Fostering a Technology-rich Professional Learning Community: A Design-based Research Cycle

Lei Nong

Department of Educational and Counselling Psychology

McGill University, Montreal

November, 2014

A thesis submitted to McGill University in partial fulfillment of the requirements of the degree of Master of Arts in Educational Psychology, Learning Sciences concentration.

Table of Contents

List of Tables 4

List of Figures 5

Abstract 6

Résumé 7

Acknowledgements 8

Introduction 9

Theoretical Framework 10

  Designed-Based Research 10

  Two Components That Support the Initial Design 15

    PLC. 15

    TPACK and learning technology by design 17

  TPACK Framework as Analytical Tool 18

A Review of Teacher Professional Development Literature 21

  Technology in Professional Development 24

    PD for the integration of technology in the classroom. 24

    Integrating technology in PD. 25

Method 27

  Context of the Case 27

Participants and the CCC-M Design Team 28
Data Collection and Analysis 29
Results: The Process from PLC Design to Refinement 31
Design Phase 31
Activities at the face-to-face meetings........ 35
Online discussions on Edmodo. 38
Implementation Phase 39
Online discussions on Edmodo. 39
Teacher learning during face-to-face meetings. 44
Revision Phase........ 48
Summary 52
Discussion........ 54
Lesson Learned from the First Design-based Research Cycle........ 54
The Role of PLC in the CCC-M Project........ 56
Concluding Remarks........ 57
References 59
Appendices........ 66
Appendix A: Anticipation guide........ 66
Appendix B: Math concepts students struggle with 67

List of Tables

Table 1 The Timetable of Leadership Meetings and PD Activities Proposed with Teachers.. 33

Table 2 The Design Process from Proposal to Activities…………………………………..……………… 34

List of Figures

Figure 1 Iterations of systematic cycles…………………………………………………………………………. 14

Figure 2 The framework of technological pedagogical content knowledge………………………. 19

Figure 3 Distribution of teacher online discussion……………………………………………………………. 40

Figure 4 Frequency of posts by each teacher……………………………………………………………………. 44

Figure 5 Process of the first research cycle………………………………………………………………………. 53

Abstract

Teachers' knowledge and skills is one of the most important factors affecting student learning. This thesis describes the early process of a teacher professional development project during which a technology-rich professional learning community was developed and validated to support ongoing teacher development. The aim of this project was to improve teachers' disciplinary understanding and digital literacy in the mathematics classroom, with a focus on student learning in the transition from elementary to secondary schools. In particular, the author highlights the use of design-based research in the design and the validation of this learning community. The results indicate that this learning community fostered a shared vision of continued development among teachers. Teachers shared their experience of practice and supported each other's learning to improve student learning. In addition, they explored the effective use of digital tools for student learning in the classroom. This study reports baseline data that will be used to examine how the conversations, teaching practice, and inquiry activities evolve in the next iterations of the professional learning community.

Résumé

Le savoir et les compétences des enseignant(e)s sont les plus importants facteurs qui contribuent à l'apprentissage des élèves. Ce mémoire de maitrise décrit la première itération d'un projet de développement professionnel durant lequel une communauté d'apprentissage professionnelle supportée par les technologies a été déployée et validée. Le but de ce projet était d'améliorer les connaissances disciplinaires et la numéracie dans les classes de mathématiques, visant spécifiquement à pallier aux difficultés éprouvées par les élèves au passage du primaire au secondaire. Le mémoire souligne l'utilisation d'une approche méthodologique de design (« design-based research ») pour la conception et la validation de la communauté d'apprentissage professionnelle. Les résultats indiquent que cette communauté d'apprentissage a réussi à développer une vision partagée pour le développement des participants. Les enseignant(e)s ont partagé leurs expériences pratiques et ont apporté les uns envers les autres un soutien collégial pour développer une meilleure compréhension des apprentissages des élèves. De plus, ils/elles se sont approprié une utilisation efficace des outils numériques pouvant servir aux apprentissages des élèves et à leur propre apprentissage. Ce mémoire de maitrise fournit des données de base qui serviront à étudier de quelles manières les conversations professionnelles, les pratiques d'enseignement, et les activités d'investigation et de réflexion évolueront dans les prochains cycles de cette communauté d'apprentissage professionnelle.

Acknowledgements

I would particularly like to thank my supervisor Prof. Alain Breuleux for his unstinting support and meticulous guidance throughout my thesis from generating the research question to writing this thesis paper. Without his persistent help, this thesis would not have been possible.

I also want to express my gratitude to my colleague Dr. Gyeongmi Heo and school board partners Lisa Rae-Nutter, Karen Rye, Tina Morotti, and Sandra Fréchette for their devoted work in our project and for their priceless inputs in my data collection and analysis.

In addition, I would like to express my thanks to Prof. Annie Savard for her helpful comments to improve this thesis.

Introduction

This study responded to the real concerns for improving students' mathematics learning in the transition from elementary to secondary schools and for the effective use of technology in the classroom. To address these problems, a group of university researchers and school experts created a three-year project that brought elementary teachers and secondary teachers together to develop a collective understanding of the situation. The goal of this project was to provide a supportive professional learning environment –a community of professional learning– that helped teachers to improve their practice of solving these problems through the iterative design and validation of such learning environment. This descriptive case study, as part of the project, focused on the initial stage of the project during which the professional learning environment was designed, implemented, and refined. The purpose of this study was to document the process of development and refinement of the professional learning environment. Three questions guided this study:

- How was the professional learning environment (i.e., the community of professional learning) designed to support teachers' continued learning in the initial stage of the project?
- What were the contents and the substance of teacher learning during the implementation phase of this professional learning environment, and how did teacher learning evolve overtime?
- How was this professional learning environment revised after the implementation phase according to the evaluation of teacher learning?

In the following section, I first elaborate on the theoretical framework that frames the design of this professional learning environment. Second, I discuss how this theoretical framework is informed by previous research in the field. I then present the case study to describe the unfolding process of development and refinement of the professional learning environment. Finally, I discuss the lessons learned from this study.

Theoretical Framework

In this chapter, I describe the conceptual framework and research method that structured the design and the validation of the professional learning environment in this study. Following that I explain the substantive learning theories involved in this conceptual model. Also, I introduce an analytical model to evaluate teacher learning during the implementation phase.

Designed-Based Research

The backbone of this study is a larger design-based research project, Creating, Collaborating and Computing in Math (CCC-M), to design, sustain, and validate the CCC-M professional learning environment.

Design-based approach or “design experiment” (Brown, 1992; Collins, 1992) is a research method that emerged with increasing interests toward studying learning within naturalistic contexts (e.g., classroom, workplace). Over the past few decades, many educational researchers realized that traditional laboratory research, with its rigorous control of learning setting and measure of limited variables, often hardly provides adequate understanding to the problems of learning that happens in the messy contexts of everyday practice (Collins, Joseph & Bielaczyc, 2004; The Design-Based Research Collective, 2003). In response to the need for methods to gain a comprehensive insight into learning in real-life contexts, design-based research was developed that “moves beyond simply observing and actually involves systematically engineering these contexts in ways that allow us to improve and generate evidence-based claims about learning” (Barab & Squire, 2004, p.2). In other words, design-based researchers deliberately use a set of learning theories to design learning environments that could be applied to real-life settings, and keep revising, updating the learning environments through the constant examination of learning within those contexts. This process in return contributes to knowledge of learning in those settings.

Central to the notion of design-based research are the two related goals of research to design and validate theory-based learning environments. First, a major purpose of design-based research is to design a learning environment through using a class of learning theories and developing a way of engineering them to support learning in specific contexts (Cobb, Confrey, diSessa, Lehrer & Schauble, 2003; The Design-Based Research Collective, 2003). The learning environment in design-based research is not built in a vacuum. Researchers draw on previous research, analyze target context, and carefully select and orchestrate a set of learning principles with an intention to promote learning in that context. Learning environments without a basis of learning theories often become activities with surface rituals or procedures. As Brown and Campione (1996) stated when discussing the various adoption of their reciprocal teaching activity in other contexts, “too often something called reciprocal teaching is practiced in such a way that the principles of learning it was meant to foster are lost, or at best relegated to a minor position" (p.291). The second goal of design-based research is to test those learning theories embedded in the learning environment through implementing the learning environment in real context. This feature reveals an experimental aspect of design-based research which differentiated itself from purely observing naturalistic learning settings. Researchers conduct design experiment with a purpose of validating or extending learning theories whereby the learning environment is developed (Barab & Squire, 2004; Cobb et al., 2003). The embedded learning theories presuppose a hypothesized process of learning and guide the implementation of the learning environment, and consequently provide a measure of control for researchers to examine the learning environment in practice. If an anticipated outcome is achieved, the learning theories can be justified in that learning environment. If the conjectures about the hypothesized learning process are refuted in actual practice, alternative theories will be generated to redesign the learning environment and put to later test.

In addition to these two central goals, design-based research serves a pragmatic function in practice. The product of the learning environment design should be applicable in real-life or authentic settings and provide useful solutions to actual problems in everyday practice (Cobb et al., 2003; Plomp, 2013; The Design-Based Research Collective, 2003). This often requires collaboration and negotiation between different participants with different expertise in producing, applying and evaluating design-based learning environments (Cobb et al., 2003; Collins, 1999; The Design-Based Research Collective, 2003). Participants such as teachers, school-based educational consultants, curriculum designers, and technology experts are often involved in design-based research to ensure the practicality of the learning environments.

Together, these perspectives of design-based research result in a stage-like, cyclical characteristic of the research. Plomp (2013) identified three stages of the overall design-based research:

1. Preliminary research: a design-based research started with identifying problems in the target context. According to the problems, researchers review literature, conduct context analysis, and consult educational practitioners and other experts. Based on these primary data and information, researchers develop a theoretical framework for the research.
2. Development or prototyping stage: this stage creates an iterative, cyclical system of design (see Figure 1). In the first step, researchers use those predetermined learning theories in the theoretical framework to develop a concrete product –a prototype learning environment– that can be used in the target context. The second step is to conduct formative evaluation to examine the prototype in implementation. Lastly, researchers revise the current prototype when the implemented prototype is not as effective as desired or when new problems from the target context emerge. During this stage, formative evaluation plays a crucial role in the improvement of the learning environment since it provides insight into the quality of the current prototype and the evidence-claims to those underlying learning theories embedded in the prototype. As a result, formative evaluation helps researchers to maintain or extend the learning theories for future design (Nieveen & Folmer, 2013).
3. Assessment stage: close to the very end of the entire design-based research, researchers conduct summative evaluation or retrospective analysis to verify the

extent to which the final prototype leads to their anticipated outcomes. They also conclude how this research validates or extends our theories of learning in the target context. Finally, researchers provide recommendations for the generalization of their research in other contexts.

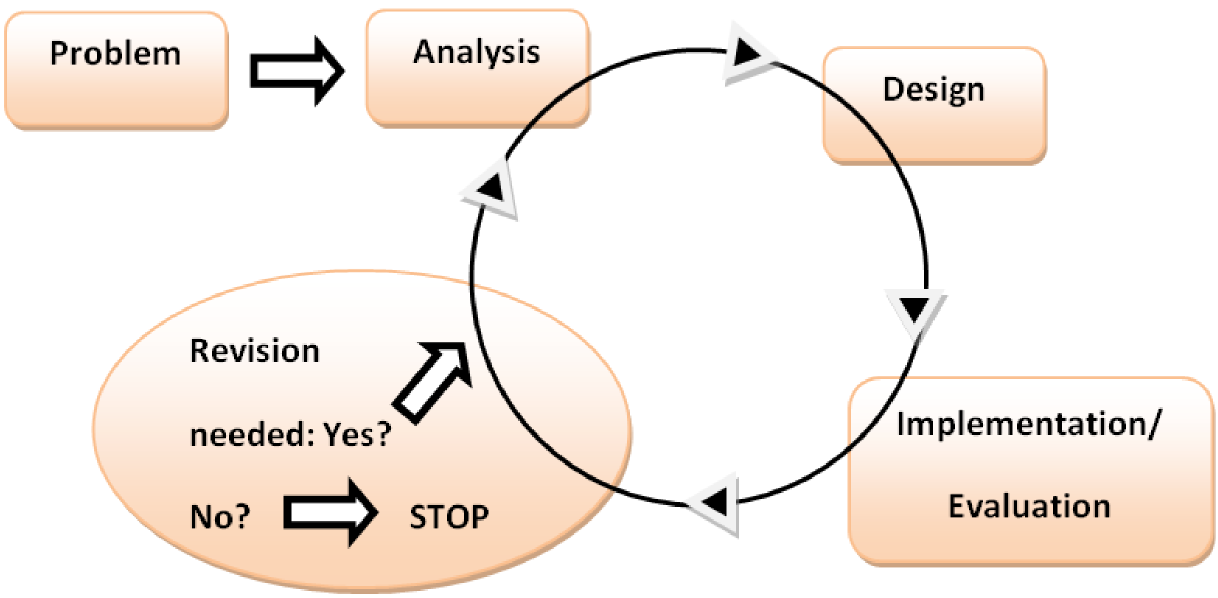

Figure 1. Iterations of systematic cycles (adapted from Plomp, 2013).

Despite the enactment of design-based research in a diverse range of contexts (Bannan, 2013; Brown & Campoine, 1999; Cobb, 2000; Steffe & Thompson, 2000; Van de Akker, 2013), there is limited design-based research investigating professional learning environments for in-service teachers, especially the development of technology-rich environments. In the CCC-M project, attention was directed toward developing a technology-rich learning environment to promote and sustain ongoing teacher professional development through an iterative design process. Specifically, this particular case study focused on the process of the first design-implementation-revision cycle in the early prototyping stage.

Two Components That Support the Initial Design

As emphasized before, the development of a learning environment in design-based research should be supported by a set of learning principles. There were two core dimensions in the initial design of the CCC-M project: a) the model of professional learning community (PLC); and b) the notion of technological pedagogical content knowledge (TPACK) and the method of *learning technology by design*.

PLC. A PLC is generally viewed as a collective enterprise that brings teachers and other educational practitioners together to share and interrogate teachers' practice in a collaborative, ongoing, and reflective way (Stoll, Bolam, McMahon, Wallace & Thomas, 2006). The model of PLC was adopted in the CCC-M project because of its potential capacity to promote and maintain learning for professionals (Bolam et al., 2005; Stoll & Louis, 2007). Definitions of PLCs vary across the literature, and the CCC-M design team adapted several common features that are reported to make PLCs effective in the design of the CCC-M learning environment.

First, a core tenet to foster a PLC is that members need to share consistent vision and collective responsibility (Stoll et al., 2006). The shared vision is a preferred picture of the future which directs the destination that PLC members work toward. By sharing common values and goals, members in PLC determine what problems they are going to solve and how to work together. Among various PLCs, a universal, undeviating focus is student learning. In other words, a PLC is created with a communal desire of improving student success through the continuous development of professionals. Furthermore, a PLC should help its members to be aware that they are collectively responsible for student learning as well as their own learning (King & Newmann, 2001). Each member is a meaningful agent that could contribute to decision making in supporting the community. It is assumed that such distributed responsibility could empower the learning efficacy of teachers and push their commitment of collective professional learning within the community (Newmann & Wehlage, 1995).

Second, PLC members learn collaboratively through sharing practice and reflective inquiry (Hord, 2004; Louis et al., 1995). In a PLC, teachers share their practice with others, such as students' difficulties, teaching strategies, and evaluation process. Such sharing is not to judge others, but to open dialogues for reflective inquiry in a respective manner. A norm of dialogue for teachers is to be critical of their own practices as well as those of others. This is valuable to prompt their own learning as well as others and improve their practice for the benefit of students. For instance, based on a student learning difficulty from the classroom, teachers reflect on the cause of such problem collectively, provide individual strategies to address this problem, question others' ideas, seek new information to solve the problem, apply new ideas to problem solving, and provide feedback to colleagues. Increasingly, teachers are expected to build trust in others and welcome different perspectives from others. It is also expected they could even have closer collaborative initiatives such as visiting others' classrooms and co-planning lessons (Newmann & Wehlage, 1995).

Third, effective PLCs require supportive conditions (Hord, 2004; Stoll et al., 2006). Whether PLCs could function productively also depends on appropriate supports. Hord (2004) identified two types of supports: a) physical factors, and b) human capacities. Physical factors might encompass the availability of learning resources, time for professional development, and technology supports. Human capacities refer to supports from the educational experts of schools and other external institutes. McLaughlin and Talbert (2001) suggested that administrators and principals play a critical role in fostering the culture of PLCs. In addition, Hord (2004) mentioned university scholars as important external supporters. University researchers could introduce relevant learning theories to practitioners and help them to connect theories to real practice.

TPACK and learning technology by design. In the CCC-M project, the design team attempted to cultivate a technology-rich learning environment. The technology integration manifested itself in two ways: firstly the design team tried to improve teachers' capacity to teach with technology and secondly digital tools were used to enhance teacher learning. The work of technology integration in the CCC-M project was influenced by the notion of technological pedagogical content knowledge (TPACK) and the approach of *learning technology by design* (Mishra & Koehler, 2006). In their article, Mishra and Koehler (2006) criticized traditional technology training programs for teachers in which technology introduction is separated from pedagogy and subject matters. They argued that the relationship among content, pedagogy, and technology is interactively related, each element providing both affordances and constraints to the other two. They further proposed the approach of *learning technology by design* to foster teachers' awareness of such relationship (i.e., knowledge of TPACK). This method posits that the experience of technology learning needs to be situated in the authentic problems of practice that allow teachers to think about how technology could be designed, used, and revised in solving those problems. By engaging teachers in sustained technology design and revision for practice, it is assumed that teachers will gain a deep understanding of TPACK. In addition, the design team also use the idea of TPACK to reflect on what and how digital tools can be used to promote teacher learning in the CCC-M learning environment.

TPACK Framework as Analytical Tool

The notion of TPACK was used to frame the CCC-M learning environment design and, most importantly in this particular study, as an analytical lens to look at teacher learning during the implementation process of the first research cycle. Extended from the notion of pedagogical content knowledge by Shulman (1986), Mishra and Koehler (2006) developed the notion of TPACK into a comprehensive framework. This framework categorizes seven types of knowledge that teachers need to know in order to teach with technology successfully (see Figure 2):

- Content knowledge (CK): CK is knowledge about the subject matter that teachers teach in the classroom. In specific, teachers should understand a) the concepts of the subject matter they teach, b) the structure of knowledge conceptual organization, and c) what are considered as the necessary rules and procedures of knowledge inquiry within that domain. For example, a math teacher must know the definition of fraction, the relationship among fraction, decimal and percentage, and what is considered as a good mathematical proof to the claim of $\frac{1}{2}+\frac{1}{3}=\frac{5}{6}$.

- Pedagogical knowledge (PK): PK is generic knowledge about learning and teaching across disciplines. It also contains the philosophical and ethical ideas that inform teachers' visions toward education. Specifically, it includes knowledge such as how students learn, how to evaluate student learning, the techniques of classroom management to encourage student learning, etc.

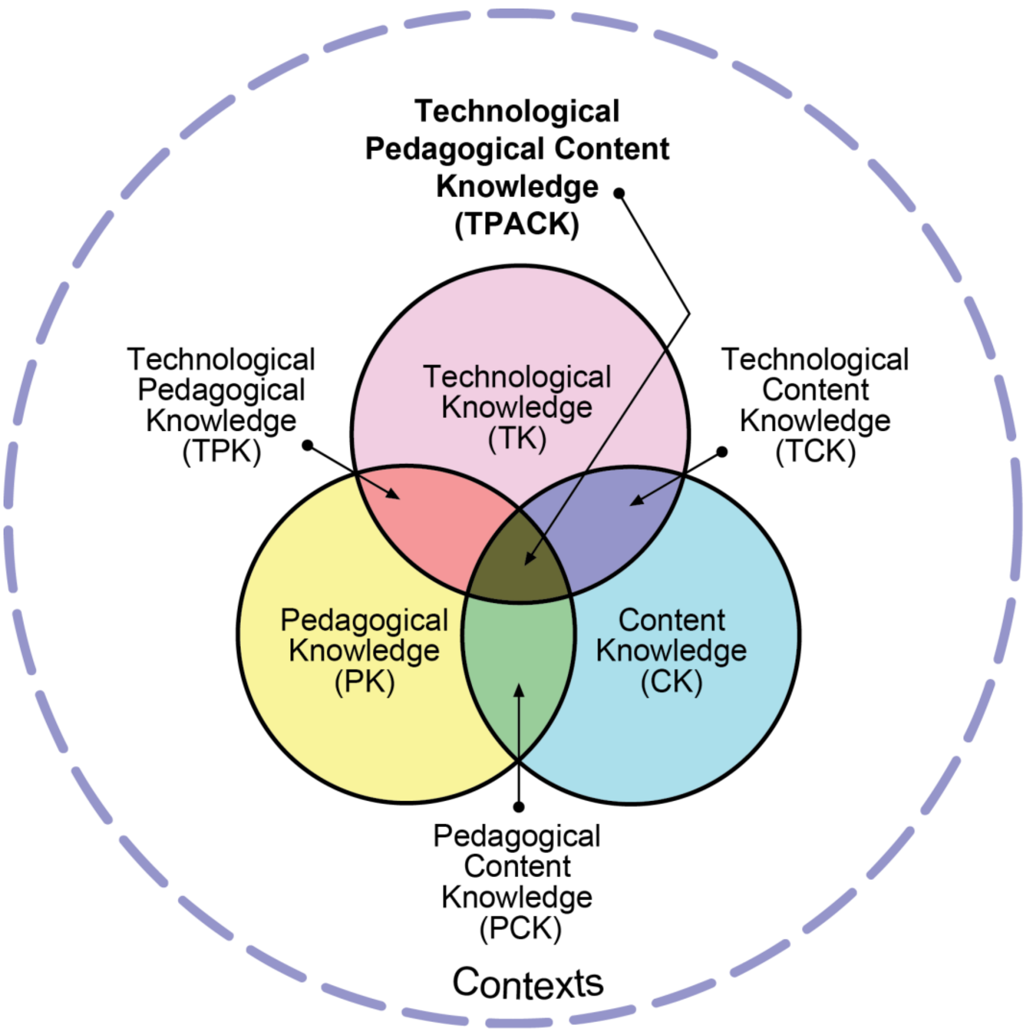

Figure 2. The framework of technological pedagogical content knowledge (adapted from Koehler & Mishra, 2014).

- Technological knowledge (TK): it involves knowledge and skills of operating educational technologies, whether these technologies are traditional educational devices (e.g., blackboard, projector) or advanced digital technologies (e.g., computer program, interactive white board).
- Pedagogical content knowledge (PCK): PCK is knowledge of content-specific pedagogy. It is not a simple combination of CK and PK, but a distinct type of knowledge that requires teachers to have a sound understanding about how to teach a specific content. It includes students' epistemology toward subject matter, students' prior content knowledge, and pedagogical techniques to advance student learning.
- Technological content knowledge (TCK): TCK is knowledge about the association between content and technology. That is, teachers need to know how the representation of subject matter could be changed by the use of different technology tools.
- Technological pedagogical knowledge (TPK): TPK is knowledge of selecting proper technology tools for different pedagogical tasks. An expert teacher could choose technology tools accordingly and knows how his (or her) choice of technology tools affect student learning.
- Technological pedagogical content knowledge (TPACK): it is a distinctive body of knowledge that requires teachers to understand the mutually supportive and restrictive relationship among technology, pedagogy, and content. Teachers need to

know how to develop content-specific teaching strategies with appropriate technologies.

The framework of TPACK enables the design team to explore the types of knowledge that teachers focus on during the implementation phase and in what ways such types of knowledge are discussed.

A Review of Teacher Professional Development Literature

There is a lot of agreement that school-improvement efforts depend on teachers' capacity to support these efforts individually and collectively (Borko, Jacobs & Koellner, 2010; Darling –Hammond & Bransford, 2005; Guskey, 2000; Stoll et al., 2006). As a consequence, ongoing professional development (PD) becomes a core factor to sustain teachers' competence for such efforts. Dissatisfied with conventional PD activities, educational researchers propose new ideas which intend to improve the development of in-service teachers. This emerging paradigm of PD highlights a learner-centered environment which engages teachers in situated, active, and collaborative learning activities (Borko, Jacobs & Koellner, 2010; Cochran-Smith & Lytle, 1999).

A call for PD reform suggests the development of teachers should be situated in their own practicing contexts (Putnam & Borko, 2000). Situated theories posit that knowledge is the product of learning activity in which it is produced (Brown, Collins, & Duguid, 1989). "How a person learns a particular set of knowledge and skills, and the situation in which a person learns, become a fundamental part of what is learned" (Putnam & Borko, 2000, p.4). Instead of introducing general theories and strategies that teachers might not know how to apply to their classrooms, situated PD assists teachers to learn useful knowledge by grounding their learning experiences in the classroom. For example, teachers could bring their problems from the classroom. PD activities subsequently support their learning and practice through understanding the problems and investigating the effective solutions to these problems.

Derived from the recent emphasis on student-centered instruction, another focus of new PD is to build teachers' capacity to understand student learning in order to support student learning effectively (Hawley & Valli, 2000). Current understanding about cognition recognizes learning as a process in which learners actively construct knowledge based on their beliefs and pre-existing knowledge (Bransford, Brown & Cocking, 2000). In a student-centered classroom, students engage in active knowledge construction, rather than repeatedly memorizing those facts and skills delivered by teachers. However, a student-centered classroom does not imply letting students to self-teach. Students need supports when they have difficulties. They need guidance when they have misconceptions. To yield successful student learning, teachers need to understand students' thinking and learning so as to facilitate their study (Doerr, 2006). For this reason, PD should help teachers to focus on student learning and support them to become powerful facilitators in their own classrooms.

In parallel with the notion of student-centered classrooms is the idea of learner-centered PD. This idea requires teachers educators and PD facilitators to treat teachers in a way they expect teachers to adopt (Putnam & Borko, 1997). That is, teachers should be empowered as active learners who construct their own knowledge of practice. Nevertheless, teachers are often required to implement “successful methods” from other practitioners regardless of their prior knowledge and beliefs toward learning and teaching. It is not surprising that teachers might distort these methods to fit in their pre-existing views (Cohen, 1990; Gregoire, 1999). Therefore, the contemporary approach to PD argues for respecting teachers’ knowledge as professionals and empowering them to be critical of their practice. Teacher educators and PD facilitators, on the other hand, assist teacher learning in their reflective inquiry about teaching practice (Stein, Smith & Silver, 1999).

Current PD also encourages collegiality among teachers (Lieberman & Pointer-Mace, 2010; Stein, Smith & Silver, 1999). Empirical research indicated that teachers viewed collaborative learning as a powerful way to improve learning (Lieberman & Wood, 2000). In a collaborative learning community, teachers could learn from others, help others, and work together to develop best teaching materials and strategies. Overtime, teachers might be able to build a collective commitment to sustain ongoing learning. Furthermore, educational researchers call for a more inclusive community. Teachers are not knowledgeable about everything. Involving outside experts (e.g., university researchers, curriculum designers, teacher educators) bring different expertise and perspective to the community and maximize the knowledge base to support teacher learning (Stein, Smith & Silver, 1999).

Overall, the above paragraphs summarize the key characteristics of innovative PD. Nonetheless, Stein et al. (1999) cautioned that maintaining the effectiveness of PD programs is more than importing new ideas. It is about how to thoughtfully incorporate these ideas in the design of PD programs, and how to implement, reflect on, and modify the design thereafter.

Informed by this caution, the design team decided to use design-based approach to validate and sustain the CCC-M learning environment.

Technology in Professional Development

The topic of technology has gained popularity in PD programs (Borko, 2004; Borko et al., 2010; Lieberman & Pointer-Mace, 2010; Mishra & Koehler, 2006). Some PD programs focus on preparing teachers' capacity to teach with technology. Some other technology-related PD programs try to use technology to support teacher learning.

PD for the integration of technology in the classroom. In recent years, more and more teachers have embraced the idea of teaching with technology. They started to appreciate the advantages of using technology in the classroom (Ertmer, 2005). While a variety of recent technologies have been introduced to teachers through workshops and other PD activities, the high-level use of technology is still inadequate (Koehler, Mishra & Yahya, 2007; Zhao, Pugh, Sheldon & Byers, 2002).

The limited high-level use of technology might be attributed to several factors. For example, technologies are introduced in an un-differentiated manner without considering teachers' beliefs toward technology use and their previous experience of using technology in the classroom (Ertmer, 2005). Teachers also need more ongoing supports to integrate technology in the classroom successfully (Zhao et al., 2002). Most importantly, the majority of educational technology training activities focus primarily on technical skills. These activities neglect the perspective of how technology is used to support pedagogy, especially content-specific pedagogy (Angeli & Valanides, 2009). In order to teach with technology successfully, "teachers need to know the affordance and constraints of various technologies and how specific technologies might support their own teaching practices and curricular goals" (Zhao et al., 2002, p.511). In view of this limitation, researchers propose the notion of TPACK (or TPCK) (Angeli & Valanides, 2009; Mishra and Koehler, 2006; Niess, 2005). This notion ultimately influences the way that the CCC-M project prepares teachers to teach with technology.

Integrating technology in PD. Technology, especially fast-changing digital tools, enables teachers to access a mass of learning resources. Abundant online websites provide a range of educational information, such as knowledge of subject matters, pedagogical ideas, ready-to-use teaching materials, etc. The development of technology also expands the opportunity for collaboration among teachers (Goldman, 2001; Lieberman & Pointer-Mace, 2010). Particularly, conferencing systems and ubiquitous online social networks help teachers to overcome the constraints of place and time. Teachers could learn with others and work collectively without meeting face-to-face at the same time.

However, concerns are raised that exposure to these innovative technologies does not necessarily lead to effective teacher learning and practice (Brophy, 2003; Goldman, 2001). For instance, teachers might take some successful strategies from an educational website without thinking critically about how to tailor these strategies to meet their students' needs. In line with the idea of TPACK, PD developers and facilitators also need to consider how to capitalize on the power of technology to enhance teacher learning. Thus, many PD programs try to deliberately integrate technologies to facilitate teacher learning. A good example of such programs is the Supporting the Transition from Arithmetic to Algebraic Reasoning Project (Borko, Jacobs, Eiteljorg & Pittam, 2008). In this project, Borko and her colleagues incorporated classroom videos as a tool to foster meaningful discussions within a teacher learning community. Classroom videos were chosen as a technological tool because it situated teachers in real practicing context. The idea here was to help teachers to notice those perspectives that they might have ignored when carrying out their lessons. During PD learning sessions, teachers spent a lot of time watching and discussing the video records from their classrooms. The video records were not presented arbitrarily. Instead, PD facilitators purposefully selected video clips that directed teachers to focus on some particular features of their instruction or student learning. The results suggested that teachers discussed more about student learning than lesson delivery at the third phase of the program compared to their discussions at the first phase. In particular, teachers shifted their discussions of student learning from whether students' solutions were correct to understanding the student thinking underlying the solutions. This type of discussions encouraged teachers to develop specific strategies to prompt student mathematical thinking and learning.

Therefore a goal of the CCC-M design team was to think thoughtfully how our choice and use of technology tools could support productive teacher learning. These technology tools should also provide supportive affordances to other learning principles in the CCC-M theoretical framework.

To sum up, recent trend in PD programs emphasizes linking teachers' learning to their actual practice, including those programs that involve technology elements. Guided by program facilitators, teachers in innovative PD programs promote their learning and teaching in an active, collaborative way. A main purpose of this study was to investigate how the design team assimilated these latest theoretical ideas to the design of the CCC-M professional learning environment.

Method

Because design-based research explores learning in authentic settings, it cannot strictly manipulate those contexts to control variables. The foci of design-based research are to lay open the completed design and implementation of learning environment, and develop a profile to characterize the perspectives of learning environment that affect the dependent variables of interests (Barab & Squire, 2004; Collins, 1999). This relies on techniques such as collecting a large range of data sources, systematic analysis of data with pre-defined measures, and a thick description to the process of design and implementation (The Design-Based Research Collective, 2003). Therefore, the method of descriptive case study (Yin, 2009) was employed in this study to document the detailed process of the first design-implementation-revision cycle of the CCC-M project.

Context of the Case

As mentioned earlier in the introduction, the setting of this case is a school-university partnership development project, Creating, Collaborating and Computing in Math (CCC-M). This project aims at improving teachers' disciplinary understanding and digital literacy in the mathematics classroom by collaborating elementary teachers and secondary teachers. The duration of the first research cycle was approximately 8 months, from August, 2013 to March, 2014.

Participants and the CCC-M Design Team

Thirteen mathematics teachers from an English school board in the Montreal area enrolled in the CCC-M project. Seven participants were grade 6 math teachers. The rest were teachers who taught secondary cycle[1] one math. All teachers were recruited by the consultants from the school board, representing 7 elementary schools and 4 secondary schools within the school board. Their teaching experience ranged from 2 to 19 years.

The CCC-M design team that developed and monitored this PD project consisted of a research team from McGill University and four educational experts from the school board. The research team comprised one university professor, one research associate, and one graduate student. The school experts contained one associate director of pedagogical service, one technology consultant, and two mathematics teaching consultants. The design team had periodic leadership meetings during the school year to plan and debrief the process of the CCC-M project. The design team were also responsible for scaffolding teacher learning. Another

[1] In Québec, elementary education comprises six years of schooling and divided into three 2-year cycles (sixth grade falls into Cycle 3). Elementary education aims at promoting general development of the child, and preparing students for secondary school. It focuses on the basic subjects, such as literacy (French or English) and mathematics. Similarly, secondary education lasts five years and consists of two cycles. The first cycle includes first three years and is equivalent to grades 7 to 9. This cycle focuses on consolidating students' learning in elementary school and helping students to think about their career options (Education in Québec, 2013).

responsibility of the design team was to provide physical supports (e.g., arranging release time for teachers to participate in PD activities, offering learning and teaching resources to teachers).

Data Collection and Analysis

The study drew from various sources of data from the CCC-M project database, consisting of five types of data: a) documents including the CCC-M proposal, the agendas of leadership meetings and PD face-to-face meetings, and a periodic report that summarized previous PD activities; b) the field notes of PD face-to-face meetings and leadership meetings; c) artifacts from face-to-face meetings; d) a transcript of the leadership meeting (debriefing meeting); and e) the log files of teachers' online posts (e.g., textual posts, video posts, and website links). After the data were collected, participants' names were replaced by pseudonyms for analysis. Other private information was also replaced by a unique code system before data analysis to ensure the confidentiality of information.

The primary methodology used in data analysis was thematic analysis, because it allows researchers to use a theory-driven approach to analyze a wide variety of information in a systematic manner (Boyatzis, 1998). The data analysis took place in four stages. First, themes and codes were generated by the research team from the theoretical framework. After that I started to analyze raw data using pre-determined themes and codes. The initial analysis was brought back to the research team for discussion afterward in order to scrutinize and refine the codes in the CCC-M data context. This was followed by using the revised codes to complete the data analysis.

Corresponding to the design-implementation-revision phases of a prototyping cycle, three major themes were generated. They also corresponded to the three leading research questions of this study. The first theme was defined as the Design Phase. From the above data sources (i.e., the CCC-M proposal, the agendas and the field notes of leadership meetings), a portrait was created to depict the process of designing the CCC-M learning environment. The second theme of Implementation Phase focused on evaluating teacher learning during the implementation. The revised codes of TPACK were used to analyze teacher learning[2]. Depending on what was the focus of teacher learning, segments from the field notes, the artifacts from PD face-to-face meetings and the log files of teachers' online posts were categorized as T (technology), C (content), or P (pedagogy). For instance, when a segment was about the technical problem of using a digital tool, it was categorized as T (technology). Some segments contained more than one perspective. For example, when a segment was about how a technology tool was used to improve student engagement, it included both T (technology) and P (pedagogy). These segments were coded as PC (joint discourse of pedagogy and content), TP (joint discourse of technology and pedagogy), TC (joint discourse of technology and content), or TPC (joint discourse of technology, pedagogy and content). The analysis at this phase was to look at what types of knowledge were discussed and the nature of teacher discourse. The third theme of Revision Phase described how the design team revised the CCC-M learning environment based on the evaluation of teacher learning. In particular, the analysis focused on the revision of activity design for the second research cycle with the aim of refining or reinforcing the pre-defined three objectives.

---

[2] The original codes of TPACK were developed by Koehler, Mishra and Yahya (2007).

Results: The Process from PLC Design to Refinement

Design Phase

The design phase started in late August, 2013 (see Table 1). From the CCC-M proposal, the design team determined an overall goal of fostering a technology-rich PLC to support teacher learning and teaching in the early cycles of the project. This goal was crucial in creating a culture of PLC that set the foundation for future PD activities. The next step was developing detailed objectives and elaborating the learning principles embedded in these objectives (see Table 2). Specifically, three objectives were developed.

- Developing a collective understanding of the situation: the idea behind this was the need for a shared vision among teachers. In order to identify the collective goals of learning within the community, teachers needed to be aware of their communal challenges and get to know others' situation of practice. Thus the design team planned a set of ongoing dialogues for teachers to develop and strengthen a collective understanding of the situation. It was expected that this joint understanding could foster the collective commitment of teacher ongoing development within the community.
- Sharing, inquiry, and reflection: the underlying principle of this objective was the importance of reflective inquiry to improve teacher practice. The CCC-M learning activities were organized to promote teacher learning through sharing, inquiry and reflection. In particular, the design team attempted to draw teachers' attention to

student learning so that teachers could think about how to provide instruction based on individual needs.

- Developing the use of digital tools for teachers and students: this objective responded to the technology aspect of the project. Guided by the notion of TPACK, the design team tried to select optimal digital tools to support effective teacher learning. Moreover, the design team identified several potential digital tools that teachers could use in their classroom for student learning. The activity structure of introducing these tools to teachers took the approach of *learning technology by design*. That is, the introduction of digital tools was embedded in the activities that required teachers to design the use of digital tools for their practice.

Based on these three objectives, the design team developed a series of concrete PD activities for the first research cycle. There were two types of PD activities during the first cycle: activities at face-to-face meetings and online discussions on Edmodo (See Table 1 & Table 2). In Table 1, a timetable is presented to describe the sequence of PD activities proposed with teachers.

Table 1

The Timetable of Leadership Meetings and PD Activities Proposed with Teachers

Time	Leadership meetings	PD activities proposed with teachers			
August, 2013	Planning meeting: designing concrete PD activities from the proposal				
September, 2013		First face-to-face meeting	AM	• Introducing community members • Introduction to the CCC-M project • Sharing successful strategies in the classroom	
			PM	• Introducing flipped classrooms • Teachers design video lessons and anticipation guided for flipped classrooms	
December, 2013		Second face-to face-meeting		• Discussion of technology-related practice	Online discussion on Edmodo
January, 2014		Third face-to-face meeting	AM	• Discussing Challenging concepts for students	
			PM	• Presentation of the use of digital tools • Creating mini-lessons using introduced digital tools	
March, 2014	Debriefing meeting: reflecting on the first research cycle, and discussing revision needed for the next research cycle				

Table 2 shows the underlying learning principles of each concrete PD activity and corresponding anticipated learning processes.

Table 2

The Design Process from Proposal to Activities

Overall goal	**Objectives**	**Embedded learning principles**	**Concrete activities**	**Anticipated learning processes**
Foster a technology-rich PLC	Developing a collective understanding of the situation	Shared vision and responsibility	A presentation that elicited the shared problems and introduced the CCC-M project. Activities at face-to-face meetings • Sharing successful strategies in the classroom (1st meeting) • Discussion of technology-related practice (2nd meeting) • Challenging concepts for students (3rd meeting)	Teachers had a collective understanding of situation and developed shared goals that they need to work toward (i.e., supporting student success in the elementary-secondary transition and developing effective technology use in the classroom.)
	Sharing, inquiry and reflection	Sharing practice and reflective inquiry	Activities at face-to-face meetings: • Sharing successful strategies in the classroom (1st meeting) • Discussion of technology-related practice (2nd meeting) • Challenging concepts for students (3rd meeting) Edmodo discussion	Teachers opened their practice to dialogue and engaged in the activities of sharing, inquiry, and reflection.

(continued)

Overall goal	**Objectives**	**Embedded learning principles**	**Concrete activities**	**Anticipated learning processes**
Foster a technology-rich PLC	Developing the use of digital tools for teachers and students	The notion of TPACK and the approach of *learning technology by design*	Activities at face-to-face meetings • Designing video lessons and anticipation guides for the flipped classroom (1st meeting) • Creating mini-lessons using digital tools (3rd meeting) EdModo discussion	First, teachers used digital tools for their own learning. Second, teachers explored the use of digital tools and integrated these digital tools in their classrooms for student learning.
	Supportive conditions[3] ① human capacity: the CCC-M learning environment involved internal supports from the school experts and external supports from the research team. ② physical supports: the CCC-M project arranged release time for teachers to participate in PD activities; offers learning resources to teachers; and provided teaching materials and devices that teachers required in the classroom.			

Activities at the face-to-face meetings. The face-to-face meetings were viewed as a crucial component of PLC to develop a collegial relationship among teachers. Moreover, the design team use these meetings to introduce new ideas and help teachers to know what learning looked like in the CCC-M learning environment. Three face-to-face meetings were planned and a set of activities were included. The logic of activity arrangement was started with a general discussion of teaching practice to conversations on specific topics.

[3] Support conditions were not identified as the objective for teacher learning, but it was viewed as a key learning principle that supported the effectiveness of the CCC-M learning environment.

The first face-to-face meeting was planned in the early Fall semester. After a brief introduction of the CCC-M community members (i.e., the design team and participating teachers), the design team presented the school board data on gaps in mathematics learning between elementary and secondary schools[4]. These data were used to elicit the communal problems that the CCC-M project wanted to address. Then the CCC-M project was introduced to give teachers a general idea of the project. The next activity in the morning was a sharing activity that asked teachers to share their successful strategies in the classroom. The reason for planning this activity was to use non-threatening conversation to encourage teachers to open their practice.

In the afternoon, the design team introduced the instructional method of the flipped classroom (Bergmann & Sams, 2012). The basic idea of the flipped classroom is that teachers move their in-class lectures ahead of the class, typically by preparing some short video lessons for students to watch before the class. By doing so, teachers could spend more time during the class to engage students in problem solving activities. In addition it gives more opportunities for teachers to interact with students and provide instruction when needed. The idea of introducing the flipped classroom method in the project was to encourage teachers to offer more instruction based on student learning rather than lecturing. The afternoon activities began with having teachers watch a short video clip and fill out an “anticipation guide” (see Appendix A for details). The anticipation guide was used to assess learners’ perception of the

[4] The end of year evaluations from the school board suggested that there was a big learning gap in mathematics between late elementary and early secondary schools in the past few years. This problem was also reported by many secondary teachers.

video topic before and after video watching. It also directed learners' attention to those important sections of the video. This was followed by a presentation of introducing the flipped classroom and an activity that allowed teachers to explore the idea of the flipped classroom in their practice. The design team grouped teachers into pairs (one elementary teacher and one secondary teacher), and then asked teachers to create an instructional video of a math concept and a corresponding anticipation guide. An iPad app called Educreations was recommended to teachers to design the video [5]. After teachers completed their videos and anticipation guides, they were asked to share their artifacts with teachers in another group. The teachers in that groups acted as students to watch the video, filled out the anticipation guide, and gave feedback.

The second face-to-face meeting was planned at the end of the Fall semester after teachers had time to apply some ideas they had learned from the first face-to-face meeting. The principal goal of this meeting was to guide teachers in the activity of sharing, inquiry and reflection. The design team asked teachers to review their technology-related experiences and then shared with their colleagues. The topic of experience sharing could be any interesting resource, strategy used, observation of their class, challenge, and suggestion of improvement. The following SHARE protocol was presented to guide the reviewing and sharing processes: a) selecting a relevant activity to be shared; b) highlighting the key aspects the experience; c) asking clarifying questions to others; d) reflecting on the experience; and e) evaluating the

[5] Educreations is an iPad app that enables its users to create video tutorials. The app turns the iPad screen into a recordable whiteboard that allows users to draw on the board and add text, photos, and animated images. Users could also record their voice while editing the board.

lessons learned. After 30 minutes of preparation, teachers were asked to discuss their thoughts. In the meantime, the design team facilitated their discussions.

The third face-to-face meeting took place in the early Winter semester. This meeting moved teachers to the activities that combined the elements of pedagogy, technology, and specific contents. In the morning, the design team engaged teachers to share those contents that students struggled with. The technology consultant from the design team then demonstrated the use of some math tools on the interactive white board (IWB)[6]. After that, she required teachers to work in groups (three or four teachers from the same level), using the IWB math tools to create a mini lesson for one of the struggling concepts. One or two of the teachers in each group were responsible for carrying out their mini lesson in the afternoon. The rest of teachers asked questions and gave feedbacks after the lesson was taught.

Online discussions on Edmodo. Teachers were too busy to meet face-to-face frequently. Consequently, the design team planned to use Edmodo as a platform to create asynchronous learning opportunities for teachers between face-to-face meetings. Edmodo was chosen because it is a specialized educational online social network that enables its users to create online learning groups. The second advantage of this platform was its security of confidential information within learning groups. Teachers could use Edmodo to post information (e.g., sharing their experience in the classroom, uploading the attachments of learning and teaching materials, posting links to educational websites) and commenting on others' posts. Besides,

[6] The IWB math tools were introduced because more and more classrooms in the school board had equipped with IWBs and some of the participating teachers had already used IWBs in their classroom.

Edmodo allows teachers to create an online learning platform for their students. Teachers could use it as a teaching tool to post teaching materials, assignments, and learning calendar. They could also answer students' questions and provide instruction for students who need supports.

At the end of the first face-to-face meeting, Edmodo was introduced to teachers. They were asked to post on Edmodo weekly between face-to-face meetings. The posts could be reviewing the experience in the classroom, sharing learning and teaching materials, and responding to others' posts. The design team also joined in the CCC-M online learning group to provide supports for teacher learning.

Implementation Phase

Online discussions on Edmodo. Teachers' posts fell into five categories: P, T, PC, TP, and TPC (see Figure 3). The posts related to technology dominated the online discussions of teachers, especially the posts about teachers' attempts to use technology in their classroom (categorized as TP and TPC).

After the first face-to-face meeting, the majority of teachers expressed their willingness to incorporate the ideas learned (e.g., the flipped classroom, Educreations, and Edmodo) in their classroom. For instance, Catherine said on Edmodo "my goal is to have my first Educreations lesson (the flipped classroom lesson) set up for the start of our next unit in two weeks, and I am excited to see the results!" Many of them briefly shared their experiences later on. John posted the Educreations videos he created and stated "I have been busy flipping my classroom and it has gotten to the point where the kids are demanding the videos." A few of teachers further discussed some problems that emerged from their classroom when implementing these ideas. Dave, for example, described his observation when using Edmodo with students:

> *I have set up each group (class) with an Edmodo.com page. My grade 8 (students) love it. They use it as a community where they can help each other and get clarifications for classes other than my own because they followed each other for most subjects. Oppositely, my grade 9 (students) never check, and if they do they won't admit it in class. I see a big difference in how the tool is perceived between groups.*

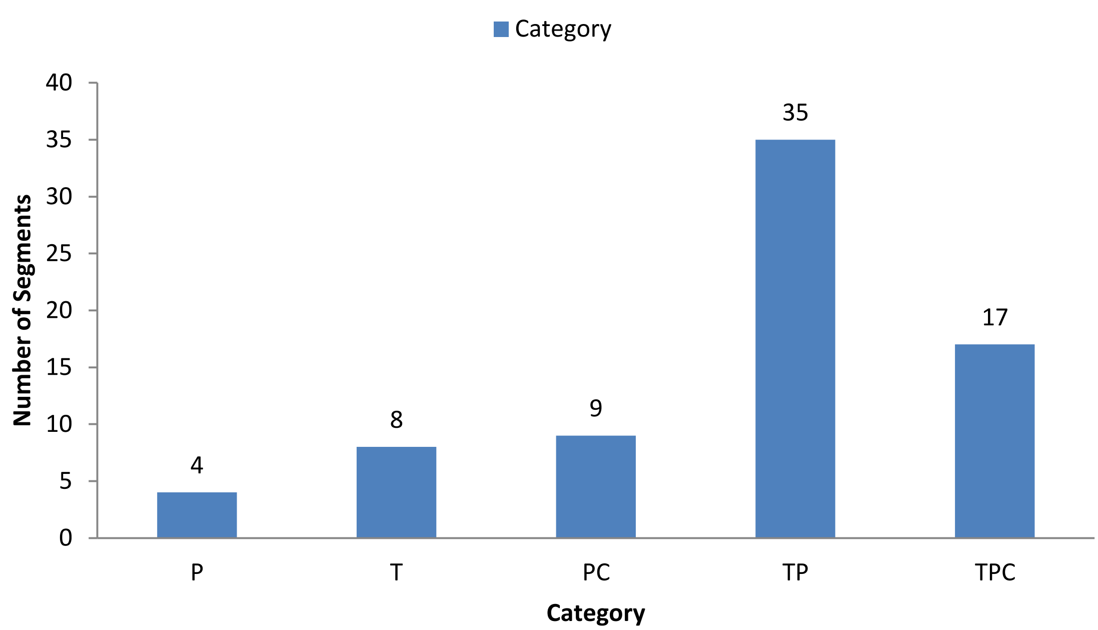

Figure 3. Distribution of teacher online discussion. Segments related to technology accounted for 82.20% of the total discussion segments.

Teachers also shared their use of other digital tools in the classroom, such as having students to solve multiple choice questions on the SMART Board, incorporating digital math games in problem-solving activities, and using PowerPoint to model students' homework.

In support of other teachers' learning, some teachers shared the pre-class videos and the anticipation guides they had designed. Besides, they posted information of digital tools that they thought useful in the classroom. For example, Kate said "(I) found a free App called YourTeacher. (It) has videos covering different topics in math, and by grade level. (It) gives good examples on how to explain a topic through video and visuals." Particularly, one of the teachers, Louise, shared her teaching website which contained different instructional materials she used. Many of these tools and ideas were adopted by other teachers in the community.

The discussion segments categorized as TPC were very similar to those in TP. These segments also included teachers' flipped classroom experiences, the integration of other digital tools, and sharing novel digital tools with other colleagues. The major difference was that teachers were able to include specific mathematics contents when discussing their practice in the classroom. However, several teachers gave more details on why they chose to use specific digital tools and how they use those tools for the contents, which revealed their perception of TPACK. One example came from Marie who explained her choice of a digital tool to support student learning:

> *(I) just wanted to share a neat iPad app with virtual base ten blocks that I used to review decomposing numbers (into ones, tens, hundreds). I found my students had difficulty coming up with different ways to break down a number and this seemed to help. The*

interface is extremely user-friendly. The students figure it out in about 2 minutes! The app is called Number Pieces and is free on the app store.

Another teacher, Serena, extended the use of Educreations video to evaluate student learning. She asked her students to create videos explaining the math concepts they had learned as teachers did[7]. She posted “4 groups (of students) made tutorials on Educreations. They each had to talk and explain the properties of their specific quadrilateral. Of course some have mistakes, but it allows me to evaluate where they're! Great evaluation tool! ”

The segments assigned to Category T pertained to the questions of using technology tools. A few of teachers wanted to have additional training activities to learn the operation techniques of some specific digital tools. Some Teachers shared the technical problems they had when using digital tools in the classroom and asked supports from the CCC-M technology consultant as well as other teachers.

A number of the posts were not related to technology, but about pedagogical strategies (categorized as P) and how teachers use different teaching strategies for specific contents (categorized as PC). For instance, Louise described how she used “warm up” activities to gauge students’ understanding after being prompted by the CCC-M consultants.

After teaching a lesson, I usually have one or two short questions that I ask the class about that concept. They write their responses on cue cards and the goal is to show me they understood the lesson. It’s a great way for me to verify if they grasped the concept

[7] This method was actually created by another teacher in the community, but she did not explain her experience of using this method in details.

or not. So they can either answer by writing an explanation in words, use examples, draw diagrams. Examples of what I used so far: what does an exponent tell us to do? ... What are the different strategies to solve a problem?

Apart from that, teachers shared the challenging concepts that students felt difficult in respond to the assignment posted on Edmodo[8] (categorized as PC).

In general, the focus of online discussion on Edmodo during the first research cycle was technology. Many of the teachers were able to learn new ideas from others and apply other's ideas in their own classrooms. Nevertheless, there were several problems emerged from the online discussions of teachers. First, most posts from teachers were quite brief, especially when sharing their experience in the classroom. The general pattern of experience sharing was: "what I have done in the classroom" plus "whether students liked it or not". There was limited discourse to reason why such teaching strategies or digital tools were used and how these strategies or digital tools help student learning. Second, there was a discrepancy between teachers' use of Edmodo. Some teachers were more active on Edmodo, while a few teachers barely posted (see Figure 4). Third, the teacher interaction in terms of promoting thinking and learning was limited. Most interactions between teachers remained at the social level, such as appreciating others' information like "thanks" and complimenting others' work like "great job". Only two of the teachers asked clarifying questions to other teachers. For example, Sally asked Louise some questions when Louise shared her first attempt of the flipped classroom. "That

[8] Before the third face-to-face meeting, one of the design team members posted a question on Edmodo asking teachers to post those concepts that students considered as challenging.

sounds great ☺ Can I ask which video you asked students to view? Also, did you have to model the process for them? I would love to try this one day but I'm quite scared. Any suggestions would be helpful." Moreover, when the consultants tried to prompt teachers to elaborate their practice, not all of them replied

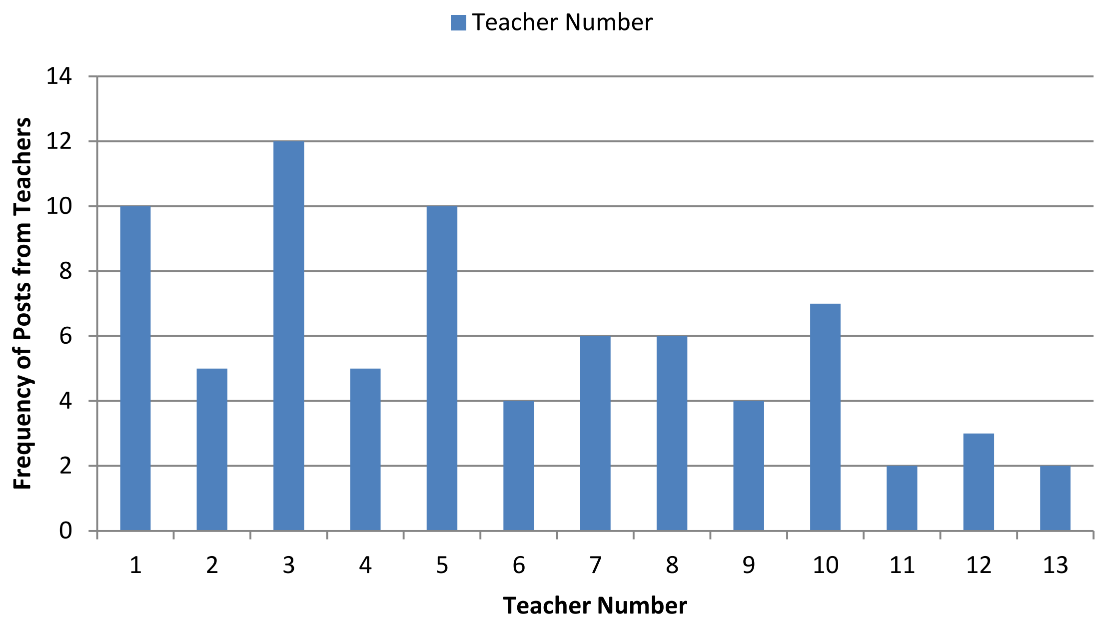

Figure 4. Frequency of posts by each teacher.

Teacher learning during face-to-face meetings. Compared to teachers' posts on Edmodo, the segments of teacher discussion at the face-to-face meetings were more clustered around specific categories, because the face-to-face meeting activities were more structured and focused. During the morning activity at the first face-to-face meeting, most discussions were around pedagogy (categorized as P). Teachers shared the strategies they thought useful in their classroom. These strategies comprised a) the ways they delivered mathematics contents,

b) different formative assessments they used, c) the strategies of motivating and supporting student learning, and d) how they organized their classroom and managed student conduct. In addition, some of the teachers talked about their use of technology in practice (categorized as TP). They mentioned that some latest technology tools (e.g., IWB, iPad, computer math games) got students more engaged and motivated students to learn. They also found technology helpful to support student learning and classroom organization. For example, one of the teachers said that she noticed part of her students did not acquire some basic math facts. So she called these students out in turns from classroom activities, and asked them to practice their basic math facts using a math game called Math Reflex on classroom computers.

The conversation at the second face-to-face meeting had a lot of overlap with the discussion on Edmodo, centered on teachers' experience of incorporating technology in classroom (categorized as TP). But in comparison to the online discussion, teachers were able to give the detailed descriptions of what they had done in the classroom, ask more questions to others, and reflect on their practice. This was because they were required to ask clarifying questions and share their reflection on practice.

Many teachers shared their experience of using Edmodo with students. They thought it was a useful platform to communicate with students. Most of them used it to post teaching materials (e.g. notes, worksheets, assignments, quizzes and pre-class videos) and answer student questions. Some of them also assigned individualized homework to each student according to student learning. Furthermore, some of teachers reported that students had created their own communities to support their own learning as well as others. Rosy, however, reflected that it was necessary to have conversations with students about the purpose of using Edmodo. Teachers needed to clarify what and how to post with students in the beginning. Otherwise students might turn it into another Facebook for entertainment rather than learning.

The flipped classroom experiences or using pre-class videos was another hot topic during the conversation. From technical aspect, Rosy gave some tips of how she made pre-class videos. She said that it was better to have a clear plan of video organization before making a video. She always practiced a few times before formal recording to ensure the fluency of her videos. In terms of implementing the flipped classroom in practice, some of the teachers discussed their combination of the flipped classroom with math centers activities[9]. Tara further mentioned that her class time was more effective if students had watched pre-class videos. Sally also noticed that students' questions became more relevant to mathematics contents after they had watched pre-class videos with anticipation guides. Those teachers who did not flipped their classroom or in their early stage of flipping classroom asked these experienced teachers about how to help the students who could not access to pre-class videos at home. One of the experienced teachers suggested it was better to post pre-class videos several days in advance so that students with difficult access could watch the videos in school computer labs. Another teacher complemented that she posted her videos on multiple digital platforms such as YouTube, Edmodo, and classroom computers. Hence her students could have different choices depending on their situations. Some teachers also gave some negative feedbacks of

[9] Math centers (group work) and math stations (individual work) refer to those activities in the classroom that allow students to practice and apply mathematics knowledge they have learned, including hands-on activities, problem solving activities, and math games.

their flipped classroom experiences. For instance, Sally reflected that some students did not concentrate on classroom instruction and activities because they were waiting for videos to teach them. Marie noticed one of her classes did not like the idea of watching pre-class videos. Her students expected she explain mathematics concepts face-to-face, so she did not flip this class anymore.

Close to the end of the meeting, the design team concluded and reminded teachers that technology should be used with clear purposes. The ideas and tools introduced by the design team were not a compulsory requirement, but potential methods or tools to support student learning. Teachers could adapt these ideas or did not use them in accordance with their situations.

At the third face-to-face meeting, teachers had an extensive discussion of the concepts that student struggled with (categorized as PC). They found that many mathematics concepts were the same in the curricula of late elementary and early secondary levels. And they were very surprised to realize that their students had similar difficulties (see Appendix B for details). There were two types of problems. First, students' perceptions of mathematics concepts were discrete without formulating an interconnected network of mathematics knowledge. Students had difficulty understanding the connection between related concepts. For instance, the most common difficulties in arithmetic were the idea of place value (e.g. 10,100 is 101 hundreds) and the relationship among fraction, decimal and percentage. Students also found it hard to transfer their mathematics understanding from one concept to another. An example was that some students could not calculate the surface area and the volume of any shape other than cubes and rectangular prisms. Second, students had difficulty applying their knowledge to problem solving, especially to solve situational problems. Many students did not know how to break down a problem, identify concepts needed to solve the problem, and link different concepts together to solve the problem.

In the afternoon, teachers were invited to think about how to bring pedagogy, content and technology together to plan a mini lesson for the concepts that students struggled with (categorized as TPC). Even though the notion of TPACK was not explicitly explained to teachers, they chose different tools according to the concepts they would like to teach. For example, one group of teachers did not use the IWB math tools as required, but chose to use IWB differently in order to help students to understand number relationships. They believed students could better understand number relationships when solving real life problems. Therefore, they downloaded a grocery flyer from a store website and presented on the IWB. After that, they created an activity asking students to explore how much money they could save if they wanted to buy a specific product on the flyer (e.g., if a box of ice cream saved 45% percent from the original price, how much money one could save, and conversely if a box of ice cream saved 2 dollars from the original price, what percent did one save).

Revision Phase

Not long after the third face-to-face meeting, the design team had a debriefing meeting. The research team presented some initial data of the evaluation of teacher learning. The whole design team then reflected on the accomplishments and the problems of the first research cycle, and discuss any revision needed for the next research cycle.

The design team agreed that the learning process of teachers basically progressed as expected. The CCC-M group was functioning very well. First, teachers had gradually developed a collective understanding of the situation. They realized that there were similarities and differences in learning and teaching between elementary and secondary levels. More importantly, they recognized the importance of communication and collaboration in order to support students' mathematics learning in the elementary-secondary transition. After the mini-lesson activity at the third face-to-face meeting, one of the elementary teachers told the technology consultant[10]:

> *She said "you know this time you (the design team) had this like, you know, elementary and high school (teachers in each groups were from the same level). I like having the mix of the elementary and high school better"… (Because) she was sitting next to the high school teacher from her school, and he says "here, let me show you this (how I teach this concept in high school). You are showing them (students) this, and this is how I show them." And she says "I need to see that", she wanted us to go back to doing more of that type of (mix activities).*

Without a chance to learn together, elementary and secondary teachers did not necessarily see the similarities and the differences of mathematics learning and teaching between these two levels. They might not be sufficiently prepared to develop a deep understanding of students' learning gap between elementary and secondary schools. The previous activities in the project allowed teachers to appreciate the value of collaboration

[10] This quote was a recall from the technology consultant at the debriefing meeting.

between teachers from both levels. They started to request more collaborative learning opportunities to investigate the situation of learning and teaching at the other level. Therefore, the updated design of activities would provide more opportunities for teachers to communicate with others, especially focusing on those common mathematics contents that student struggled with. Also, the design team planned to start some schools visits for teachers to explore the situation of mathematics learning and teaching in a real classroom at the other level (i.e., an elementary teachers would visit a secondary teacher's classroom, and vice versa). By doing so, the design team hoped to strengthen teachers' shared belief that their collaboration could contribute to their practice of improving student mathematics learning in the elementary-secondary transition.

Second, participating teachers were able to take an active stance to embrace new ideas from their colleagues and the design team. They showed a good attitude to share their practice and support others' learning. This suggested that they had built trust in others as well as the design team. However, teachers' conversations were mainly about describing experience and sharing information (especially the online discussions). There was still a lack of in-depth dialogue of reflective inquiry. One of the reasons was that teachers were too busy to have such learning opportunities. The packed schedule of teachers did not allow time for reflection and inquiry. The teachers were reacting to constant demands, and would have benefited from seeing a process model for systematic reflective inquiry. They often lacked opportunities to see how to dig into their teaching as well as student learning. One of the mathematics consultant reflected that she was only able to have a few chances to engage teachers in systematic reflection activities. A participating teachers told her, "I wish I would have time to do this, I didn't realize the importance of doing this, and I wouldn't have seen it had I know how going through the processes." Consequently, the activities in the next cycle turned out to be a great opportunity to provide teachers with both time and guidance for reflective inquiry. The initial plan was to develop a theoretical model of reflection to guide the reflective learning activities for teachers. The first activity of reflective inquiry could have teachers reflect on the student learning difficulties that they had identified previously.

The design team also thought that teachers might have some reflective thoughts in every day practice, such as "this activity does not work out well" or "students do not perform well in the exam". But not all of them had a habit to record it and thus the reflections vanish easily. So the design team attempted to foster teachers' habit of recording their immediate reflective thoughts. The design team would suggest teachers to use whatever convenient technology tools they prefer (e.g., video recorders or memos on their Smartphone or iPad) to record their problems and ideas about practice. These problems and ideas could become the topics of future reflective activities.

Third, teachers had developed the use of different digital tools in their classroom for students. Teachers showed a great enthusiasm to try out new technology tools and share the use of digital tools with their colleagues. Some of teachers had already revealed their perception of TPACK during online discussion. These teachers deliberately used different technology tools according to student learning needs. Moreover, activities during the face-to-face meetings gave teachers a sense that their adoption of digital tools needed to consider how these tools met their instruction, curriculum, and local situation. The aim in the next cycle was to explicate the notion of TPACK to teachers. Additionally, the design team would reinforce teachers' notion of TPACK through ongoing reflection of their use of digital tools, which in fact resonated with the focus of reflective inquiry.

By contrast, teachers did not take full advantage of technology use for their own learning. The online discussion on Edmodo was less productive compared to those at the face-to-face meetings. This situation required the design team to identify a way to foster teacher learning on Edmodo. The design team still needed to scaffold teacher online learning in a more productive way. The primary idea was to ask teachers their opinions on effective Edmodo use. Then the design team could plan more effective learning activity on Edmodo.

Summary

In summary, the whole process from the design phase to the revision phase generated the first research cycle (see Figure 5). The cycle started from designing a professional learning environment based on the predetermined learning theories. This was followed by implementing the learning environment and evaluating teacher learning. The cycle ended with refining the design of the learning environment for the next cycle according to the evaluation of teacher learning.

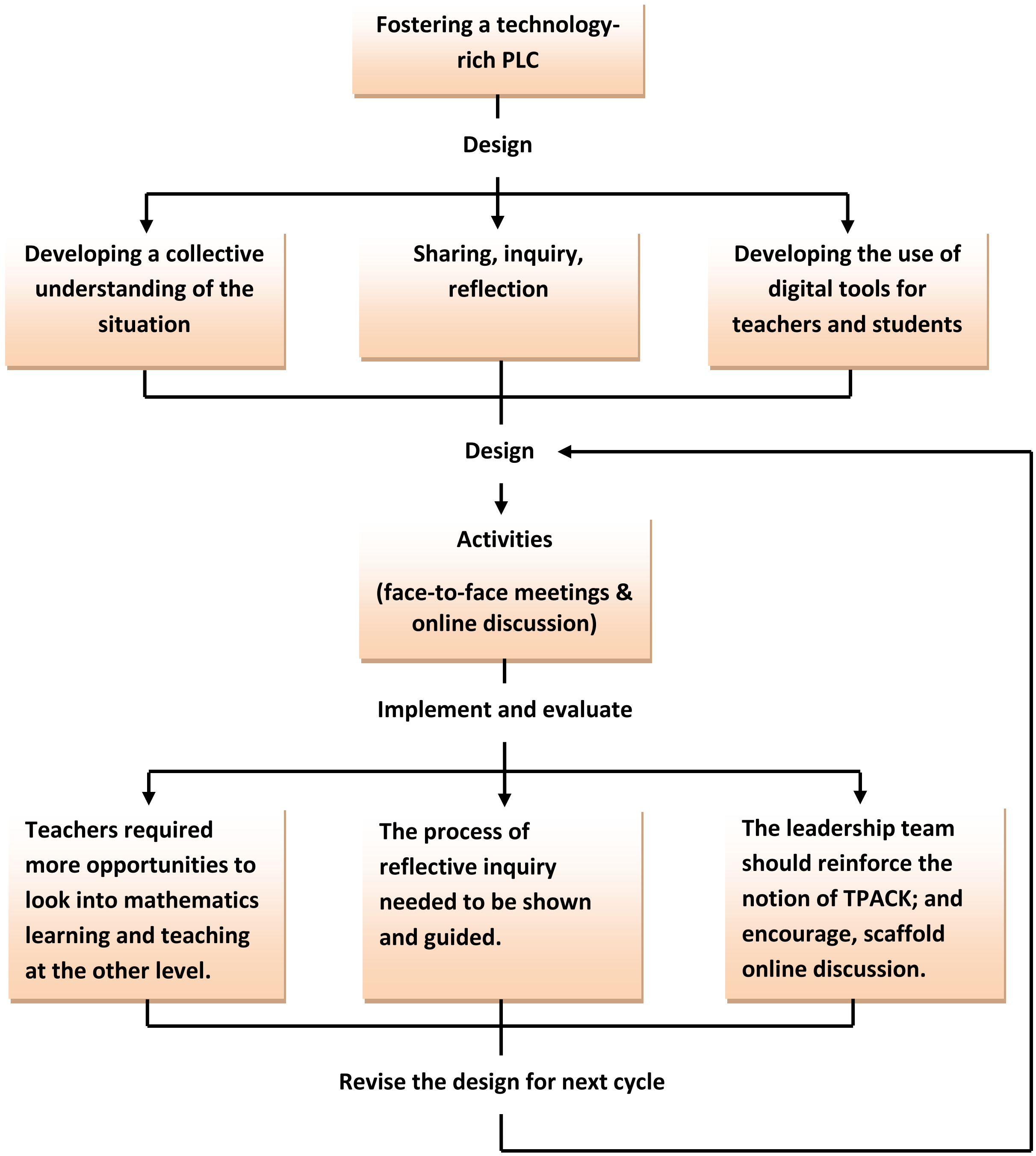

Figure 5. Process of the first research cycle.

Discussion

Lesson Learned from the First Design-based Research Cycle

Developing effective PD programs for in-service teachers is not an easy task. To design a complex PD program like the CCC-M project, program developers need to construct a rigorous plan to achieve its multiple goals and ensure that every element in the design will not clash with others. Design-based research emphasizes grounding the design of learning environments in a solid theoretical basis (Brown & Campione, 1996; Cobb et al., 2003; The Design-Based Research Collective, 2003). Therefore, the challenge of the CCC-M project was to develop a thorough and coherent theoretical model to structure the CCC-M professional learning environment. For this reason, the research team did an extensive review of literature and sought proper learning theories for the project. Following that, the design team orchestrated these learning theories into a comprehensive framework to assure that every element of the design had a theoretical basis and fitted together.

Moreover, PD program developers need to consider the applicability of learning environment in real learning setting. An important lesson learned from the first research cycle is the power of partnership between university researchers and school experts in the design of learning environment. The product of the CCC-M professional learning environment was a collective work from the research team and school experts. In specific, the research team brought their expertise of developing a theory-based learning environment, and school experts brought their knowledge of students, teachers, and relevant digital tools. Actually, the CCC-M project was derived from these experts' concerns of the students' mathematics learning gap and the effective use of technology in the classroom. And since they had rich experience in working with teachers (some of them were still teaching), they provided many useful suggestions in activity design. For example, it was their idea to start teachers' conversation of practice by sharing teachers' successful strategies in the classroom. The pre-established trust between these experts and participating teachers also benefited the trust building of teachers toward their colleagues and the research team. Therefore, a key of success in the project was the involvement of both university researchers and school experts. The research team was able to learn the strategies of working with in-service teachers from school experts. School experts were accessed to the latest ideas in theory from the research team to support teacher learning. A good example was their adoption of the notion of TPACK and the method of *learning technology by design* in activity design. The detailed procedure of the mini-lesson activity was designed by school experts. Furthermore, the partnership between the research team and school experts formulated a strong group of facilitators to promote teacher learning.

Another challenge emerged from the first research cycle was the limitation of formative assessment for teacher learning. As discussed before, formative assessment is an important tool to provide empirical evidences to the quality of prototype learning environment. The initial analytical tool chosen to evaluate the process of teacher learning was the framework of TPACK. This was because the framework of TPACK could be used to evaluate the contents of teacher learning (what types of knowledge were focused by teachers) and the substance of teacher discourse (in what ways such types of knowledge were discussed: sharing, inquiry, or reflection). However, this framework was turned out not sensitive to capture the progression of teachers' collective understanding of the situation. In other words, the assessment of social recognition was not included by the initial analytical tool. It was not until the leadership debriefing meeting did the design team realized that teachers had built a shared vision of practice. A suggestion for the next research cycle was to refine the evaluation system in order to assess the social perspective of teacher learning.

The Role of PLC in the CCC-M Project

For many years, researchers have suggested the importance of teacher communication and collaboration in teacher continued learning and practice (Hord, 2004; Lieberman & Wood, 2000; Little, 1982). Particularly, the improvement of student learning in the elementary-secondary transition is unachievable without the collective effort from elementary and secondary teachers. Nevertheless, the isolation between elementary and secondary teachers is still a big issue. Teachers do not have enough chances to communicate to their colleagues at the other level. One of the secondary teachers from an elementary-secondary school told the research team after the first research cycle, “I really want to develop a closer relationship with the elementary people in our building.” Even though elementary teachers and secondary teachers worked in the same building at his school, the experience in the CCC-M project was his first opportunity to talk to elementary teachers. The CCC-M project created a PLC to provide elementary and secondary teachers with a collective learning opportunity to explore their shared problem. Again, the norm of teachers’ collegiality within this PLC was not to blame the other side’s responsibility for the problem, but to enhance their teaching practice of supporting students’ learning transition from elementary to secondary schools. If teachers were to develop a deep understanding of the problem, elementary teachers could better prepare students for secondary schools and secondary teachers could advance their knowledge of supporting students' adaptation to secondary math learning. Obviously the participating teachers have recognized the norm and the value of collaborative learning. They asked for more opportunities to communicate with their colleagues in the CCC-M community and even other teachers from outside. An implication for future research is to scale up this project into school-wide initiatives to open the dialogue between more elementary and secondary teachers.

The culture of PLC not only fostered a shared vision among teachers to encourage continued development, but also provided a supportive affordance to improve teachers' effective use of technology in the classroom. The notion of TPACK emphasizes the convergence of technology, pedagogy, and content by situating teachers' exploration of technology tools in their practice (Angeli & Valanides, 2009; Mishra and Koehler, 2006). This idea is consistent with the tenet of PLC that the growth of practice is best achieved by situated learning in the context of practice (Leithwood, Jantzi, & Steinbach, 1998). The integration of technology learning in teachers' practice, especially in addressing their shared problem, enabled teachers to see how technology tools can be used productively to improve their practice.

Concluding Remarks

This descriptive case study presented a design-based research cycle during a technology-rich PLC was designed and validated to support ongoing teacher development. The baseline data reported by the study will be used to examine how the conversations, teaching practice, and inquiry activities evolve in the next iterations of the PLC. The results suggested that teachers built a shared vision of collaborative learning. They shared their experience of practice and supported others' learning in the community. Moreover, they explored the effective use of digital tools for student learning in the classroom. To sustain the effectiveness of the CCC-M PLC in the following research cycles, it is necessary to keep in mind that the design of PLC learning environment is not perfect in the first place, but requires ongoing, systematic validation along with the evolvement of teacher learning.

References

Angeli, C., & Valanides, N. (2009). Epistemological and methodological issues for the conceptualization, development, and assessment of ICT–TPCK: Advances in technological pedagogical content knowledge (TPCK). *Computers & Education*, *52*(1), 154-168.

Bannan, B (2013). The integrative learning design framework: An illustrated example from the domain of instructional teachnology. In Plomp, T. & Nieveen, N. (Eds.), *An introduction to educational design research* (pp. 114-133). Enschede: Netherlands Institute for Curriculum Development (SLO).

Barab, S., & Squire, K. (2004). Design-based research: Putting a stake in the ground. *Journal of the Learning Sciences*, 13(1), 1-14.

Bergmann, J., & Sams, A. (2012). *Flip your classroom: Reach every student in every class every day.* International Society for Technology in Education (ISTE).

Bolam, R., McMahon, A., Stoll, L., Thomas, S., Wallace, M., Greenwood, A., . . . Smith, M. (2005). *Creating and sustaining effective professional learning communities*. Research Report 637. London: DfES and University of Bristol.

Borko, H. (2004). Professional development and teacher learning: Mapping the terrain. *Educational researcher*, *33*(8), 3-15.

Borko, H., Jacobs, J., Eiteljorg, E., & Pittman, M. E. (2008). Video as a tool for fostering productive discussions in mathematics professional development. *Teaching and Teacher Education*, *24*(2), 417-436.

Borko, H., Jacobs, J., & Koellner, K. (2010). Contemporary approaches to teacher professional development. *International encyclopedia of education*, *7*, 548-556.

Boyatzis, R. E. (1998). *Transforming qualitative information: Thematic analysis and code development*. Thousand Oaks, CA: Sage Publications.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). *How people learn: brain, mind, experience ,and school*. Washington, DC: National Academy Press.

Brophy, J. (Ed.) (2003). *Advances in research on teaching: Vol. 10. Using video in teacher education.* Oxford, UK: Elsevier.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational researcher*, *18*(1), 32-42.

Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. *The journal of the learning sciences*, *2*(2), 141-178.

Brown, A. L., & Campione, J. C. (1999). *Psychological theory and the design of innovative learning environments: On procedures, principles, and systems*. In Schauble, L., & Glaser, R. (Eds.), *Innovations in learning: New environments for education*. Lawrence Erlbaum Associates.

Cobb, P. (2000). Conducting teaching experiments in collaboration with teachers. In Kelly, A. E., & Lesh, R. A. (Eds.), *Handbook of research design in mathematics and science education* (pp.307-334). Lawrence Erlbaum Associates.

Cobb, P., Confrey, J., diSessa, A., Lehrer, R., & Schauble, L. (2003). Design experiments in educational research. *Educational researcher*, *32*(1), 9-13.

Cochran-Smith, M., & Lytle, S. L. (1999). Relationships of knowledge and practice: Teacher learning in communities. *Review of research in education*, 249-305.

Cohen, D. K. (1990). A revolution in one classroom: The case of Mrs. Oublier. *Educational evaluation and policy analysis*, *12*(3), 311-329.

Collins, A. (1992). Toward a design science of education. In E. Scanlon & T. O'Shea (Eds.), *New directions in educational technology* (pp. 15-22). New York, NY: Springer Verlag.

Collins, A. (1999) The changing infrastructure of education research. In E. Lagemann & L. Shulman (Eds.), *Issues in education research* (pp. 289-298). San Francisco, SF: Jossey-Bass.

Collins, A., Joseph, D., & Bielaczyc, K. (2004). Design research: Theoretical and methodological issues. *The Journal of the learning sciences*, *13*(1), 15-42.

Darling-Hammond, L., & Bransford, J. (2005). *Preparing teachers for a changing world: What teachers should learn and be able to do.* San Francisco, SF: Jossey-Bass.

Doerr, H. M. (2006). Examining the tasks of teaching when using students' mathematical thinking. *Educational Studies in Mathematics*, *62*(1), 3-24.

Education in Québec. (2013). Retrieved from http://www.gouv.qc.ca/portail/quebec/pgs/commun/portrait/education/?lang=en

Ertmer, P. A. (2005). Teacher pedagogical beliefs: The final frontier in our quest for technology integration?. *Educational technology research and development*, *53*(4), 25-39.

Goldman, S. R. (2001). Professional development in a digital age: Issues and challenges for standards-based reform. *Interactive Educational Media 2*, 19–46.

Gregoire, M. (1999). *Paradoxes and paradigms in an eighth grade pre-algebra class: A case study of a "good" math teacher.* Paper presented at the meeting of the American Educational Research Association, Montreal, Canada (ERIC Document Reproduction Service No. ED431600).

Guskey, T. R. (2000). *Evaluating Professional Development*. Thousand Oaks, CA: Corwin.

Hawley, W. D. and Valli, L. (2000). *Learner-centered professional development*. Phi Delta Kappa Center for Evaluation, Development, and Research. Research Bulletin Number 27.

Hord, S. M. (Ed.). (2004). *Learning together, leading together: Changing schools through professional learning communities*. New York, NK: Teachers College Press.

King, M.B. & Newmann, F.M. (2001). Building school capacity through professional development: Conceptual and empirical considerations. International *Journal of Educational Management 15*(2), 86–93.

Koehler, M. J., Mishra, P., & Yahya, K. (2007). Tracing the development of teacher knowledge in a design seminar: Integrating content, pedagogy and technology. *Computers & Education*, *49*(3), 740-762.

Koehler, M. J., & Mishra, P. (2014). *The TPACK image*. TPACK.ORG. Retrieved from http://www.tpack.org/

Leithwood, K., Jantzi, D. & Steinbach, R. (1998). Leadership and other conditions which foster organizational learning in schools. In K. Leithwood & K. S. Louis (eds), *Organizational learning in schools*. Lisse, the Netherlands: Swets & Zeitlinger.

Lieberman, A., & Pointer-Mace, D. (2009). Making practice public: Teacher learning in the 21st century. *Journal of Teacher Education*, *61*(1-2) 77–88.

Lieberman, A., & Wood, D. (2000). *Inside the National Writing Project: Connecting network learning and classroom teaching.* New York: Teachers College Press.

Little, J. W. (1982). Norms of collegiality and experimentation: Workplace conditions of school success. *American Educational Research Journal*, *19*(3), 325-340.

Louis, K.S., Kruse, S.D. & Associates. (1995). *Professionalism and community: Perspectives on reforming urban schools.* Thousand Oaks, CA: Corwin Press Inc.

McLaughlin, M.W. & Talbert, J.E. (2001). Professional communities and the work of high school teaching. Chicago: University of Chicago Press.

Mishra, P., & Koehler, M. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *The Teachers College Record*, *108*(6), 1017-1054.

Niess, M. L. (2005). Preparing teachers to teach science and mathematics with technology: Developing a technology pedagogical content knowledge. *Teaching and Teacher Education*, *21*(5), 509-523

Nieveen, N. & Folmer, E. (2013). Formative Evaluation in Educational Design Research. In Plomp, T. & Nieveen, N. (Eds.), *An introduction to educational design research* (pp. 152-169). Enschede: Netherlands Institute for Curriculum Development (SLO).

Newmann, F.M. & Wehlage, G.G. (1995). *Successful school restructuring: A report to the public and educators by the center on organization and restructuring of schools*. Madison, Wisconsin: CORS.

Plomp, T. (2013). Educational design research: An introduction. In Plomp, T. & Nieveen, N. (Eds.), *An introduction to educational design research* (pp. 10-51). Enschede: Netherlands Institute for Curriculum Development (SLO).

Putnam, R. T., & Borko, H. (1997). Teacher learning: Implications of new views of cognition. In Fraser, B., & Tobin, K. G. (Eds.), *International handbook of teachers and teaching* (pp. 1223-1296). Netherlands: Springer Verlag.

Putnam, R. T., & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher learning?. *Educational researcher*, *29*(1), 4-15.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard educational review*, *57*(1), 1-23.

Steffe, L. P., & Thompson, P. W. (2000). Teaching experiment methodology: Underlying principles and essential elements. In Kelly, A. E., & Lesh, R. A. (Eds.), *Handbook of research design in mathematics and science education* (pp. 267-306). Lawrence Erlbaum Associates.

Stein, M. K., Smith, M. S., & Silver, E. A. (1999). The development of professional developers: Learning to assist teachers in new settings in new ways. *Harvard educational review*, *69*(3), 237-270.

Stoll, L., Bolam, R., McMahon, A., Wallace, M., & Thomas, S. (2006). Professional learning communities: A review of the literature. *Journal of educational change*, *7*(4), 221-258.

Stoll, L., & Louis, K. S. (2007). Professional learning communities: Elaborating new approaches. In *Professional learning communities: Divergence, depth and dilemmas*, 1-13.

The Design-Based Research Collective. (2003). Design-based research: An emerging paradigm for educational inquiry. *Educational Researcher*, 5-8.

Van den Akker, J. (2013). Curricular development research as a specimen of educational design research. In Plomp, T. & Nieveen, N. (Eds.), *An introduction to educational design research* (pp. 52-71). Enschede: Netherlands Institute for Curriculum Development (SLO).

Yin, R. K. (2014). *Case study research: Design and methods*. Thousand Oaks, CA: Sage Publications.

Zhao, Y., Pugh, K., Sheldon, S., & Byers, J. (2002). Conditions for classroom technology innovations. *The Teachers College Record*, *104*(3), 482-515.

Appendices

Appendix A: Anticipation guide

Topic or learning goal: ____

Pre-viewing				*Post-Viewing*
Agree	*Disagree*	*Statement*	*Agree*	*Disagree*
		Insert statements here E.g. The exponent is the same as a power.		

What is the **Main Idea** of the video?

Re-state, in your own words, what you've learned:

Appendix B: Math concepts students struggle with

Math concepts students struggle with in elementary cycle 3 and secondary cycle 1

Arithmetic	Geometry/Measurement
• Place Value – understanding the relationship between place values (10 100 is also 101 thousands) • Relationship between decimals and whole numbers (decimal notation and money – understanding what to do with extra place values) • % - relationship between fractions/decimals/percentages • Decimal numbers – whole vs. part • Finding % of a number • Percentages, decimals, ratios • LCM, GCF • Changing improper and mixed fractions	• Manipulating geometry tools in transformational geometry – using compass and protractor, dexterity • Understanding difference between area and perimeter • Understanding of square units vs. linear units • Metric conversions (decimals, different units), unit conversions other than metric • Volume and surface area of any shape other than cubes or rectangular prisms • Angles – interior/exterior angles, complementary, supplementary, bisector • Triangle theorem – rules with variables/unknowns, when numbers are absent

Other

• Transfer of skills from one concept to another, seeing connections between concepts
    o remembering what area is once we start talking about volume
    o understanding when to round even though they are proficient at rounding
• linking different concepts together within one operation/word problem
• Applying concepts in situational problem contexts
• Identifying the concept to do in a word problem