Title: When Deeper Conceptual Understanding is Just One Click Away: Using Technology-Enhanced Formative Assessment to Promote Physics Teacher-Candidates' Pedagogical Content Knowledge

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Abstract (197 words):

In 1986 Shulman coined a term Pedagogical Content Knowledge (PCK) to emphasize that effective teaching requires mastering both subject-matter and subject-specific pedagogies. Since then PCK became a leading theoretical framework in teacher education. Nowadays, educational technologies, such as electronic response systems (clickers) are becoming useful tools in helping teacher-candidates develop their PCK. Clickers allow implementation of continuous formative assessment by asking multiple-choice questions, polling students in real time, and adjusting lessons according to students' responses. The pedagogical effectiveness of clicker-enhanced pedagogy depends on teacher's ability to design, evaluate and implement multiple-choice questions that address student conceptual difficulties. This study investigates the effectiveness of a semester-long clicker-enhanced secondary physics methods course at a large North American university in helping teacher-candidates learn how to (a) design pedagogically effective multiple-choice physics questions, and (b) evaluate questions designed by others. To evaluate the pedagogical effectiveness of teacher-candidates' generated questions we designed a PCK rubric and applied it to the analysis of teacher-candidates-generated multiple-choice physics questions. The results of the analysis and our observations of teacher-candidates during the school practicum indicate that modeling technology-enhanced formative assessment in a physics methods course helped teacher-candidate enhance their PCK and their confidence in physics teaching.

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Introduction

In 1986 Lee Shulman coined a term Pedagogical Content Knowledge (PCK) (Shulman, 1986). PCK emphasizes that effective teaching requires teachers to master the subject-matter, as well as acquire relevant subject-specific pedagogies (Shulman, 1987). This is especially relevant to Science, Technology, Engineering and Mathematics (STEM) teacher education, which will be the focus of this paper. Shulman made it clear that general pedagogical knowledge, that was for decades the focus of North American teacher education programs, is insufficient for successful STEM teaching. Moreover, the lack of emphasis on teacher-candidates' and practicing teachers' content knowledge and the assumption that they will be able to acquire it seamlessly in the process of teaching, have proven to have detrimental effects on the quality of North American STEM education (Human Resources and Social Development Canada & Statistics Canada, 2006; Organization for Economic Cooperation and Development, 2009). While most North American STEM teachers have undergone a lengthier training, than their international counterparts (Ma, 1999; Schmidt et al., 2011), their content knowledge in their disciplinary area is often lacking (Fensham, Corrigan, Dillon, & Gunstone, 2011; Watson & Harel, 2013). This can be explained by the reduced focus on subject-specific methods courses in North American teacher education programs and the lack of high quality content-specific professional development opportunities for practicing teachers (Erickson, 2012). In North America, teacher education is often conducted as a post Baccalaureate Degree or a professional certification program. For example, in the province of British Columbia in Canada[1], in order to become a physics teacher, teacher-candidates must earn a B.Sc. in physics (or its equivalent) and complete a year-long teacher education program at an accredited institution. Due to the budgetary and other constraints, many teacher education programs assume that teacher-candidates have mastered the content knowledge necessary for teaching in the course of their B.Sc. degree. Thus, the programs focus on the general (content-free) pedagogical aspects of the teaching profession. Yet, ample education research in indicates that only a small percentage of American undergraduates achieve mastery of basic STEM concepts that extends beyond factual memorization and allows students to form a meaningful understanding of the natural world (Hake, 1998; Mazur, 2009, 2011). This gap between the teacher-candidates' subject content knowledge and the PCK knowledge they must acquire in order to become competent teachers is only going to grow. The preliminary physics content baseline test administered in the current study (Hestenes, Wells, & Swackhamer, 1992) had shown that physics teacher-candidates had not mastered the physics content corresponding to the secondary physics curriculum. For example, only 3 out of 11 (27%) teacher-candidates answered correctly a physics question dealing with the concept of inertia that did not require any calculations (Figure 1).

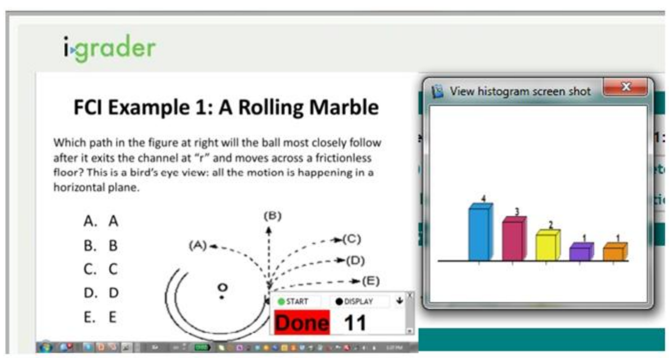

Figure 1: The distribution of teacher-candidates' responses to a secondary physics conceptual physics question.

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[1] In Canada, education is a provincial responsibility. Thus, every province has its own teacher education requirements. For example, in Ontario, Teacher Education Programs are one or two year long, while in British Columbia, the programs are all less than one year long.

As STEM education standards are shifting from fact-driven to process-driven standards (Committee on Conceptual Framework for the New K-12 Science Education Standards & National Research Council, 2013), STEM teachers will be required to have an extensive PCK. Helping them to acquire this knowledge should become the priority of contemporary teacher education programs. This paper investigates how modern technologies, such as electronic response systems (clickers) used in methods courses in STEM teacher education programs can help promote teacher-candidates' PCK and prepare them for teaching in the 21st century.

Theoretical Framework

In the last decades, PCK became a leading theoretical framework in teacher education. However, as technology use expands to K-12 schooling, PCK has evolved into Technological Pedagogical Content Knowledge (TPCK) framework that also incorporates technological knowledge (Mishra & Koehler, 2006, 2007) (Figure 2). TPCK framework emphasizes the role of technology as a pedagogical tool that teachers can use to promote student learning (Milner-Bolotin, Fisher, & MacDonald, 2013b). It is worth noting that teachers' ability to use technology in general and teachers' ability to use technology to promote student learning are not equivalent. As the current generation of STEM teacher-candidates are "digital natives" (Prensky, 2001), one might assume that they have an extensive knowledge of how to learn using technology and how to use these tools to promote STEM learning by their students. Unfortunately, research evidence suggests that this is rarely the case and all STEM teachers need extensive support to help them design and implement technology-enhanced learning environments that promote meaningful learning (Cha, 2013; Crippen & Archambault, 2012; Mikelsons, 2013).

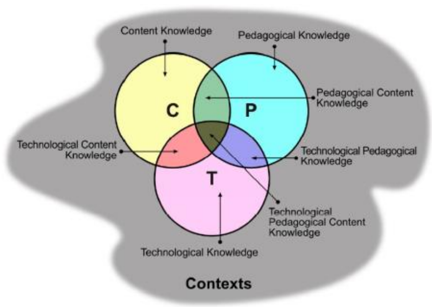

Figure 1: Technological Pedagogical Content Knowledge Framework by Koehler and Mishra (2007)

Another important aspect embedded into the TPCK theoretical framework and often overlooked by the researchers is its dynamic, as opposed to static, nature. Since TPCK framework emphasizes interactions between technological, pedagogical and content knowledge and all of them are continuously evolving, teachers' PCK must also be a dynamic construct. Different aspects of PCK will be highlighted under different conditions depending on the nature of the lesson, the students, teacher's pedagogical goals, etc. The nature of interactions between different kinds of teacher's knowledge will shift as well. For example, STEM teachers, who have acquired deep PCK, continuously collect feedback from their students and are capable of adjusting their lessons based on this feedback (Milner-Bolotin, 2004). This is where modern technology, such as clickers may be especially beneficial. Clickers allow teachers to administer continuous formative assessment by asking multiple-choice questions, polling students in real time, and adjusting their lessons accordingly. Clicker-enhanced pedagogy personalizes education, while stressing deep conceptual understanding and meaningful learning (MacArthur, Jones, & Suits, 2011; McIlroy, 2012).

Due to their prohibitive cost clickers have been mostly used in large university classrooms in the form of Peer Instruction pedagogy (Crouch & Mazur, 2001; Fagen, Crouch, & Mazur, 2002; Mazur, 1997b; Milner-Bolotin, Antimirova, & Petrov, 2010). Yet the low-tech version of clickers (flashcards) had been used in K-12 education for decades (Lasry, 2008; Lasry, Mazur, & Watkins, 2008). While flashcards preclude student anonymity and make data collection by the teacher more difficult, both pedagogies rely on effective conceptual questions that target specific student difficulties. Identification of these difficulties and the design of pedagogically effective questions that can help student overcome them have been the focus on STEM education research for decades (McDermott, 2001; McDermott & Redish, 1999). Lately, the Bring Your Own Device movement opened new opportunities for polling students – using their smart phones, tablet computers, etc. This will inevitably accelerate the proliferation of technology-enhanced formative assessment in K-12 schools.

As mentioned above, the pedagogical effectiveness of clicker-enhanced pedagogy depends not only on the technology, but by the teachers' ability to design, evaluate, and implement content-specific multiple-choice questions that promote student conceptual understanding. Novice STEM teachers usually struggle with designing effective materials, which is especially true of multiple-choice conceptual "clicker" questions. As a result, they revert to fact-driven rote memorization questions. This becomes a significant impediment for incorporating research-based technology-enhanced formative assessment into their classrooms.

Research Goals and Methodology

Current study aimed to bring the results of STEM education research into the teacher education practice (Wieman, 2012) through the use of modern technologies. The goal is to enhance teacher-candidates' PCK through their engagement with – Peer Instruction pedagogy (Fisher, MacDonald, & Milner-Bolotin, 2013; Mazur, 1997a; Milner-Bolotin et al., 2013b).

The study investigates the effectiveness of a one-semester long (3 months, 39 hours) secondary physics methods course in a teacher education program at a large North American university in helping teacher-candidates learn how to (a) design pedagogically effective multiple-choice questions suitable for high-tech (clickers) or low-tech (flashcards) mathematics and science teaching, and (b) evaluate questions designed by others. The study included 12 physics teacher-candidates enrolled in a one year-long teacher education program. Clicker-enhanced pedagogy was modeled in this course using conceptual questions from the Mathematics and Science Teaching and Learning through Technology Resource (Milner-Bolotin et al., 2013b). Teacher-candidates practiced asking and answering multiple-choice conceptual physics questions extensively during the course. Teacher-candidates also used these questions during their three-month-long school practicum. To evaluate the pedagogical effectiveness of the teacher-candidates-generated questions we devised a PCK rubric and applied it to the analysis of 72 multiple-choice questions designed by teacher-candidates in a culminating course assignment (Milner-Bolotin, Fisher, & MacDonald, 2013a). Teacher-candidates were also interviewed twice during the course of their teacher education and a number of them also participated in a focus group. The interviews and focus groups asked teacher-candidates to reflect on various aspects of their learning, including their attitudes about the use of clickers in the physics methods course, the impact of this pedagogy on their PCK, and on their practicum. One of the authors also observed teacher-candidates during their school practicum, specifically paying attending to how they used conceptual questions in their classrooms. Lastly, a graduate teaching assistant was present during most of the physics method course meetings, making continuous observations of teacher-candidates' participation in the discussions of conceptual clicker questions.

Analysis

The study employed a mixed method design and included both qualitative and quantitative analysis to be discussed below.

Quantitative Results

One of the course assignments asked teacher-candidates to author at least five multiple-choice physics questions relevant to the secondary curriculum. The questions had to include meaningful distractors (incorrect responses) and explanations of the reasons for choosing them. Therefore, every question had to include the question itself, a solution (explanation of the correct answer), and justifications of the distractors (Figure 3). Some of the teacher-candidates also clarified their pedagogical choices. In total, 72 multiple-choice questions have been submitted.

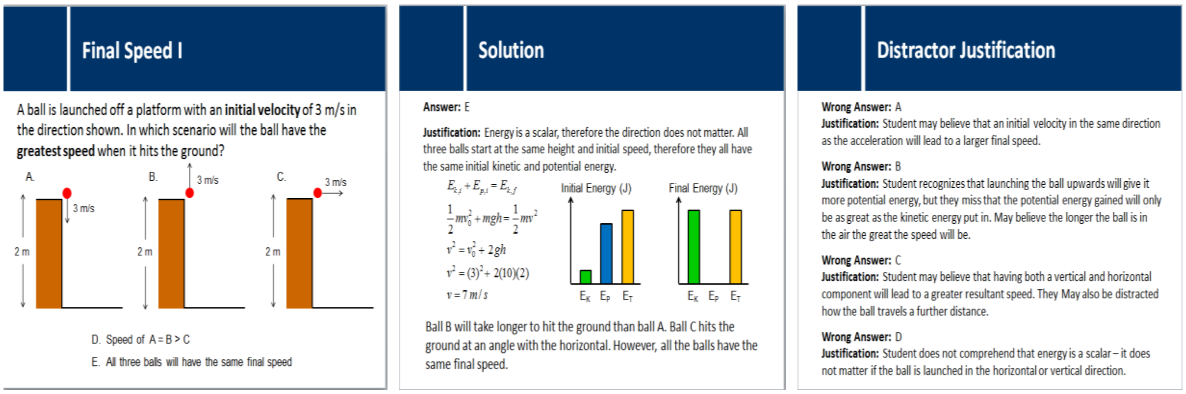

Figure 3: An example of a multiple-choice question, its solution and distractors' justification

As discussed earlier, the researchers independently rated each one of the questions using the PCK rubric designed for the study and discussed in detail in another paper (Milner-Bolotin et al., 2013a). The rubric focused on the content knowledge required to answer the question and on its pedagogical value. For each rubric, 1 indicated the minimum and 5 indicated the maximum value. The results of the analysis (Table 1) indicate that teacher-candidate were able to devise or adapt from known sources scientifically accurate conceptual physics questions that probed students' conceptual difficulties and had meaningful distractors. Moreover, many questions had shown potential for inquiry which is especially important in a physics teaching context.

	Content knowledge				**Pedagogical knowledge**				
	Cognitive level	Targets student difficulties	Science accuracy	Distractors' quality	Answer justification	Question clarity	Multiple representations	Potential for inquiry	Originality (1-5)
Average	3.04	4.38	4.59	4.06	4.58	4.58	2.47	3.27	1.8

Table 1: Summary of results of the analysis of teacher-candidates' multiple-choice questions

Qualitative Results

The qualitative data included teacher-candidates' reflections and feedback, as well as their responses to conceptual multiple-choice questions used in the physics methods course itself (Figure 1). Since clicker-enhanced pedagogy was modeled consistently, it was important to observe how teacher-candidates engaged with these questions and if they found them valuable.

Figure 1 shows teacher-candidates' responses to a conceptual question from a well-known introductory physics instrument (Hestenes et al., 1992). While the correct answer to the question is B, only 3 out of 11 teacher-candidates (27%) who participated in the poll chose it. This question demonstrates that teacher-candidates themselves, despite having earned at least a B.Sc., or its equivalent, in physics face significant difficulties in conceptual understanding of basic topics encountered in physics curriculum at a secondary level. These difficulties would not have been revealed if teacher-candidates were not asked to vote (anonymously) on this question and then voting results were displayed to the group in the form of response histogram. As soon as teacher-candidates saw the answer distribution, they felt compelled to discuss the question and justify their answers. They were also able to appreciate the difficulties their future students might encounter while exploring Newton's laws of motion and specifically the concept of inertia.

Teacher-candidates' feedback also indicated how their engagement with this pedagogy had affected their PCK. One teacher-candidate indicated that "clicker questions are a great way to test student understanding of a topic and distractors can test misconceptions", while another mentioned "the importance of using conceptual questions in assessment of/for/as learning". A third teacher-candidate specifically indicated: "I've learnt the benefits of "clicker" conceptual type questions and how to implement them into the class". While not all teacher-candidates mentioned clicker-enhanced pedagogy in their feedback, most of them mentioned the value of formative assessment and conceptual questions in science teaching emphasizing that "physics concepts can continually be reinforced and reimagined".

Discussion

We have collected overwhelming evidence in favor of using clicker-enhanced formative assessment in STEM methods courses in order to facilitate the development of teacher-candidates' PCK. We have demonstrated that most of the clicker-questions used in the meetings produced meaningful discussions and deep conceptual learning. Every question we modeled in the methods course was based on the STEM education research that identified student difficulties and suggested pedagogical approaches to address them. Teacher-candidates' own difficulties answering these questions (Figure 1) prompted them to articulate and revisit their own ways of thinking, often promoting them to devise new pedagogies applicable to their future teaching.

The quality of in-class discussions, teacher-candidates' feedback, and of their own conceptual questions (Table 1) speak to the pedagogical effectiveness of clicker-enhanced pedagogy in science methods courses. As the course progressed, teacher-candidates became much more focused not only on answering the conceptual questions correctly, but also on analyzing science concepts targeted by the question and discussing the choice of the distractors. Designing powerful multiple-choice science questions is a very difficult task (Beatty et al., 2008; Beatty, Gerace, Leonard, & Dufrense, 2006; Haladyna, Downing, & Rodriguez, 2002) as it requires teachers to possess deep PCK of the subject. Novice teachers think of multiple-choice questions as belonging solely to the low levels of Bloom's taxonomy (knowledge and comprehension), while expert teachers are able to design higher level multiple-choice questions at the levels of applications, analysis (Bloom, 1956; Lord & Baviskar, 2007). Most of the questions designed by the teacher-candidates belonged to the application and analysis levels of Bloom's taxonomy (Table 1). More than 90% of them were part of a sequence, thus opening a door to inquiry. About 87% of the questions used more than one representation (words, diagrams, graphs, algebraic expressions) in the question and in the solution. Approximately 86% of the questions were rated high or very high on the scientific accuracy of the question and the solution. In addition, from the students' pedagogical notes to their questions, it was obvious that most of the questions (more than 95%) targeted very specific science concepts and attempted to address potential student conceptual difficulties. Not surprisingly none of the questions were entirely original, yet most of them were new to teacher-candidates. Many of the questions included significant modifications and improvements that were pedagogically justified by the teacher-candidates. We believe that this research evidence strongly supports the statement that clicker-enhanced pedagogy should have a place in science methods courses as it effectively promotes the development of teacher-candidates' PCK and their ability to incorporate continuous formative assessment in their teaching. This also transferred to their school practicum: most of the teacher-candidates successfully incorporated formative assessment in their teaching.

Conclusions

Secondary STEM teacher-candidates are faced with a variety of challenges during their teacher education program, which are exacerbated by the lack of solid content knowledge in their teaching area. As it has been demonstrated above, teacher-candidates often lack the content expertise in the area they will be certified to teach in. This discrepancy, between the content knowledge they were supposed to possess prior to entering the program and the content knowledge they actually have, places significant pressure on them and on their methods courses' instructors. Teacher education programs should begin to acknowledge and address this issue, focusing on enhancing teacher-candidates' PCK throughout their programs.

Consequently, teacher-candidates who do not feel confident in their content knowledge are likely to be unable to apply the general pedagogies to the STEM context. This also is relevant to inquiry-oriented and student-centered education. These pedagogies require a much deeper PCK from teachers than a traditional lecture-style teaching. Moreover, it is unreasonable to expect that teacher-candidates who have not experienced these pedagogies as students or as teacher-candidates will be open to these teaching methods during their formative teaching years.

Teacher-candidates are the agents of change of the 21st century STEM teaching. Thus research-based pedagogies should be modeled in the teacher education courses. The STEM teachers we educate today should possess a solid PCK foundation enhanced by the knowledge of modern technologies that have a potential to enhance STEM education (Harris, Mishra, & Koehler, 2009; Koehler & Mishra, 2009). Modern technologies, such as electronic response systems, can play a significant role in this process both inside and outside of the teacher education programs helping to close the gap between STEM teachers we certify and STEM teachers we would like to be teaching our children. This paper begins addressing this gap by evaluating the pedagogical effectiveness of technology-enhanced formative assessment in a physics methods course. The study also assesses teacher-candidates' gains in PCK as a result of their active engagement with conceptual science questions. This research has also demonstrated the value of clickers in aiding instructors in identifying gaps in teacher-candidates' PCK and to address them in a supportive way. Most of the teacher-candidates conveyed their appreciation of how formative assessment was used in the course and expressed their interest in using clickers with their future students. The results of the analysis and our observations of teacher-candidates during the school practicum indicate that modeling research-based technology-enhanced formative assessment in a physics methods course helped teacher-candidate enhance their PCK and their confidence in physics teaching. This study helped close the gap between STEM education research and teacher education practice, but more needs to be done to assure that STEM teacher-candidates of today are prepared to become successful teachers of tomorrow.

References

Beatty, Ian D., Feldman, Allan, Leonard, William J., William J. Gerace, Cyr, Karen St., Lee, Hyunju. (2008). *Teacher Learning of Technology-Enhanced Formative Assessment*. Paper presented at the National Association for Research in Science Teaching, Baltimore, MD. http://arxiv.org/ftp/arxiv/papers/0806/0806.4924.pdf

Beatty, Ian D., Gerace, William J., Leonard, William J., & Dufrense, Robert J. (2006). Designing effective questions for classroom response systems teaching. *American Journal of Physics, 74*(1), 31-39.

Bloom, Benjamin S. (1956). *Taxonomy of Educational Objectives: Cognitive Domain.* (Vol. 1). New York: Longman.

Cha, Jeongho. (2013). Faculty Members Infusing Technology Across Teacher Education: A Mentorship Model. *An Exploratory Study on the Use of Clickers in Preservice Chemistry Teacher Education, 57*(4), 499-506.

Committee on Conceptual Framework for the New K-12 Science Education Standards, & National Research Council. (2013). *Next Generation Science Standards: For States, by States*. Washington DC: The National Academies Press.

Crippen, K. J., & Archambault, L. (2012). Scaffolded Inquiry-Based Instruction with Technology: A Signature Pedagogy for STEM Education. *Computers in the Schools, 29*(1-2), 157-173.

Crouch, Catherine H., & Mazur, Eric. (2001). Peer Instruction: Ten years of experience and results. *American Journal of Physics, 69*(9), 970-977.

Erickson, Gaalen. (2012). Science Teachers' Professional Development (pp. 205-222).

Fagen, Adam P., Crouch, Catherine H., & Mazur, Eric. (2002). Peer Instruction: Results from a Range of Classrooms. *The Physics Teacher, 40*(April), 206-209.

Fensham, Peter J., Corrigan, Deborah, Dillon, Justin, & Gunstone, Richard. (2011). Knowledge to Deal with Challenges to Science Education from Without and Within *The Professional Knowledge Base of Science Teaching* (pp. 295-317): Springer Netherlands.

Fisher, Heather, MacDonald, Alexandra, & Milner-Bolotin, Marina. (2013). *Design, Implementation & Evaluation of Research-Based Resources in Secondary Science Teacher Education*. Paper presented at the Canadian Society of Studies in Education Conference 2013, Victoria, BC, Canada.

Hake, Richard R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics, 66*(1), 64-74.

Haladyna, T. M., Downing, S. M., & Rodriguez, M. C. . (2002). A review of multiple-choice item-writing guidelines for classroom assessment. *Applied measurement in education, 15*(3), 309-333.

Harris, Judith, Mishra, Punya, & Koehler, Matthew. (2009). Teachers' Technological Pedagogical Content Knowledge and Learning Activity Types: Curriculum-Based Technology Integration Reframed. *Journal of Research on Technology in Education, 41*(4), 393-416.

Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force Concept Inventory. *The Physics Teacher, 30*(3), 141-157.

Human Resources and Social Development Canada, & Statistics Canada. (2006). Measuring up: Canadian Results of the OECD PISA Study: The Performance of Canada's Youth in Science, Reading and Mathematics (2006 First Results for Canadians Aged 15) (pp. 6). Ottawa: Human Resources and Social Development Canada.

Koehler, Mathew J., & Mishra, Punya. (2009). What is technological pedagogical content knowledge? *Contemporary Issues in Technology and Teacher Education, 9*(1), 60-70.

Lasry, Nathaniel. (2008). Clickers or Flashcards: Is There Really a Difference? *The Physics Teacher, 46*(May), 242-244.

Lasry, Nathaniel, Mazur, Eric, & Watkins, Jessica. (2008). Peer Instruction: From Harvard to the two-year college. *American Journal of Physics, 76*(11), 1066-1069.

Lord, Thomas, & Baviskar, Sandhya. (2007). Moving Students From Information Recitation to Information Understanding: Exploiting Bloom's Taxonomy in Creating Science Questions. *Journal of College Science Teaching, 37*(March-April), 40-45.

Ma, Liping. (1999). *Knowing and Teaching Elementary Mathematics: Teachers' Understanding of Fundamental Mathematics in China and in the United States*. New Jersey: Lawrence Erlbaum Associates.

MacArthur, James, Jones, Loretta, & Suits, Jerry. (2011). Faculty Viewpoints on Teaching Large-enrollment Science Courses with Clickers. *Journal of Computers in Mathematics and Science Teaching, 30*(3), 251-270.

Mazur, Eric. (1997a). *Peer Instruction: Getting Students to Think in Class.* Paper presented at the Changing role of Physics Departments in Modern Universities: Proceedings of ICUPE, The University of Maryland.

Mazur, Eric. (1997b). *Peer Instruction: User's Manual*. Upper Saddle River, NJ: Prentice Hall.

Mazur, Eric. (2009). Farewell, Lecture? *Science, 323*, 50-51.

Mazur, Eric (Writer). (2011). Confessions of a Converted Lecturer [Video archive]. In Perimeter Institute for Theoretical Physics (Producer). Canada: Perimeter Institute for Theoretical Physics.

McDermott, L.C. (2001). Oersted medal lecture 2001: Physics education research: The key to student learning. *American Journal of Physics, 69*, 1127-1137.

McDermott, L.C., & Redish, E.F. (1999). Resource letter: PER-1: Physics Education Research. *American Journal of Physics, 67*, 755-767.

McIlroy, Anne. (2012, Thursday, May 3, 2012). Clickers help teachers read the classroom, *The Globe and Mail*.

Mikelsons, Catrina (2013). [Technology in Mathematics Education: The Role of Professional Development in Technological Pedagogical Content Knowledge].

Milner-Bolotin, Marina. (2004). Tips for Using a Peer Response System in the Large Introductory Physics Classroom. *The Physics Teacher, 42*(8), 47-48.

Milner-Bolotin, Marina, Antimirova, Tetyana, & Petrov, Anna. (2010). Clickers beyond the First Year Science Classroom. *Journal of College Science Teaching, 40*(2), 18-22.

Milner-Bolotin, Marina, Fisher, Heather, & MacDonald, Alexandra. (2013a). Investigating the Impact of Clicker-Enhanced Pedagogy in a Secondary Physics Methods Course. *Teacher Education and Practice*.

Milner-Bolotin, Marina, Fisher, Heather, & MacDonald, Alexandra. (2013b). *Using Technology for Conceptual Learning in Physics Teacher-Education: Engaging Teacher Candidates as Learners and Teachers.* Paper presented at the International

Perspectives on Technology-Enhanced Learning: Lessons, Challenges and Possibilities, Vancouver, BC, Canada.

Mishra, Punya, & Koehler, Matthew J. (2006). Technological Pedagogical Content Knowledge: A Framework for Teacher Knowledge. *Teachers College Record, 108*(6), 1017-1054.

Mishra, Punya, & Koehler, Matthew J. (2007). Technological Pedagogical Content Knowledge (TPCK): Confronting the Wicked Problems of Teaching with Technology.

Organization for Economic Cooperation and Development. (2009). Programme for International Student Assessment (PISA).

Prensky, Marc. (2001). Digital Natives, Digital Immigrants Part I: A new way to look at ourselves and our kids. *On the Horizons, 9*(5), 1-6.

Schmidt, William H., Blömeke, Sigrid, Tatto, Maria Teresa, Hsieh, Feng-Jui, Cogan, Leland S., Houang, Richard T. (2011). *Teacher Education Matters: A Study of Middle School Mathematics Teacher Preparation in Six Countries*. New York: Teachers College Press.

Shulman, Lee S. (1986). Those Who Understand: Knowledge Growth in Teaching. *Educational Researcher, 15*(2), 4-14.

Shulman, Lee S. (1987). Knowledge and Teaching: Foundations of the New Reform *Harvard Educational Review, 57*(1), 1-23.

Watson, Anne, & Harel, Guershon. (2013). The Role of Teachers' Knowledge of Functions in Their Teaching: A Conceptual Approach With Illustrations From Two Cases. *Canadian Journal of Science, Mathematics and Technology Education, 13*(2), 154-168.

Wieman, Carl E. (2012). Applying New Research to Improve Science Education. *Issues in Science and Technology*(Fall), 1-9.