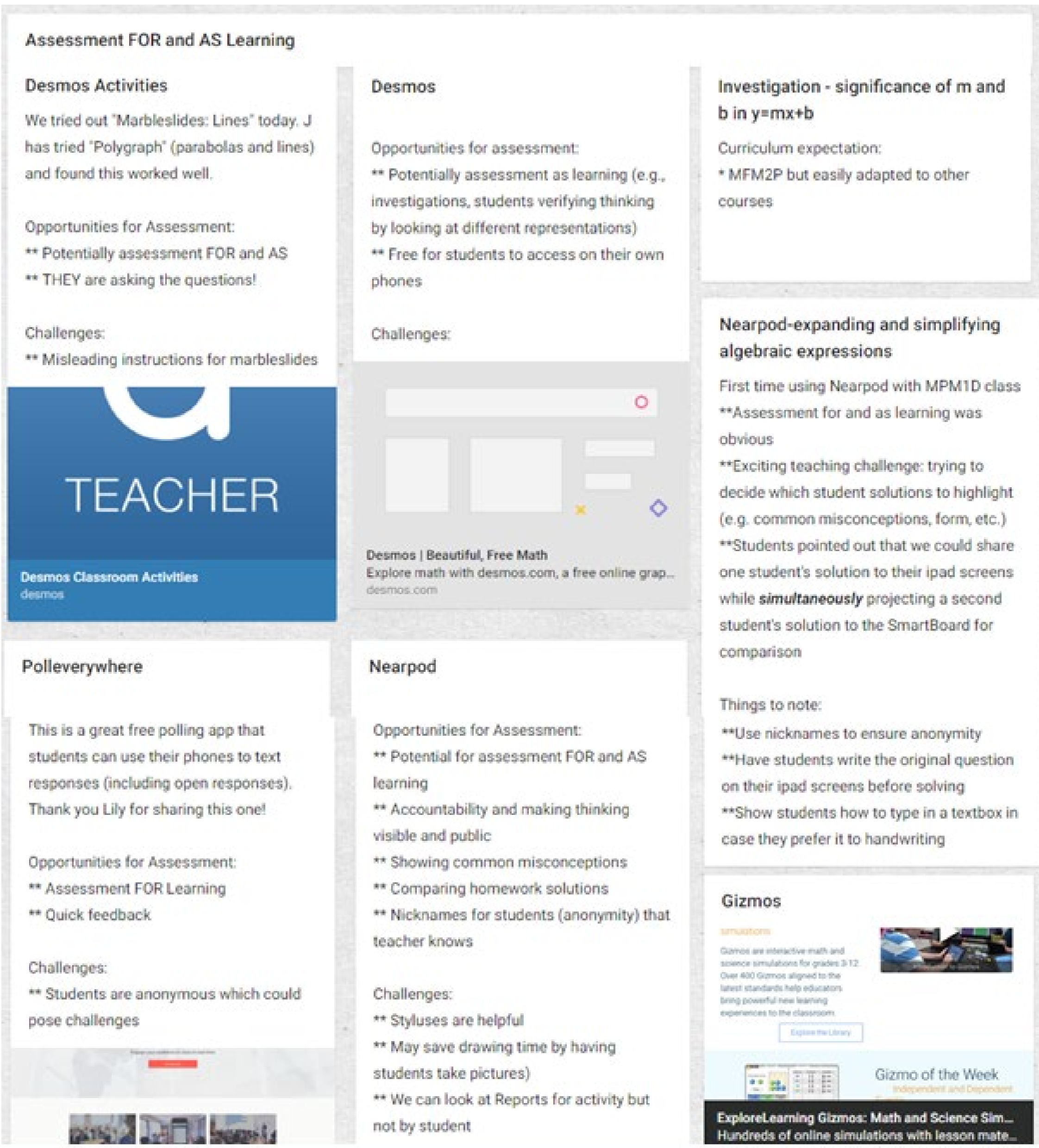

Redefinition
Tech allows for the creation of new tasks, previously inconceivable
Transformation
CEMC Courseware
Blogger
twitter
YouTube
Desire2Learn

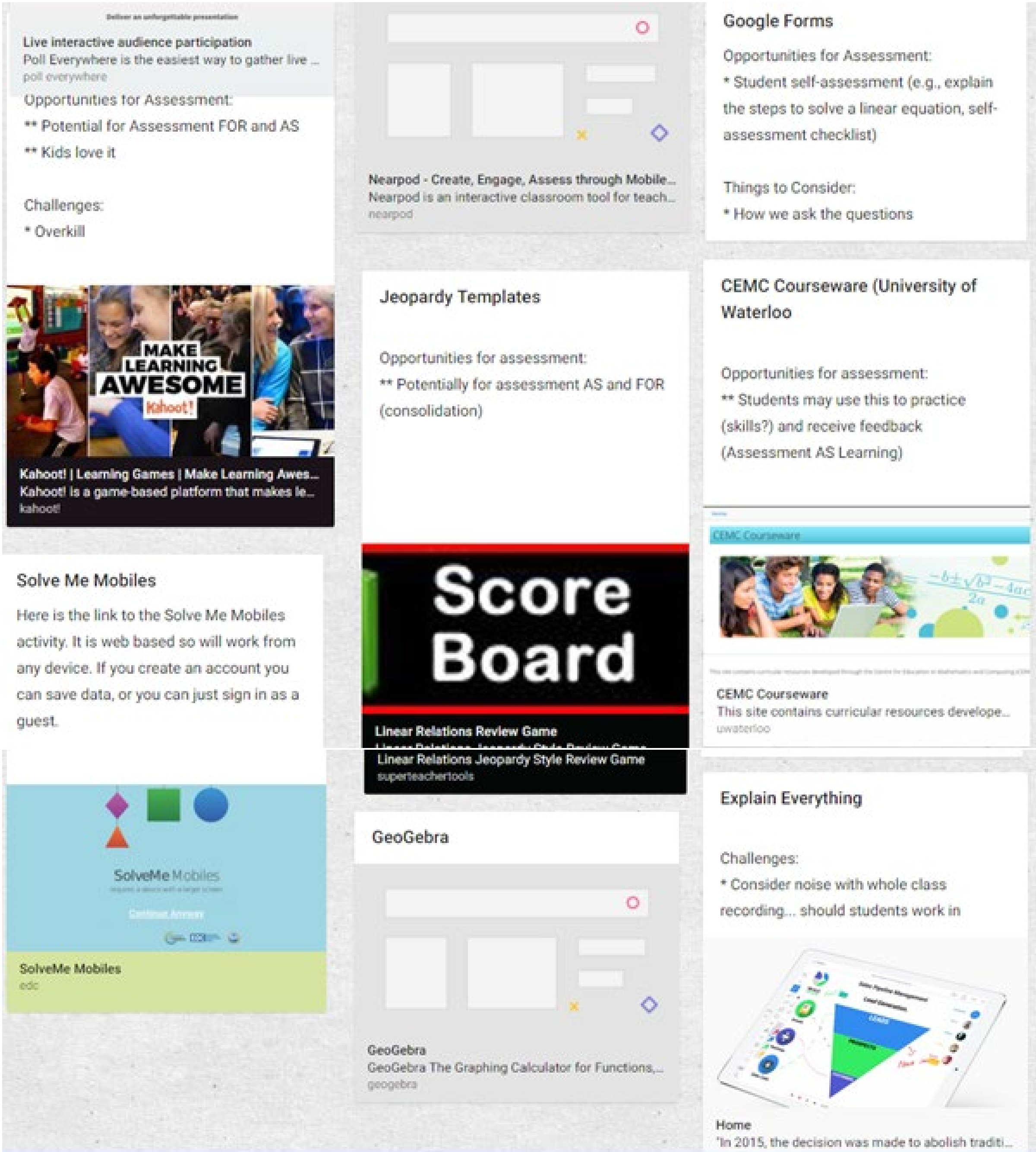

Redefinition
Tech allows for the creation of new tasks, previously inconceivable
Transformation
padlet
A Blank Wall to Post....
Principles of Mathematics, Grade 9, Academic
(MPM1D)
Analytic Geometry

APPENDIX L: Using Technology in Assessment Padlet

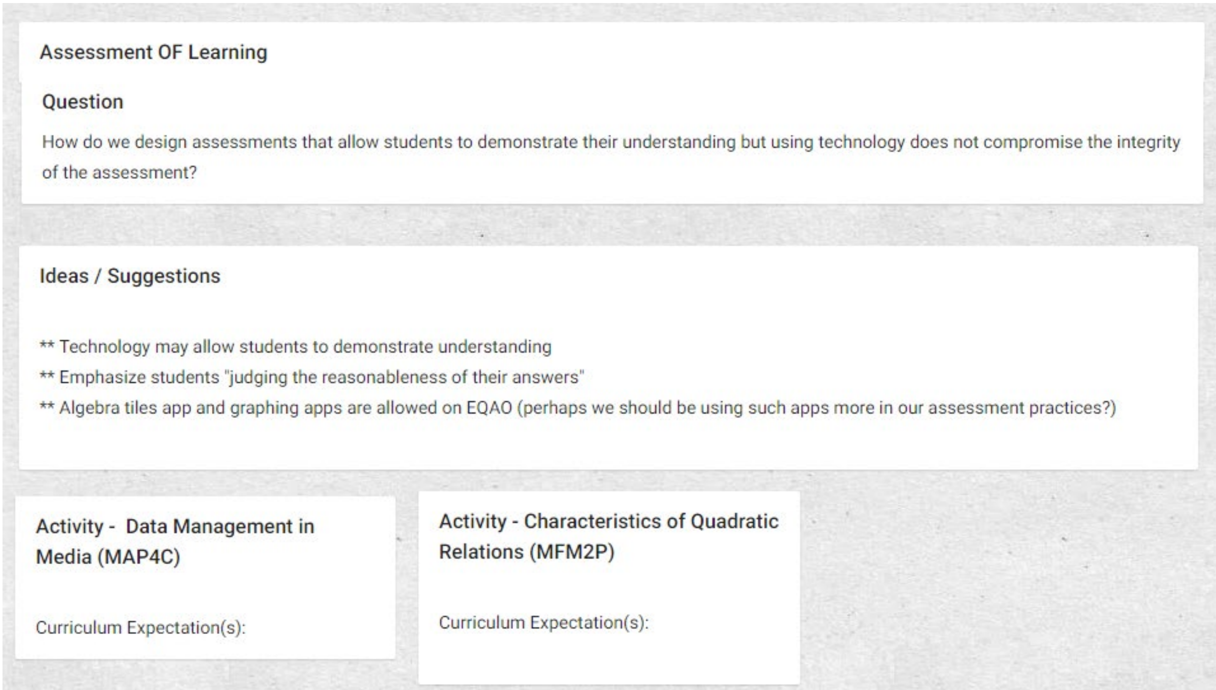
At the second face-to-face meeting I was asked to develop a Padlet to curate ideas and links to tools that connected to this project. Participants were invited to add but only the coaches actually did. The Padlet included a cluster of postings (e.g., notes, links to resources) related to "Assessment *as* and *for* learning," a cluster of postings related to "Assessment *of* learning," and a cluster of "Other - Tips/Resources." Below are images of the items included within each of these clusters.

Padlet images of posting in the "Assessment *as* and *for* learning clusters

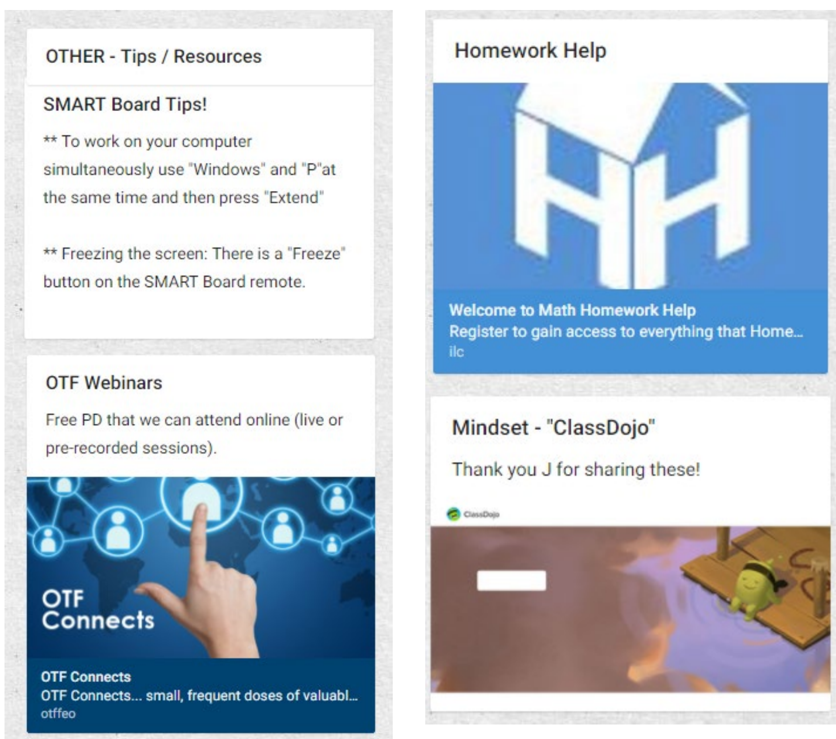



Live interactive audience participation
Poll Everywhere is the easiest way to gather live ...
poll everywhere
Opportunities for Assessment:
** Potential for Assessment FOR and AS
** Kids love it
Challenges:
* Overkill
MAKE LEARNING AWESOME
Kahoot!
Kahoot! | Learning Games | Make Learning Awes...
Kahoot! is a game-based platform that makes le...
kahoot!
Nearpod - Create, Engage, Assess through Mobile...
Nearpod is an interactive classroom tool for teach...
nearpod
Google Forms
Opportunities for Assessment:
* Student self-assessment (e.g., explain the steps to solve a linear equation, self-assessment checklist)
Things to Consider:
* How we ask the questions
Jeopardy Templates
Opportunities for assessment:
** Potentially for assessment AS and FOR (consolidation)
CEMC Courseware (University of Waterloo
Opportunities for assessment:
** Students may use this to practice (skills?) and receive feedback (Assessment AS Learning)
CEMC Courseware
CEMC Courseware
This site contains curricular resources develope...
uwaterloo
Solve Me Mobiles
Here is the link to the Solve Me Mobiles activity. It is web based so will work from any device. If you create an account you can save data, or you can just sign in as a guest.
Score Board
Linear Relations Review Game
Linear Relations Jeopardy Style Review Game
superteachertools
SolveMe Mobiles
SolveMe Mobiles
edc
GeoGebra
GeoGebra
GeoGebra The Graphing Calculator for Functions,...
geogebra
Explain Everything
Challenges:
* Consider noise with whole class recording... should students work in
Home
"In 2015, the decision was made to abolish traditi...

Padlet images of posting in the "Assessment *of* learning clusters



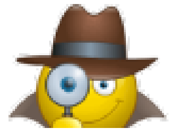
Padlet images of "Other - Tips / Resource" cluster



APPENDIX M: Sample Assessment *of* Learning Tasks

Grade 10 assessment (*of* learning) task (Jill)

MFM2P Performance Task
Quadratic Relations



Overall Goals:
- Manipulate algebraic expressions (factor & expand), as needed to understand quadratic relations
- Identify characteristics of quadratic relations (graph, table of values, equations)

For this task you will create a short video clip using Explain Everything to tell us all about your quadratic relation. You only have 3 **minutes max** so use your time wisely.

Be sure to include:
:

Equations
- Standard form
- Factored form
- Explain how you can tell from each form what the zeros and y-intercepts are

Table of Values
- Table of values
- Verify that the relation is quadratic (include 1st and 2nd differences).

Graph
- Sketch the graph
- Show zeros (x-intercepts) and y-intercepts
- Show any other key features that are important (e.g., maximum/minimum, vertex, axis of symmetry, vertex coordinates)

Anything else that might be relevant

Due: Thursday, December 16th

Be Creative & Have Fun!

Sample assessment *of* learning problems shared by Kelly to include in provincial conference presentation.

Technology allows a variety of ability levels to succeed at completing common tasks.

Students who have difficulty solving for an unknown in a quadratic equation through factoring or using the quadratic formula can access the problem through the use of technology (Desmos). Students can be challenged to solve the problem in as many ways as they can.

1. 8. Sasha works at the Botanical Gardens and is planning a new rectangular rose garden 20 m by 30 m. She plans to build a walkway, with a uniform width, all around the garden. Her budget is $6000 and she knows it will cost $\$10/m^2$ to construct the walkway. How wide can the walkway be? Include a diagram.

2. A rectangular garden with dimensions 12 m by 8 m is surrounded by a walkway of uniform width. The total area of the garden and the walkway is 252 cm^2. Find the width of the walkway. Include a diagram.

3. **A farmer wants to create two identical pens by fencing in a rectangular space and running a fence through the middle. A fencing company will build the fence for $7.50/m. The farmer wants a total fenced area of 10,000 square metres. What is the least amount that he will pay for the fence?**

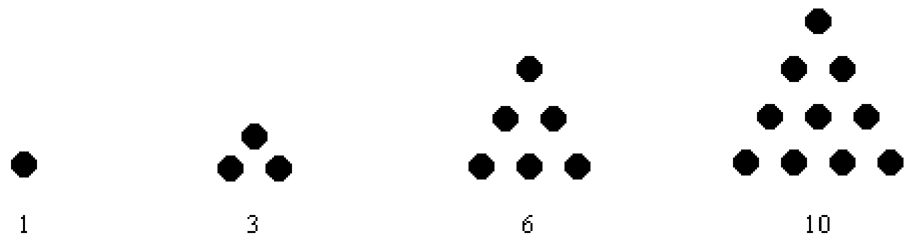
4. Nancy walks 15 m diagonally across a rectangular field. She then returns to her starting position along the outside of the field. The total distance she walks is 36 m. What are the dimensions of the field?

5. **Find the points where the graphs of the relations y=-5x+2 and y=0.5x^2-x+8 intersect. Show this 2 ways.**

6. The population of a city is modelled by the equation $P = 0.5t^2 + 10t + 200$, where t is the time in years and P is the population in thousands. Note: t=0 corresponds to the year 2000.

a) What will the population in 2000?
b) What is the population in 2002?
c) When is the population 350,000?

7. The first four triangular numbers are shown below.



a) What are the next two triangular numbers?
b) What relationship can be used to find any triangular number? Technology may be used. Explain your technique.
c) What is the 100th triangular number?
d) Is 145 a triangular number? Explain

8. Max operates a store, part of a national chain, that sells CDs in a mall. Max has a one-price-for-all policy: all single CDs sell for \$20 each. The national sales manager has given Max permission to change his pricing in an attempt to increase revenue. Max knows that, over the last six months, he has sold an average of 280 CDs a day at \$20 each. The company's market research indicates that for every \$0.50 increase in unit price, daily sales will drop by five units. What unit price will maximize Max's daily revenue? What is the maximum daily revenue?

9. Suppose your student council did a survey on ticket prices for the upcoming Spring Fling dance. They found that 480 students would buy tickets if the price were \$5 per ticket. For each \$0.10 increase in the price of a ticket, the number of students who will attend the dance drops by 8. Predict the maximum revenue the student council can receive from the sale of tickets. Show the steps of your solution.

10. A fast-food restaurant determines that each \$0.10 increase in the price of a hamburger results in 25 fewer hamburgers sold. The usual price for a hamburger is \$2.00 and the restaurant sells 300 hamburgers each day. Find the optimum price for a hamburger. What is the optimal revenue?

11. The underside of a bridge forms a parabolic arch. The arch has a maximum height of 30 m and a width of 50 m. Can a sailboat pass under the bridge, 8 m from the axis of symmetry, if the top of its mast is 27 m above the water? Justify your solution.