Progress Report

Reimagining Technology-Enhanced STEM Teacher Education for 21st Century: From more technology to increased quality of teaching and learning

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If we teach today as we taught yesterday, then we rob our students of tomorrow.
John Dewey (1859-1952)

Introduction

Dewey's vision for education as a life-long process where students have many opportunities to experience the world around them and to apply acquired knowledge to their lives is as relevant today as it was a century ago (Dewey, 1938). At the same time, the world as Dewey (and most of us) knew it doesn't exist anymore: today we are experiencing enormous socio-political changes, trends of globalization, massive worldwide population and economic shifts, and the boom of fast-emerging life-altering technologies. In the last half-a-century, the world of education has also changed dramatically. Many educators around the world have embraced novel educational tools and pedagogies, while enjoying unprecedented access to information (T. G. Ryan & Young, 2014; J. M. Spector, 2015). Concurrently, the trends of standardized testing and the influence of international educational assessments made the lives of educators even more challenging (OECD, 2016; J. M. Spector, 2015). These unparalleled developments have affected students, parents, teachers, teacher-educators, and educational administrators forcing them to re-think what knowledge, skills and attitudes students must acquire in order to function successfully in a modern society. These rapid societal changes have also altered how we view successful Science, Technology, Engineering and Mathematics (STEM) education for the 21st century (Let's Talk Science, 2012) and the role of technology in education (Kim, Choi, Han, & So, 2012; Kurt & Ciftci, 2012; B. J. Ryan, 2013; Wright & Wilson, 2011). This 21st century vision of the role of educational technologies and unlimited access to information is reflected in the new expectations of STEM teachers (Jones & Leagon, 2014; Luft & Hewson, 2014; van Driel, Berry, & Meirink,

2014) that prompted an avalanche of educational reforms both in the West and in China (Committee on a Conceptual Framework for New K-12 Science Education Standards, 2013; Cuban, 1990; Feder, 2010; Fu, 2010, 2015; Hake, 2007; Jones & Leagon, 2014; Quinn, 2011). For example, in Canada, many provinces, including British Columbia, are currently undergoing a complete curricular reform in the STEM-related areas (British Columbia Ministry of Education, 2015). These efforts are aimed at encouraging teachers to re-examine their teaching practices, re-consider their roles in the educational processes and re-evaluate the role of technology in supporting their students' learning.

While all these reforms have good intensions, these ever-changing expectations pose significant challenges to teachers who are too often they are immersed in novel learning environments they have never experienced as students (Avalos, 2011; Milner-Bolotin, 2016a, 2016b). These reforms also pose significant challenges to STEM teacher educators who are to prepare teachers for embracing this new and rapidly changing reality. At the same time, there is ample research showing that technology itself is insufficient for changing teachers' educational practice – at the core of any meaningful change lies the Technological Pedagogical Content Knowledge (TPACK) possessed by teachers and not the smorgasbord of novel technological tools (Cuban, 2001; Koehler & Mishra, 2015; Mishra & Koehler, 2007; Mishra, Koehler, & Henriksen, 2011). The acquisition of TPACK begins during the teacher education programs and continues during their entire career (J. Harris, Mishra, & Koehler, 2009; Mishra et al., 2011).

As we expect this trend to continue, it is important to consider how technology might alter STEM teaching practices and STEM teacher education in the 21st century. As part of the **Future School 2030** research project we will attempt to identify key elements of successful teacher professional learning practices that results in teacher professional growths and increased student learning. At the final stage of the project, we will suggest practical models for engaging pre-service and in-service STEM teachers in technology-enhanced professional development. However, first we should answer the following questions in the context of STEM teacher education:

1. Why should we use technology in STEM teacher education and how might we use it?
2. What new opportunities do emerging technologies offer to STEM teacher educators?
3. What are teachers' incentives for adopting novel educational technologies?
4. How do we support teachers in adopting new educational technologies?
5. How do we ensure novel technologies inspire new student-centered pedagogies and increase meaningful student STEM engagement?

In order to answer these questions we have to decide on adopting a theoretical framework that will allow us to describe the development of teacher knowledge. This will be done in the following section.

Literature Review and Theoretical Framework

Overview of Existing Theoretical Frameworks for Studying Teacher Knowledge

In the last four decades, researchers have proposed multiple conceptual frameworks for investigating the development of teacher knowledge (Abbitt, 2011; Ball, Thames, & Phelps, 2008; Blömeke & Delaney, 2012; Corrigan, Gunstone, & Dillon, 2011; J. B. Harris & Hofer, 2011; Hourigan & Donaghue, 2013; Koh & Divaharan, 2011; Manizade & Martinovic, 2016; Martinovic & Manizade, 2016; Milner-Bolotin, 2016a). This research project will adopt a novel multi-dimensional view of teacher knowledge that combines different dimensions of thinking about teacher knowledge and teacher professional development: TPACK, Teachers-ZPD and Deliberate Pedagogical Thinking with Technology. To understand this framework we should first describe each one of these dimensions and then combine them into an overarching theoretical framework for the current study.

TPACK (D1) The first dimension (D1) of the our theoretical framework is based on the original Pedagogical Content Knowledge (PCK) framework proposed by Shulman in the 1980s (Shulman, 1986a, 1986b) will serve the backbone of the current research project. Shulman emphasized that teachers should possess subject-specific content knowledge (CK), general pedagogical knowledge (PK), and pedagogical content knowledge (PCK), where PCK can be considered to be the overlap of the two. The PCK framework was later expanded to include the knowledge of educational technologies—technological knowledge (TK)—thus morphing into the Technological Pedagogical (and) Content Knowledge framework (TPACK) (Koehler & Mishra, 2015). TPACK framework separates the content specific knowledge (i.e., specific disciplinary knowledge, such as the knowledge mathematics, physics or chemistry) from the knowledge of how these subjects are taught in the K–12 context, and how technology can be used to enhance student learning (Figure 1).

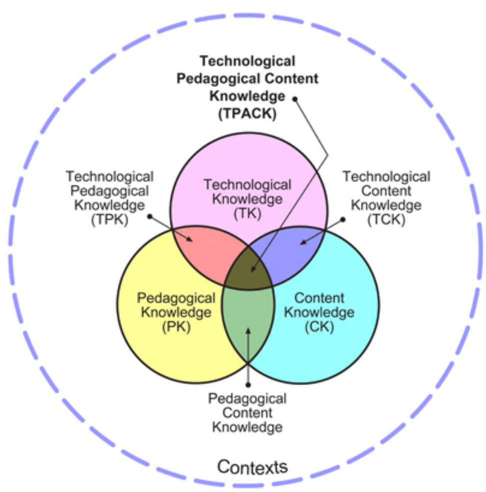

Figure 1: *Technological Pedagogical and Content Knowledge (TPACK) framework, from Koehler and Mishra's 2009 study.*

Teacher Zone of Proximal Development (T-ZPD) (D2) The second dimension of the current theoretical framework is grounded in the research by Blömeke and Delaney (2012) that examines the competencies of mathematics teachers. They referred to the TPACK aspect of teacher knowledge as cognitive abilities or professional knowledge, emphasizing not only what teachers already know, but their ability to acquire knew knowledge. We will extend their theoretical framework to describe additional STEM teacher competencies, such as affective characteristics and ability and openness for collaboration with peers (Figure 2) (Milner-Bolotin, 2017). Thus, we will use TPACK in a greater sense, focussing not only on the overlap of the three knowledge domains (CK, PK, and TK), but also on teachers' affective and cognitive characteristics, as well as teachers' ability to expand their current knowledge through individual study, practice and collaboration with peers.

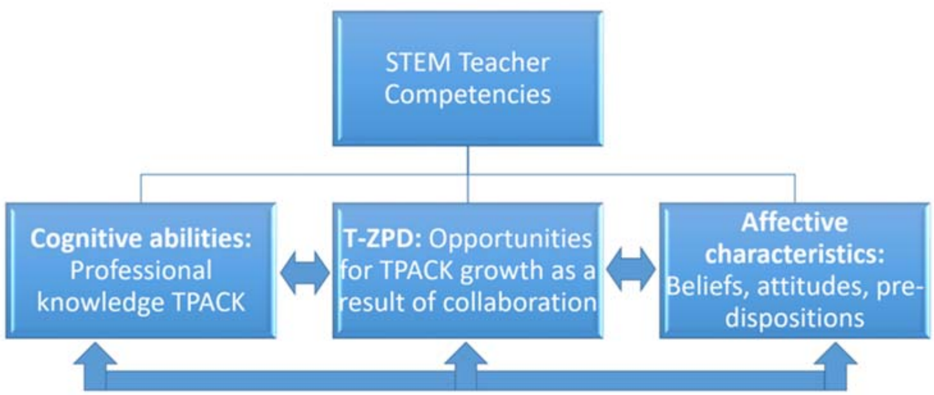

Figure 2: *A big picture of STEM teacher competences, as a combination of cognitive abilities, affective characteristics and potential opportunities for TPACK growth as a result of collaboration with peers (Teacher Zone of Proximal Development or T-ZPD). Arrows indicate the interactions between different facets of teachers' professional competencies.*

Thus, this research will build on the original framework by Blömeke and Delaney (2012) by emphasizing that teacher competencies, can be developed through collaboration with peers (Figure 2). Moreover, instead of looking at these competencies as static, we will consider their dynamic nature by asking: How can these competencies be developed if teachers are to collaborate with peers (more or less-experienced teachers)? By emphasizing the value of teacher collaboration we will focus on the potential growth of professional competencies of STEM teachers. This is especially relevant in the era of rapidly changing educational practices and expectations from teachers. This approach is an adaptation of the original Zone of Proximal Development concept suggested by Vygotsky early in the 2oth century, to the context of teaching and teacher-education (Vygotsky, 1978). We refer to it as the *Teacher Zone of Proximal Development* (T-ZPD). T-ZPD describes the gap between what a teacher has already mastered (the actual level of development, as expressed by their current TPACK) and what they can achieve when provided with opportunities to collaborate with peers and more experienced educators. T-ZPD represents the potential for the development of teachers' TPACK (Figure 3). The need to consider the dynamic nature of TPACK affected by teachers' interactions with peers, students, parents, administrators, and the society at large, reflects our belief in teaching as a highly professional endeavour. In order to keep up-to-date, teachers must always learn, update and question their knowledge, interact with others in the field, and continuously reflect on their practice. The view of ever-evolving mastery of teaching and the importance of a community in becoming and being an effective teacher is situated in Vygotsky's socio-cultural learning theory (Daniels, 2001; Vygotsky, 1978; Zuckerman, Chudinova, & Khavkin, 1998).

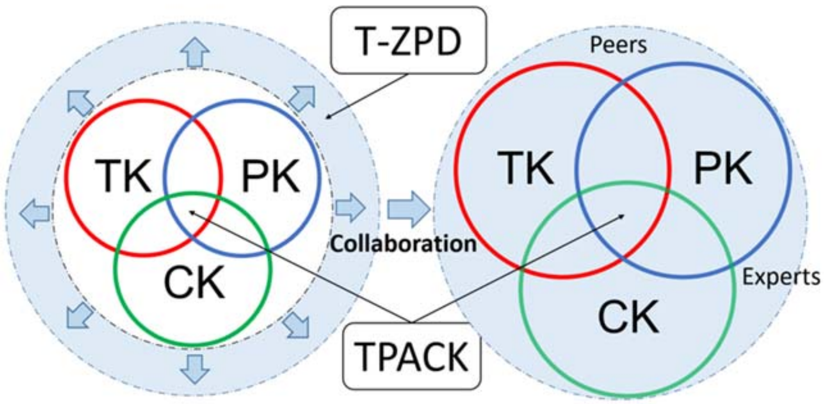

Figure 3: *Growth of teachers' TPACK due to collaboration with peers more experienced teachers. The light blue area in the left image shows the Teacher-Zone of Proximal Development (T-ZPD). As a result of collaboration all aspects of teachers' knowledge have grown, including their TPACK.*

It is difficult to acquire teaching skills while working in isolation (Clark et al., 1996; Linn & Burbules, 1993; B. S. Spector, Strong, & King, 1990). It is more effective to master these skills through apprenticeship and collaboration with peers. However, this collaboration should not be an isolated occurrence. This often happens when teachers attend one-time professional development events that are not followed up by a peer-collaboration focussed on the implementation of these pedagogies. These one-time professional development opportunities rarely bring sustained changes in teachers' practice (Luft & Hewson, 2014). There is ample research evidence that in order to support teachers in adopting research-informed STEM teaching practices, they have to have multiple opportunities to inquire about their own practice, adopt and adapt new pedagogies, collaborate with colleagues, and acquire the necessary TPACK (British Columbia Ministry of Education, 2015; Burridge & Carpenter, 2013; Krajcik & Mun, 2014; Schmidt et al., 2011).

Deliberate Pedagogical Thinking with Technology (D3) The last dimension in our theoretical framework is built on the concept of teachers using technology to achieve specific educational goals. This is a practical aspect of teachers' knowledge emphasizing not only they know, but how they can implement this knowledge deliberately in their own practice. Since we view technology as a tool utilized by teachers and students to support meaningful student engagement with STEM, the only way to evaluate the effectiveness of teacher professional development is to examine how teachers are able to transform their practice as a result (MacArthur, Jones, & Suits, 2011). The teachers who have acquired extensive TPACK but are unable to implement it into their teaching practice are not any more effective than teachers who have very limited TPACK but who use it effectively. Thus, the third dimension of Deliberate Pedagogical Thinking with Technology is the bridge between the educational theory, teachers' knowledge and the teaching practice.

3D Theoretical Framework for 21st Century Teacher Professional Development

Combining three theoretical dimensions for teacher knowledge described above, we build a novel theoretical framework for investigating teacher knowledge and guiding teacher professional development (Figure 4). This framework focusses on teachers' knowledge, their attitudes, ability to learn and to implement what they have learned into practice.

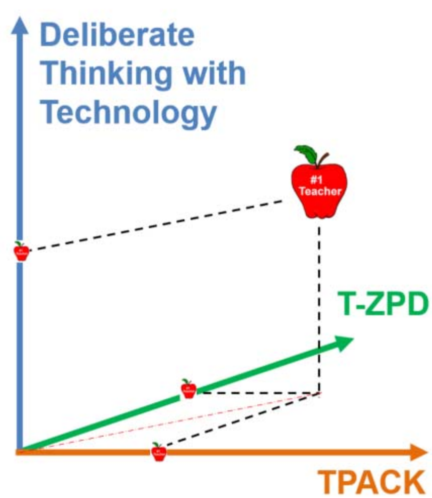

Figure 4: *3D theoretical framework for investigating teacher knowledge and for guiding teacher professional development: D1 stands for Technological and Pedagogical Content Knowledge (TPACK), D2 is Teacher Zone of Proximal Development and D3 represents teacher's ability to use emerging technologies to achieve specific pedagogical purposes. Thus teacher's knowledge is represented in 3D.*

In the following section we consider how this theoretical framework can be used to analyze a specific case of teacher professional development: a fully online programme offered by the University of British Columbia, called Master of Educational Technology (www.met.ubc.ca).

Case Study: Master of Educational Technology at UBC

Master of Educational Technology fully online graduate program is one of the most successful and innovative programs offered by UBC Faculty of Education (www.met.ubc.ca) (Figure 5). The program attracts K-12 and post-secondary educators, as well as instructional designers, professionals and business leaders from all over the world (currently, MET students come from 35 countries). Since its inception more than 20 years ago, hundreds of students have graduated in it. The program is relatively small and online courses are limited to 24 students. It is an internationally recognized graduate program, thus its graduates earn a Master's degree that is recognized by the educational institutions around the world, academia and industry.

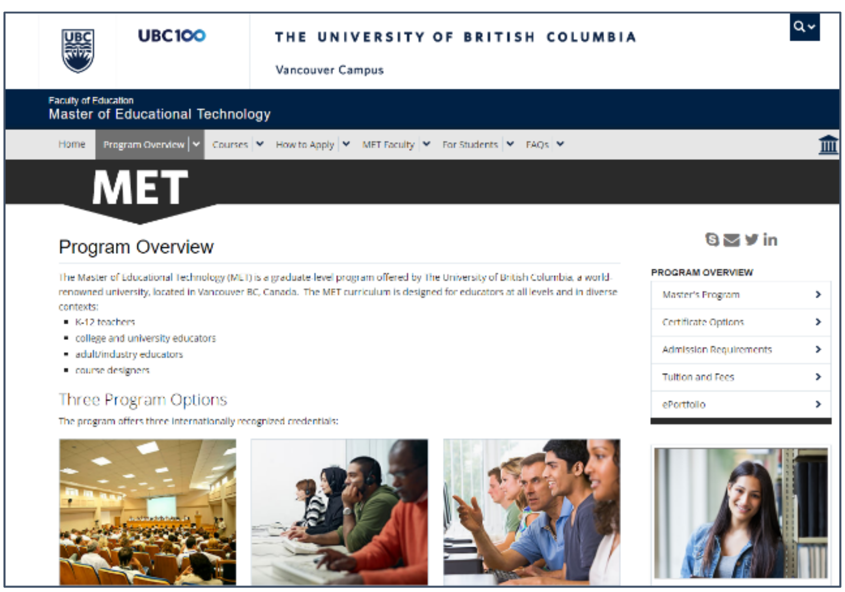

Figure 5: *The web site of the Master of Educational Technology program offered by the University of British Columbia (www.met.ubc.ca).*

The curriculum for the program is designed and delivered by UBC faculty members (professors and lecturers) and is supported by the certified instructional designers from the UBC Centre for Teaching Learning and Technology (http://ctlt.ubc.ca/). As any other graduate program, MET includes required and elective courses (Table 1). In order to complete it, a graduate student has to complete 10 graduate courses and create an online e-portfolio in the form of a blog (Shafrir, Etkind, & Treviranus, 2006). Online courses in the MET emphasize collaboration and reflection, while at the same time giving students opportunities to experience educational technologies as learners and reflect on them as teachers (Milner-Bolotin, 2015).

Considering the 3D Theoretical Framework described above, we can see how MET program is designed to address each and every dimension of the theoretical framework for examining teacher knowledge discussed above (Table 2).

Table 1: *List of required (core) and elective courses offered by the MET program in 2016.*

Required Courses	Elective Courses
ETEC 500: Research methodology in Education ETEC 510: Design of Technology-Supported Learning Environments ETEC 511: Foundations of Educational Technology ETEC 512: Applications of Learning Theories to Instruction	ETEC 520: Planning & Managing Learning Technologies in Higher Ed. ETEC 521: Indigeneity, Technology and Education ETEC 522: Ventures in Learning Technology ETEC 530: Constructivist Strategies for E-Learning ETEC 531: Curriculum Issues in Cultural and Media Studies ETEC 532: Technology in the Arts & Humanities Classroom ETEC 533: Technology in the Math & Science Classroom ETEC 540: Text Technologies: The Changing Spaces of Reading & Writing ETEC 565A: Special Course in Subject Matter Field: learning technologies – selection, design and application ETEC 565G: Special Course in Subject Matter Field: Culture and Communication in Virtual Learning Environments ETEC 565M: Special Topics – Mobile Education ETEC 580: Self-Directed Research Projects ETEC 590: Graduating Project

Table 2: *Examples of how all three dimensions of the 3D Theoretical Framework are being addressed by the MET program.*

	Examples of Relevant MET Pedagogical Practices	Evidence
D1: TPACK	Extensive literature review and analysis, group discussions, design of technology-oriented educational resources and educational activities relevant to participants' practice.	Participants not only learn about new technological tools and innovative pedagogical practices, but also put them in use in their own classrooms, as well as with their peers.
D2: T-ZPD	All courses encourage participants' collaboration, thus encouraging them to learn from and with each other, as well as from and with the instructor.	Most of the courses incorporate collaborative projects and ask participants to provide peer feedback. Thus technology-enhanced collaboration is modeled in the MET program.
D3: Deliberate Pedagogical Thinking with Technology	Every course involves a reflection component, as well as the final MET program graduating project has a reflection component. MET instructors model deliberate use of technology in their own courses, thus participants experience it as learners and as educators.	As part of the program, participants are continuously thinking of their own technology-enabled and enhanced learning and how it related to their own practice.

In the following section we will briefly discuss pros and cons of the MET program and consider how it can enhance professional development opportunities for 21st century educators and how it can be improved to support professional development of 21st century STEM teachers.

Discussion

Online Master of Educational Technology program at UBC (www.met.ubc.ca) offers valuable opportunities for STEM teacher professional development interested in exploring how educational technologies and novel technology-enhanced pedagogies can influence their own practice. Both, MET program's research focus and deliberate pedagogical design help educators who participate in the program to reconsider their pedagogical practices and build self-confidence with using novel technology-enhanced learning environments in their own classrooms (Jonassen & Land, 2012; Jonassen, Peck, & Wilson, 1999). This is especially relevant in the era of fast technological changes and educational policies encouraging teachers to incorporate technology in their teaching (British Columbia Ministry of Education, 2015)

Program flexibility in terms of the mode of delivery, choice of courses and projects coupled with ample opportunities for collaboration with educators from all around the world are unprecedented and highly valued by program participants and by the instructors. As one of the program graduates remarked: "*When a document begins in British Columbia, is refined in China, polished in Ontario, proofed in Japan, and submitted from New York, you know you've been part of a truly global learning experience.*" Program participants also appreciate the quality of their educational experiences, as program is adjusted and improved frequently in an attempts to incorporate educational innovations, address current educational trends and reform efforts.

However, as any other educational opportunity, MET program has its own challenges. The most notable challenge is the cost of the program and the lack of affordability for many educators, especially the ones teaching in disadvantaged areas. Unlike free MOOC courses that are becoming more common now, MET is rather expensive as it takes a very personal approach to each and every student. It would be very interesting to see if the modern technology can help creating an MOOC professional development course for teachers that can offer opportunities for teachers around the world to expand their pedagogical practices and learn from peers. So far, the MET model is a rather expensive professional development opportunity for teachers as compared to other short term program that do not grant a graduate degree.

Table 3 summarizes pros and cons of this program. This information is gleaned from the anonymous course evaluations and personal teaching experiences of the author (Milner-Bolotin, 2014).

Table 3: *Pros and cons of MET online graduate program as a professional development opportunity for 21st century teachers.*

	Pros	Cons
For instructors	Ample opportunities for international collaboration, learning about new technologies, curricula, teaching ideas Flexibility in course delivery (online) Ability to address current trends and issues and tailor the program to students New venue for educational action research, exploring novel pedagogies and educational approaches.	Very time consuming, labour intensive, requires strong skill in student engagement and online facilitation Requires a lot of personal contact with the students, mentorship and guidance Requires a lot of planning and structuring, as well as flexibility in program delivery Raises awareness than in online courses more is often less, thus makes the design of the program very challenging.
For students	An academic practice-related program offered by a leading university. Grants a graduate degree: opens door for career advancement, continuing education. Small groups, a lot of personal contact with the professor and other participants, learning flexibility. Many opportunities to learn from international participants about new technologies, curricula, teaching ideas. Allows for learning while working full time and raising a family.	Requires a lot of discipline, ability to learn, be open to collaboration and to accepting and providing feedback. Can be very overwhelming for people working full time and doing it in addition to their other responsibilities. Relatively expensive (compared to face-to-face graduate programs). Significant time commitment – requires a lot of discipline.

MET program is a valuable example of the research-based professional development opportunity for teachers in Canada and worldwide. However, it has significant drawbacks. This professional development opportunity is initiated by the students and is financed by them. This limits their appeal, as not everybody can afford it. It is also more expensive than other face-to-face graduate programs. However, since program participants often advance in their careers after graduation, this is a big enough of an incentive for many of them to participate.

Another significant challenge for the MET program is the lack of formal follow up with the participants after graduation. After the program is over, the participants are not likely to continue their collaboration or to keep in touch with their instructors. There is no consistent follow up for the program and very limited additional professional development opportunities are available to program participants. Therefore, one of the current challenges faced by the program is to create a program "post-graduate extension", such as professional development and collaboration among teachers that began during the program will continue throughout their careers. One possibility might be to create a framework where program graduates become leading teachers in their own school districts. This model is used in many countries, including the United States, Canada, a number of European countries (Darling-Hammond, Wei, Andree, Richardson, & Orphanos, 2009). For example, in Israel and some other countries the concept of leading or master teachers is very common. Leading teachers are teachers who have experienced additional professional development, mastered desired pedagogical skills and are tasked with leading their peers to change their practices. It is well established that teachers can be very successful at leading their peers through professional development and change as they know first-hand what this change meant for them and they have similar experiences as their colleagues (Bogler & Somech, 2004). This can be an untapped opportunity for the MET program – to create an international network of teacher-leaders who are ready to support their peers in successful technology implementation in their own practice.

An additional challenge for the MET is to conduct an ongoing formative and summative assessment of the program's effectiveness based on its impact on its graduates. Specifically, it is important to evaluate if and how program graduates are able to improve their professional knowledge, pedagogical strategies, and attitudes about using the results of educational research in their teaching.

Progress Report

The research project will consist of six interdependent stages and will open opportunities for future follow up studies. So far, we have accomplished the first three of these stages, as shown in Figure 6, which constitute about half of the project.

This is expected progress, as the projected started in the fall of 2016 and will continue into the summer of 2017. In the second half of the project, I will be collaborating more closely with my Chinese colleagues who are also interested in examining face-to-face and online teacher professional development and teacher education for 21st century schools.

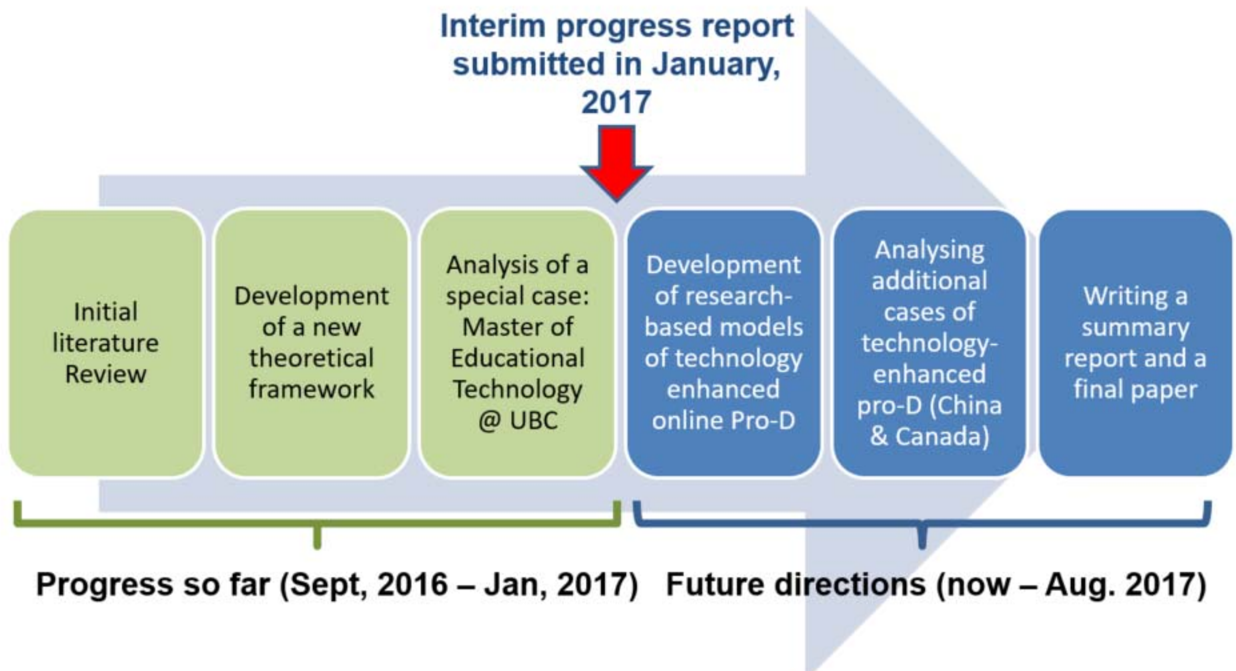

Figure 6: *Project progress report as of January, 2017.*

Conclusions and Future Directions

When applying for this grant, I indicated that I was interested in examining how internet can support life-long teacher professional development and how we can provide high quality STEM education for all students. In this research, I aimed to examine new internet-inspired opportunities to improve the quality of STEM teaching, teacher preparation, and teacher life-long professional development.

During the following months I will focus on proposing and examining a viable model (models) for online professional development programs that can support professional development of STEM teachers in both China and in Canada. The online professional development model is especially relevant to China and Canada, as both countries span over vast territories, thus having many teachers located in remote areas. These teachers are in dire need for professional development, yet they do not have access to the same opportunities as teachers located in large urban centers.

I am also planning to suggest a comparative research study that will allow us to compare existing professional development opportunities available to Chinese and Canadian teachers. This will be a focus of the following up research we will pursue in the future.

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