Handbook of Research on Transforming Mathematics Teacher Education in the Digital Age

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Chapter 5

Mathematics Education Technology Professional Development:
Changes over Several Decades

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ABSTRACT

The effective use of digital technologies in school settings calls for appropriate professional development opportunities that will transform inservice teachers' knowledge for integrating technologies as effective mathematics learning tools. To inform such opportunities, this study examined the contents of published mathematics education technology professional development papers over several decades using Sztajn's (2011) standards for high quality reporting in mathematics professional development research studies, the Technological Pedagogical Content Knowledge framework, and the Comprehensive Framework for Teacher Knowledge. Both the Professional Development Implementation and Evaluation Model and Education Professional Development Research Framework are recommended for further guidance on reporting key features of mathematics education technology professional development.

INTRODUCTION

The professional development of teachers with regard to technology integration in mathematics is especially important in today's society. The present study examined the contents of published mathematics education technology professional development papers, and recommends both the *Professional Development Implementation and Evaluation Model* and the *Education Professional Development Research*

Framework; these provide additional direction for reporting important features of mathematics education technology professional development. Guskey (2000) defined professional development as "those processes and activities designed to enhance the professional knowledge, skills, and attitudes of educators so that they might, in turn, improve the learning of students" (p. 16). Guskey's definition of professional development was used throughout this study.

Leading professional organizations have advocated for teachers to receive training related to teaching effectively with technology. In 1998, the International Society for Technology and Education (ISTE) released the National Education Technology Standards for Students (NETS•S) with the goal of supporting effective use of technologies in school settings. ISTE recognized that these new standards called for different types of teacher knowledge, and thereafter released the NETS Teacher Standards (NETS•T) in 2000. In the 2007 and 2008 revisions, ISTE shifted its focus from skills and knowledge needed to operate the technology to a) skills and knowledge for students to effectively use technology and b) skills and knowledge for teachers to teach with technology. Likewise, in 2006, the Association of Mathematics Teacher Educators (AMTE) stated that, "Mathematics teacher preparation programs must ensure that all mathematics teachers and teacher candidates have opportunities to acquire the knowledge and experiences needed to incorporate technology in the context of teaching and learning mathematics" (p. 1).

The United States Department of Education released Title II-D, Enhancing Education Through Technology Act of 2001, within the No Child Left Behind Act of 2001 (USDOE, 2001), which advocated for effective technology integration through teacher training and curriculum development to ensure that by 2006, each student was technology literate by the end of eighth grade. Likewise, the National Council of Teachers of Mathematics (NCTM), in the *Principles and Standards for School Mathematics* (2000) as well as in their 2011 technology in teaching and learning position statement and in their *Principles to Actions* (2014), advocated for technology as an important tool to enhance mathematics instruction.

A strong research foundation is critical for developing effective professional development for technology integration in mathematics education (Ronau et al., 2015). To advance this foundation, our study examined the contents of published mathematics education technology professional development literature over the course of several decades.

BACKGROUND

Research about general professional development (i.e., not specific to mathematics or technology) lays an important foundation for understanding mathematics education technology professional development research. The effectiveness of professional development has been an area of research for many years; this research helped frame our definition of professional development. At the core of Guskey's (2000) definition of professional development is improving students' learning through enhancing teachers' professional knowledge, skills, and attitudes. Similarly, Loucks-Horsley, Stiles, Mundry, Love, and Hewson (2010) contended that the core of effective professional development is improving student learning and extending teachers' knowledge directly related to their teaching practices. They describe effective professional learning as: "directly aligned with student learning needs; is intensive, ongoing, and connected to practice; focuses on the teaching and learning of specific academic content; is connected to other school initiatives; provides time and opportunities for teachers to collaborate and build strong working relationships; and is continuously monitored and evaluated" (p. 5). The actions in their

Professional Development Design Framework are: Commit to Vision & Standards, Analyze Student Learning & Other Data, Set Goals, Plan, Do, and Evaluate Results.

Garet, Porter, Desimone, Birman, and Yoon (2001) have also evaluated professional development effectiveness by conducting a national survey on the structural (i.e., organizational) and core (i.e., substance) features of the Eisenhower Professional Development Program. The structural features included the activity type (study group versus traditional workshop), duration (time span and contact hours), and degree of teachers' collective participation (groups of teachers from the same school, department, or grade as compared to individual teachers from various schools). The core features (also supported by the work of Carey & Frechtling, 1997; Darling-Hammond, 1997; and Lieberman, 1996) addressed the focus of the professional development activities and included organizing the content (mathematics or sciences); integrating active learning (observing and being observed); planning classroom implementation; reviewing student work; and presenting, leading, and writing. Further core features that addressed the coherence of the professional development included connections with goals and other activities, alignment with state and district standards and assessments, and communication with others. Garet et al. found that activities that spanned a longer period of time and lasted longer encouraged active learning as they provided more opportunities for teachers to plan for classroom instruction, observe other teachers, be observed teaching, analyze student work, and give a presentation or demonstration. Longer activities also promoted coherence through connecting teachers' goals and teaching experiences, aligning activities with standards, and encouraging communication among teachers. Duration had a moderately positive influence on teachers' content knowledge. Garet et al. also found that teachers who reported that their content knowledge was enhanced were also likely to report that they changed their teaching practices. Cohen and Hill (2000) and Kennedy (1998) also found that when professional development focuses on specific content as opposed to general pedagogy, student achievement is more likely to be positively affected.

Sztajn (2011) advocated standards for high-quality reporting in mathematics professional development research studies. As a result of an ERIC search for articles published between 2000 and 2009 in the *Journal for Research in Mathematics Education*, Sztajn located exactly seven articles pertaining to professional development with practicing K-12 teachers. As a result of the wide variation among the features reported in these seven articles, Sztajn initially used Loucks-Horsley et al.'s (1998) five inputs (i.e., knowledge and beliefs, context, goals, critical issues, and strategies) to organize the features reported, and then selected the following features "as possible candidates for standards on what should be reported" (p. 231):

- Espoused learning theories;
- Information about participants and their schools or districts;
- Presence of other change initiatives in participants' schools or districts;
- Program goals;
- Content focus on mathematics, student thinking, or curriculum materials;
- Collective participation;
- Teachers' voice in decision making about the MPD [mathematics professional development];
- Time (durations, span, organization);
- Artifacts used; and
- Specific mathematics content topic(s) addressed. (p. 231)

For further clarification, we describe below the features that are not self-explanatory. The espoused learning theories encompass both the teacher and student learning theories that guide the design of the mathematics professional development (MPD), and these theories should be aligned to each other. Sztajn (2011) contends that these learning theories "should be stated explicitly in research reports" (p. 228). Therefore, we defined 'espoused' as being explicitly stated. Describing other change initiatives in participants' schools or districts aids the reader in understanding how certain school-related issues may influence the goals of the professional development. 'Collective participation' is defined by Garet et al. (2001) as "the degree to which the activity emphasizes the collective participation of groups of teachers from the same school, department, or grade level, as opposed to the participation of individual teachers from many schools" (p. 920). Finally, descriptions of the specific artifacts and mathematics content provide a window for visualizing the activities teachers were engaged in during the professional development. Although Sztajn (2011) acknowledges that there are pros and cons to reporting standards for mathematics professional development, she contends "reporting standards can enhance comparisons among MPDs regardless of the research approach used" (p. 233).

The research questions that guided the present study were:

1. How has mathematics education technology professional development changed over time in relation to reporting Sztajn (2011) key features such as: espoused learning theories used in the design of the professional development; information about participants and their schools or districts; presence of other change initiatives in participants' schools or districts; program goals; content focus on mathematics, student thinking, or curriculum materials; collective participation; teachers' voice in decision making about the professional development; time (duration, span, organization); artifacts used; and specific mathematics content topic(s) addressed?
2. What types of outcomes have been used to measure effectiveness of mathematics education technology professional development, have they changed over time, and how do they vary across grade levels?

Results of these two questions provided guidance for the development of a conceptual framework and structure for interpreting and reporting mathematics education technology professional development.

CONCEPTUAL FRAMEWORK

To guide the analysis of professional development practices in our current study on mathematics education technology professional development over time, we used Sztajn's (2011) standards for high-quality reporting in mathematics professional development research studies to address research question 1. We also used the Technological Pedagogical Content Knowledge (TPACK) (Mishra & Koehler, 2006; Niess, 2005) framework to address the professional development program goals in research question 1. Koehler and Mishra (2008) envisioned the TPACK framework as "a flexible knowledge framework that teachers need to develop in order to successfully integrate technology in their teaching" (p. 10). To understand student and teacher knowledge outcomes (research question 2), we examined the papers in our sample through the lens of the Comprehensive Framework for Teacher Knowledge (CFTK) (Ronau & Rakes, 2011). The CFTK (Ronau & Rakes, 2011) defines teacher knowledge as a complex interaction of six aspects of teacher knowledge (i.e., subject matter, pedagogy, orientation, discernment, individual,

and environment) spanning across three dimensions: Subject Matter and Pedagogy (Field dimension), Discernment and Orientation (Mode dimension), and Individual and Environment (Context dimension). As teachers enhance their knowledge as defined by TPACK, they expand their knowledge of integrating technology, pedagogy, and content within classroom instruction while simultaneously influencing themselves to integrate the six CFTK aspects with regard to technology:

- Subject matter knowledge (e.g., knowledge of how technology influences student learning of mathematics),
- Pedagogical knowledge (e.g., knowledge of how to teach effectively with technology),
- Discernment knowledge (e.g., knowledge of how student and teacher cognition and metacognition is influenced by technology and how technology will influence learning about mathematics),
- Orientation knowledge (e.g., knowledge of how technology influences student affect generally and toward mathematics and how using technology influences students' affect toward mathematics),
- Individual knowledge (e.g., knowledge of how student backgrounds influence how they learn with technology), and
- Environment knowledge (e.g., knowledge of how the inclusion of technology changes the learning environment and influences learning of mathematics).

In summary, the three frameworks that formed the theoretical perspective with which we analyzed the papers in our sample included Sztajn's (2011) standards for high-quality reporting in mathematics professional development research studies, the TPACK framework, and the CFTK framework.

METHODOLOGY

This section shares the techniques and sources of the systematic literature search used to find papers addressing mathematics education technology professional development as well as the coding and procedures. The present study is part of a larger study that analyzed mathematics education technology publications between 1968 and 2009 (Bush et al., 2015; Ronau et al., 2014, 2015).

Literature Search

The literature search was conducted through two stages—the larger study and the present study—using a systematic process based on the techniques outlined by Cooper, Hedges, and Valentine (2009) and Lipsey and Wilson (2001). The papers for the present study (papers addressing mathematics education technology professional development) were from the overall sample of the larger study (papers addressing mathematics education technology). In both stages, we defined constructs before coding, defined keywords before conducting the literature search, defined a coding process, trained coders, cross-checked results, and computed inter-rater agreement. The sample from the larger study was compiled from multiple electronic databases (e.g., EBSCOWeb, ERIC, ProQuest Research Library and Digital Dissertations, JSTOR). For these publications, the inclusion criteria were:

1. The paper must examine a technology-based intervention (e.g., technology, calculators, computers), and

2. It must be about mathematics education (e.g., mathematics, algebra, geometry, visualization, representation).

The sample for the larger study consisted of 1,210 relevant papers. Each author/coder was paired with each of the other coders (i.e., six coders = 15 coding teams) so that each paper was both coded and cross-checked. This coding format created a counter-balanced design with all six coders, providing a way to maximize construct validity and inter-rater reliability of the coding. A database with over 200 variables was used in the coding process, with 91.5% inter-rater agreement (see Ronau et al., 2014 for more details of the overall literature search and coding process).

The papers for the current study were filtered from the database created for the larger study, and thus met the criteria of the larger study. The filter applied to the database-extracted papers that were coded as teacher development. The initial filter sample for the current study consisted of 116 papers. For a paper to be included in the present study, it had to address teacher development (Guskey, 2000); that is, the training of inservice teachers (those already certified) regardless of whether the experience earned college course credit. Papers that addressed teacher preparation were excluded; that is, papers that addressed the training of both undergraduate and graduate preservice teachers earning initial certification. Each paper was read to verify that it met the criteria, and 47 papers were retained for the present study. Nine excluded papers discussed a professional development opportunity with an online component (e.g., discussion groups, distance learning) where the online component did not provide any evidence of teaching and learning mathematics with technology. The other 60 excluded papers presented theory, classroom activities, or research on inservice teachers but did not address professional development.

Coding Process

The 47 papers in the present study were fully examined by two authors using Sztajn's (2011) standards for high-quality reporting in mathematics professional development research studies along with the TPACK and CFTK frameworks (Mishra & Koehler, 2006; Niess, 2005; Ronau & Rakes, 2011). When discrepancies in coding arose, additional authors were consulted. After the papers were coded, a third author verified the codes for the TPACK framework.

Each paper was examined for the standards identified by Sztajn (2011) as being important to report in mathematics professional development: espoused learning theories; participant information; change initiatives; program goals; focus on mathematics, student thinking, or curriculum materials; collective participation; teachers' voice in decision making; time; artifacts used; and mathematics content. We allowed the list of information about participants and their schools or districts reported to emerge from our examination of the papers. We then combined common characteristics such as undergraduate and graduate mathematics courses taken with mathematical content background. With the final list of 20 reported participant characteristics, each paper was examined and relevant characteristics for each paper were recorded. We coded teacher participants' grade-level bands into categories, similar to how mathematics content is often described in terms of specific grade levels (e.g., NCTM, 2000). The categories were K-5, 6-8, and 9-12 where the NCTM (2000) PreK-2 and 3-5 grade-level bands were combined. Some papers were coded as being in more than one grade-level band (e.g., K-5 and 6-8). The type of technology addressed in the professional development was coded as artifacts used and was defined as mathematics-specific and content-neutral technology tools, which align with NCTM's (2011) recommendation. We limited technology to digital technologies; tools such as overhead projectors and physical

manipulatives were excluded. The content topic(s) addressed were categorized using the same strands as identified in the NCTM (2000) *Principles and Standards for School Mathematics*: algebra, calculus, geometry, number, probability and statistics, problem solving, reasoning and proof, or unspecified mathematics content. The program goals were further analyzed using the TPACK framework, including Technological Knowledge (TK), Pedagogical Knowledge (PK), Content Knowledge (CK), Technological Pedagogical Knowledge (TPK), Technological Content Knowledge (TCK), Pedagogical Content Knowledge (PCK), and TPACK. The six aspects of teacher knowledge (i.e., subject matter, pedagogy, orientation, discernment, individual, and environment) of the CFTK framework (Ronau & Rakes, 2011) were used to define teacher outcomes. In addition, teacher orientation (teacher attitudes, beliefs, etc.) was analyzed. Altogether, seven different teacher outcomes were analyzed.

RESULTS

The 47 papers in the present study included 40 research papers and 7 non-research papers (theory development, classroom activities, editorials, etc.). Of the 47 papers, 11 (23%), which included nine research and two non-research papers, discussed the opportunity for the participants to earn graduate credit hours either through a graduate-level course or other professional development opportunity. No papers in this sample of 47 papers were published prior to 1980; three were published between 1980 and 1989, 14 between 1990 and 1999, and 30 between 2000 and 2009. The ratio of professional development papers per total number of mathematics education technology papers in the larger study was 3/48 in the 1980s (6.25%), 14/320 in the 1990s (4.38%), and 30/818 in the 2000s (3.67%). These percentages are low, but not unexpected as Sztajn contends most mathematics professional development "are never studied or reported on in research journals" (p. 222). The overall low number of professional development papers and the lack of relative increase suggest that little has been published about the effectiveness of mathematics education technology professional development.

Research Question One

Research question one (RQ1) addressed how mathematics education technology professional development has changed over time in relation to Sztajn's (2011) standards for high-quality reporting in mathematics professional development, including: espoused learning theories used to design the professional development; information about participants and their schools or districts; presence of other change initiatives in participants' schools or districts; program goals; content focus on mathematics student thinking, or curriculum materials; collective participation; teachers' voice in decision making about the professional development; time (duration, span, organization); artifacts used; and specific mathematics content topic(s) addressed.

Learning Theories

Since Sztajn (2011) contends that both teacher and student learning theories "should be stated explicitly in research reports" (p. 228), we coded only those that were explicitly stated ($n = 20$, 43%). The percentage of papers that explicitly stated a learning theory increased across the three decades (1980s, 1990s, and 2000s): 0%, 28.6%, and 53.3% respectively. This increase is promising because including an explicit

learning theory that supports the design of the professional development is necessary for the mathematics education community to clearly interpret the goals and activities of that professional development. When a learning theory was explicitly stated, these included: constructivism, situated learning, social constructivism, socio-cultural view of learning, socioculturalism, symbolic interactionism, both situated learning and legitimate peripheral participation, and both socioculturalism and the Community of Inquiry framework. Except for constructivism, which was addressed in five papers, each of the learning theories was addressed in exactly one paper.

Participant Information

The type of information provided in the papers about the participants and their school districts varied widely. No information was universally reported. The two most common characteristics reported about the participants was their teaching grade level ($n = 43$) and number of participants ($n = 37$). Other characteristics reported more than one time were the participants' school location ($n = 20$), number of individual schools they represented ($n = 15$), teaching experience in years ($n = 8$), gender ($n = 8$), school district's details (e.g., number of schools in the district, school district student population, school districts' students' standardized test data) ($n = 7$), technology background ($n = 7$), mathematics content background ($n = 6$), experience teaching with educational technology ($n = 5$), age ($n = 3$), number of years teaching at their current school ($n = 3$), prior mathematics courses taught ($n = 3$), and degree ($n = 2$). Other pieces of information, each of which appeared in only one paper, were teachers' certification level, ethnicity, highest degree earned, number of years teaching mathematics, online experience, and also whether or not the teachers were newly hired. In summary, the participant information that the respective authors chose to share in each of the 47 papers varied widely, with teaching grade level and number of participants reported most often.

On average, each paper reported four items of information about participants and their schools or districts (see Table 1). The number of items most often reported was two, and three dissertations reported nine, 11, and 12 items. Sixteen papers (approximately 34% of the 47 papers) reported only one or two specific details about the participants, which made it difficult to interpret the impact of the professional development because the details about participants and their schools that may affect the professional development program goals could not be determined. For example, the program goals may vary for a group of teachers with minimal background in teaching mathematics with technology in general or with a specific technology, as compared with a group of teachers who have integrated technology into their teaching for several years. Finally, one dissertation that is not reported in Table 1 did not clearly address the participants in the professional development, but rather described the teachers in the research study associated with the professional development. Although these teachers were also participants in the professional development, we could not infer characteristics about all participants in the professional development.

The participants represented in the 47 papers were most often a mixed group of middle and high school teachers ($n = 13$ papers), followed by only high school teachers ($n = 12$ papers), only middle school teachers ($n = 10$ papers), and only elementary school teachers ($n = 5$). Of the remaining seven papers, four did not address the participants' grade level taught. In two papers, participants were a mix of K-12 grade teachers. In one of these two papers, there were eight K-3, seven 4-5, seven 6-8, and ten 9-12 teachers; and in the second paper, there were 33 5-9 teachers. In a third paper, the group of participants was a mix of middle, high school, junior college, and university participants.

Table 1. Number of participant characteristics per paper type

Paper Type	Number of Participant Characteristics Reported									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**9**	**11**	**12**
Book Chapter	1	-	1	-	-	-	-	-	-	-
Conference Paper	1	-	-	1	-	-	-	-	-	-
Dissertation	-	7	2	4	4	2	2	1	1	1
Journal Article	3	4	4	2	2	1	1	-	-	-
Master Thesis	-	-	-	-	1	-	-	-	-	-
Total Number of Participant Items Reported	5	11	7	7	7	3	3	1	1	1

Note. N = 46 papers.

We had difficulty distinguishing between the professional development participants and the participants of the study reported in some research papers. For example, an author may have conducted a study with a subset of the participants who were in the professional development. Often, a list of details about the participants in the study was provided, but no list about the professional development participants was provided, even when elaborate details about the professional development were reported. Although some information about the professional development participants was evident since the research study participants were subsets of the professional development participants, further details about the professional development participants would have allowed the mathematics education community to better interpret the results of the research study.

Change Initiatives

The presence of other change initiatives in participants' schools or districts was seldom reported in the 47 papers. In the 1980s papers, one paper acknowledged that standards from national organizations and committees, along with state curricula, advocate for an increased use of the computer as a problem-solving tool in the mathematics classroom. The other two papers did not address the presence of other change initiatives.

Only three of the 14 papers from the 1990s addressed a change initiative. In one paper, the schools had previously invested in a collection of technology devices that would allow them to integrate mathematics and science lessons from classroom to classroom through distance learning. Professional development was organized to encourage teachers to use the technology devices to further enhance their instruction. In the second paper, the school was in the process of revamping the entire mathematics curriculum and accepted the invitation from a research group to offer to teachers a professional development opportunity that would help support their restructuring efforts. To aid the adoption of new and innovative curricula, the professional development focused on deepening teachers' mathematical content knowledge and technology curriculum integration. The third paper also focused on supporting the districts' implementation of new curricula—an integrated high school science, mathematics, and technology curricula.

Ten of the 30 papers from the 2000s addressed the presence of other change initiatives. The change initiatives reported were to address state standards enhanced by technology ($n = 2$), national curricular recommendations by NCTM enhanced by technology ($n = 1$), the general need for technology integra-

tion ($n = 4$), or the need for a specific technology integration ($n = 2$). The change initiative in the tenth paper was the organization of teachers into interdisciplinary clusters (math, science/social studies, and language arts). Across all decades in our study, the presence of other change initiatives was reported in 14 (30%) papers. Except for one of these 14 papers, the change initiatives acknowledged the need for integrating technology into the teaching and learning of mathematics.

Program Goals

The program goals in the 47 papers were examined using the TPACK framework. These program goals varied widely from focusing specifically on helping teachers use a technology tool (TK) to helping teachers effectively incorporate technology into lessons they created in order to enhance instruction (TPACK). In the 1980s, one professional development paper had program goals that focused on teachers demonstrating the ability to use technology—specifically, handheld calculators and microcomputer systems. The second paper focused mainly on teachers' TPACK as teachers developed computer-based activities that demonstrated the correct use of technology, employed a problem solving approach, and were pedagogically sound. The third paper addressed TCK, TPK, TK, and TPACK. Along with learning how to use a non-scientific calculator as an instructional tool in teaching mathematics (TPACK), the teachers also learned how to: use a calculator as a flash card device (TCK), demonstrate the use of the calculator for students (TPK), and use the calculator to solve addition and subtraction problems (TK). Overall, one paper focused on teachers learning to use the technology, the second focused specifically on TPACK, and the third focused on TPACK and several TPACK components.

The program goals of the 14 papers in our sample from the 1990s mainly focused on TPACK. Eleven papers described professional development programs with goals centered on TPACK—such as integrating technology into teachers' teaching and their students' learning of mathematics, integrating technology into the teaching of problem solving, or designing curricula for students that builds on the power of technology to connect mathematical concepts. One of these eleven papers also focused on teachers' content knowledge. Of the three remaining papers, one focused on developing teachers' skills with technological tools (TCK) and expanding their mathematical content knowledge (CK). The professional development in the other two papers seemed to focus primarily on the learning of the technology tool itself (TK).

The program goals of the 30 professional development papers written in the 2000s varied widely, with TPACK a focus in 23 papers. In 13 of these 23 papers, the main program goal was TPACK—such as implementing technology tools in mathematics with emphasis on an inquiry approach to teaching and learning, encouraging changes in teaching and learning with the influence of technology and standards, and using technology in mathematics teaching that supports and facilitates conceptual development of mathematics content. The other 10 papers that included a program goal of enhancing TPACK discussed other specific TPACK components: three addressed TK, two addressed TCK, one addressed CK, one addressed PCK, one addressed both TCK and PCK, and one addressed TCK, PCK, and CK.

There were seven papers that did not have a program goal focused on TPACK. Two papers focused on both TCK and CK, two focused on both TCK and PCK, while the other three focused on PCK and CK, or TK only. When CK was a focus in these seven papers, it was apparent that technology was not a focus, and the goal was to increase teachers' mathematical content knowledge of geometry, algebra, and calculus; history of mathematics; or geometry. When TCK was a focus, the goal was to develop teachers as users of technology or to develop their awareness of technology resources. Goals focused on PCK included: to enhance teachers' knowledge of problem-solving strategies or knowledge of how children

think and learn; and to develop teachers as facilitators of teaching mathematics, where technology was not a focus. Across all decades included in our study, TPACK was the most common program goal; it was evident in 36 papers, 12 of which included additional program goals related to TPACK components.

Focus on Mathematics, Student Thinking, or Curriculum Materials

When analyzing whether the professional development included a focus on mathematics, student thinking, or curriculum materials, the most common theme was a content focus on mathematics and curriculum materials, and we viewed technology as a curriculum material. The three papers from the 1980s all explained that teachers were learning to use technology. Two of these papers reported the integration of teaching mathematics with technology; one explicitly referenced using a textbook to help reinforce the integration of technology. None of these papers addressed student thinking.

All 14 papers in the 1990s addressed a content focus on both mathematics and technology. Two specifically focused on how to use the technology, one focused on simultaneously developing teachers' technologies skills and mathematical knowledge, and eleven explored teaching mathematics with technology. In four of these papers, additional curriculum materials were emphasized. No professional development paper in the 1990s addressed student thinking.

All 30 papers in the 2000s addressed professional development that was focused on both mathematics and technology, but with varying degrees. More specifically, one paper reported on teachers learning to use a technology, two focused on teachers learning to use a technology while simultaneously enhancing their content knowledge, one focused on teachers deepening their understanding of school mathematics and how to teach mathematics with some emphasis on technology, and two others separately discussed teaching and learning mathematics with technology. The remaining 24 papers integrated mathematics and technology and discussed appropriate ways of teaching and learning mathematics with technology. Four papers addressed student thinking; two analyzed work samples, one focused on observation and reflection, and one focused on the discovery approach for teaching. Six of the 30 papers referenced curriculum materials, including NSF-supported curriculum, textbook series, instructor- or teacher-created materials, and technology-specific curriculum materials. Overall, the papers in the sample typically reported the specific mathematics content and technology, but often did not address additional curriculum materials or student thinking.

Collective Participation

The degree to which the papers addressed collective participation varied across decades. Zero of the three papers in the 1980s, eight of the 14 papers in the 1990s, and 12 of the 30 papers in the 2000s addressed whether or not collective participation was a component of the professional development. Of the eight papers from the 1990s, collective participation was indeed a component in five papers as participants were from the same school district ($n = 3$), same school ($n = 1$), or a subset of the total participants were from the same school ($n = 1$). In the other three papers, collective participation was not a component as teachers were either from different local schools or from schools across the state.

Although collective participation was addressed in 12 papers from the 2000s, it was clearly not a component of the professional development in one paper as teachers were not from the same school or school district. Of the eleven other papers, five stated that all of the participants were from the same school, and three indicated that the participants were from the same school district. In the three remain-

ing papers, a subset of the total participants (about 36%) were from the same school ($n = 1$ paper), or the participants included small teams of teachers from several different schools ($n = 2$). Across all three decades, whether or not the professional development included collective participation was addressed in only 20 of the 47 papers. Of the ten professional development features reported in research question one, collective participation was the feature least often addressed.

Teachers' Voices

The next professional development feature analyzed was teachers' voices in decision making about the professional development. Teachers' voices were addressed in one of the three 1980s papers as teacher participants met prior to the professional development and approved a list of mathematics objectives to be taught during a six-week period. Similar to the 1980s, teachers' voices were addressed in one paper in the 1990s where teacher participants decided which specific mathematics content should be the focus of the professional development. Teachers' voices were more prevalent in the 2000s papers, where 24 of the 30 papers addressed this feature. Examples of teachers' voices included teachers creating their individual learning plan for 20 of 30 required professional development credit hours; teachers recommending specific technology integration; teachers identifying the lack of adequate technology equipment in their schools and the professional development responding to their needs; teacher-led collaboration; teachers individually receiving direct support from a professional development mentor; and a school-based teacher who served as the catalyst of the professional development. The increase of teachers' voices in making decisions about their professional development from the prior two decades to the 2000s is promising.

Time

In the 47 papers, reporting on the professional development time differed widely with respect to duration, span, and organization. All three papers in the 1980s included one summer session each; one was three weeks (or 15 days), one was six weeks, and one was not specified. Only one paper indicated that an academic-year component was included, in which the teachers met for three hours on an unspecified number of Saturdays. In only one paper, the organization of the professional development was discussed and included a daily outline of the topics covered.

Seven of the 14 papers in the 1990s addressed a three-credit graduate-level course, though it was mentioned in one paper that earning graduate credit hours was optional. Although the duration in the number of contact hours was not provided in these seven papers, one course was offered only during summer, whereas three courses were offered only during a fall or spring semester. The remaining three courses included both a summer and academic year follow-up component, where the follow-up sessions varied and consisted of one, five, or six follow-up days. A comprehensive description of the course was provided in only one of these seven papers, and a general agenda was provided in a different paper. Although more than a graduate-level course, one paper in the 1990s described a graduate-level program spanning three years, including a four-week summer institute, one course each during fall and spring semesters, and a winter institute spanning Thursday evening, all day Friday, and all day Saturday. In the six remaining papers of the 1990s, the time span included: summer only ($n = 2$), summer and one academic year follow-up session, summer and two academic year follow-up sessions, two months during the academic calendar, or was not addressed. Only one of the six papers that included a time span specified the duration given in contact hours. A complete daily agenda was provided in four of these six papers.

In seven of the 30 papers published in the 2000s, some graduate-level credit hours were offered. It was explained in three of these seven papers that participants were offered three graduate credit hours. Two of these three papers included a 15-week course offered during either the fall or spring semester; 45 contact hours was specifically reported in one paper. It was unclear in the third paper when the two-month seminar was offered. Of the four remaining papers that included graduate-level credit hours, the duration was not discussed in one paper, 100 contact hours was included in the second paper, three years was included in the third paper, and a 30-credit-hour professional development that included two summer institutes (total of 10 credit hours) with an unspecified number of follow-up sessions over two school years (total of 20 credit hours) was discussed in the fourth paper. This fourth paper did not include the contact hours, thus duration was not clearly stated in this paper. However, it was noted that the credit hours were optional. In 2 of the 23 remaining papers of the 2000s, the time span was specifically stated as fifteen hours and 45 hours. In 18 of the 23 remaining papers of the 2000s, the time span was generally stated and included: two and one-half days ($n = 1$), six days ($n = 2$), one week ($n = 2$), two weeks ($n = 2$), three weeks ($n = 3$), 15 weeks ($n = 1$), one month ($n = 1$), one year ($n = 2$), two years ($n = 3$), and three calendar years ($n = 1$). In the final three papers from the 1990s, the duration was not specified. In summary, the number of contact hours was specifically stated in only four papers from the 2000s.

Artifacts Used

The description of artifacts used differed widely among the 47 papers. We included the technology(ies) used in the professional development as an artifact (see Table 2). There were seven technologies reported in the three papers from the 1980s: compass software, computer programming, database software, graphing software, non-scientific calculators, scientific calculators, and spreadsheet software. As can be expected, the variety of technologies reported per decade increased from seven in the 1980s to 15 in the 1990s, and 26 in the 2000s. Technology that first appeared in the professional development papers for the 2000s included: Animate, applets, blogs, digital cameras, Interactive Whiteboards, Microsoft Word, movie software, presentation software, SMART Boards, student response systems, tutorial software, and videos. The only two technologies used across all three decades were graphing software and spreadsheet software. The use of dynamic geometry software increased the most from the 1990s to the 2000s, being used in the professional development programs from approximately 7% (1 out of 14 papers) to 30% (9 out of 30 papers). From the 1990s to the 2000s, there was an increase in both the general use of the Internet (from 7% to 17%) and the use of spreadsheet software (from 21% to 30%).

In addition to different technology tools and types, some professional development papers described other non-technology-based artifacts used during their professional development. In the 1980s, it was cited in two papers that a total of four non-technology-based artifacts were used, including: activity sheets/worksheets, teacher instructions, a text, and an outline of topics. One paper described only technology-related artifacts.

There were 14 papers in our sample from the 1990s, and 11 papers cited a variety of non-technology-based artifacts with the most popular being activities/units ($n = 4$ papers) and participant-made tasks/models/projects ($n = 3$ papers). All other artifacts were only referenced in one paper each and included: examples of student work, physical props, teacher worksheets, videotapes, teacher guides, student guides, worksheets, supporting literature, reformed curriculum, resources, a textbook, and teacher work samples and reactions.

Table 2. Number of technology types examined, by content strand and decade

Technology Type	1980s	1990s	2000s
Algebra Software		3	2
Animate			1
Applets[a]			4
Blogs			1
CAD		1	
CAS		1	
CBLs		1	3
Compass Software	1		
Computer Programing	2		
Database Software	1		
Data Collection Peripheral Devices, Not Specified			1
Digital Cameras			1
Distance Learning		1	1
Dynamic Geometry Software		1	9
Games Software		2	
Graphing Calculators		4	10
Graphing Software	1	3	3
Interactive Whiteboards			2
Internet, General		1	5
Mathematics Software, General			2
Microsoft Word			1
Motion Detectors		1	3
Movie Software			1
Non-Scientific Calculators	1		
Presentation Software			4
Probes		1	1
Scientific Calculators	1	2	
SMART Boards			2
Spreadsheet Software	1	3	9
Statistics[b] Software		1	2
Student Response Systems			1
Tutorial Software			1
Videos			1
Unspecified			1

Note. N = 47 papers.

[a]Applets are small programs that simulate manipulatives virtually or provide an exploration activity in a digital environment.

[b]Statistics included computational and instructional software.

Thirty professional development papers in our sample were written in the 2000s, and 20 papers cited non-technology-based artifacts. Nine papers cited lessons/units/activities, six cited participant-made lessons/activities, two cited curriculum, two cited assignments, two cited a webpage of resources, two cited samples of student work/thinking, and two cited tests. All other artifacts were cited in only one paper each and included: books, teacher-created learning plans, teacher presentations, videos of lessons, online discussion forums, scaffolding tools, whiteboards, observations, reflections, mentor logs, surveys, audio recordings, journal prompts, labs, textbook, and pacing guides.

Mathematics Content

To help provide the overall picture of the technology artifacts reported in the 47 professional development papers, we will report the technology type with respect to the specific mathematics content topic(s) addressed. First, though, we report the specific mathematics content topic(s) addressed in the 47 papers across all three decades (see Table 3). There were four content strands addressed in the three professional

Table 3. Mathematics content strand by decade

Content Strand	1980s	1990s	2000s
Algebra		6	7
Algebra, Business Math, Calculus, Geometry, Probability, and Statistics		1	
Algebra, Calculus, Geometry, and Problem Solving			1
Algebra, Calculus, Mathematical Modeling, Number, Probability, and Statistics			1
Algebra and Discrete Mathematics	1		
Algebra and Geometry	1	2	3
Algebra, Geometry, and Calculus			1
Algebra, Geometry, and Data Analysis			1
Algebra, Probability, and Statistics			1
Algebra and Problem Solving		1	
Calculus, Data Analysis, Geometry, Mathematical Modeling, Probability, and Statistics		1	
Data Analysis			2
Geometry			3
History of Mathematics			1
Data Analysis, Mathematical Modeling, Probability, and Statistics			1
Mathematical Modeling and Statistics		1	
Number	1		2
Number and Problem Solving		1	
Problem Solving		1	1
Statistics			1
Statistics and Data Analysis			1
6th, 7th, 8th Grade Mathematics			1
Not Addressed			2

development papers from the 1980s (i.e., algebra, discrete mathematics, number, and geometry). The number of content strands reported increased to ten in the 14 papers published in the 1990s, and was ten again for the 30 papers published in the 2000s. Also in papers from the 2000s, one addressed 6th, 7th, and 8th grade mathematics, while two did not address specific mathematics content.

Across all three decades, one content strand was the focus in 25 papers, two content strands were the focus in 11 papers, and more than three content strands in five papers. Algebra was the most frequently reported content strand ($n = 27$) and consisted of: pre-algebra, algebra, algebra I, algebra II, conic sections, exponential growth, linear algebra, matrix algebra, and trigonometric functions. Geometry was the second most common content strand ($n = 14$). The ratio of papers that addressed algebra per decade declined from approximately 71% to 50% from the 1990s to the 2000s. Similarly, the ratio of papers that addressed problem solving declined from approximately 21% to 7%; however, data analysis increased from 7% to 17%. Two other content strands that slightly increased were number (7% to 10%) and geometry (29% to 30%). All other content strands addressed in more than one paper decreased approximately 7% or less from the 1990s to the 2000s: mathematical modeling (14% to 7%), calculus (14% to 10%), probability (14% to 10%), and statistics (21% to 17%). It is possible that algebra was the most frequently reported content strand because algebra proficiency is the mathematics gatekeeper for success in high school, postsecondary school, and many career paths (Capraro & Joffrion, 2006; Edwards, 2000; Erbas, 2005; Stephens, 2005).

Research Question Two

The second research question (RQ2) explored the types of teacher and student outcomes that have been used to measure the effectiveness of mathematics education technology professional development research using student outcomes and teacher outcomes from the CFTK framework. Of the 47 professional development papers, 35 addressed more than one outcome, which suggests that professional development can target multiple areas of growth. For example, professional development might examine both teacher knowledge of subject matter and teacher knowledge of orientation (attitudes, beliefs).

Table 4 displays the number of times student outcomes, teacher knowledge outcomes, teacher orientation outcomes, and teacher behavior outcomes were targeted, organized by grade-level band and decade. While the total number of professional development papers was 47, the total count of outcomes as shown in Table 4 is 122 because many papers had more than one outcome; however, four papers did not examine any student or teacher outcomes. Student outcomes were measured in 10 papers with student achievement ($n = 4$), student orientation ($n = 4$), and student behavior ($n = 4$) studied most often, and student conceptual learning addressed in two professional development papers. Furthermore, eight papers addressed both student and teacher outcomes.

There were exactly 28 papers (1, 9, and 18 from the 1980s, 1990s, and 2000s respectively) that addressed the teacher knowledge outcome; however, this number is not reflected in Table 4 because, again, more than one outcome was reported in many of the papers. Subsets of teacher knowledge outcomes most often addressed were teacher knowledge of pedagogy ($n = 17$) and teacher knowledge of subject matter ($n = 16$). Finally, teacher knowledge orientation ($n = 10$), teacher knowledge discernment ($n = 8$), teacher knowledge environmental context ($n = 4$), and teacher knowledge individual context ($n = 1$) were measured less often.

The teacher orientation outcomes and/or behavior outcome (teaching choices reflect best practices and professional activities) were measured in exactly 35 papers (2, 12, and 21 from the 1980s, 1990s,

Table 4. Number of student, teacher, and other outcomes examined, by grade-level band and decade

Outcomes, by Grade-Level Band and Decade	1980-1989			1990-1999							2000-2009							Grand Total
	K-5	K-5, 6-8, 9-12	Outcomes Decade Total	K-5	6-8	6-8, 9-12	9-12	K-5, 6-8, 9-12	Not Addressed	Outcomes Decade Total	K-5	6-8	6-8, 9-12	9-12	6-8, 9-12, Junior College, University	Not Addressed	Outcomes Decade Total	
Total Student Outcomes	1	0	1	0	2	0	2	0	0	4	1	1	2	3	0	2	9	14
Achievement	1	—	1	—	1	—	1	—	—	2	1	—	—	—	—	—	1	4
Behavior	—	—	0	—	—	—	—	—	—	0	—	1	—	2	—	1	4	4
Conceptual Learning	—	—	0	—	—	—	—	—	—	0	—	—	1	1	—	—	2	2
Procedural Learning	—	—	0	—	—	—	—	—	—	0	—	—	—	—	—	—	0	0
Orientation	—	—	0	—	1	—	1	—	—	2	—	—	1	—	—	1	2	4
Total Teacher Knowledge (CFTK) Outcomes	0	1	1	4	1	13	3	2	0	23	5	5	11	9	1	1	32	56
Discernment	—	—	0	1	—	—	1	—	—	2	1	1	—	1	1	—	6	8
Environment	—	—	0	—	—	2	—	—	—	2	1	—	1	—	—	—	2	4
Individual Context	—	—	0	—	—	—	—	—	—	0	—	—	—	1	—	—	1	1
Orientation	—	—	0	1	1	2	2	—	—	6	—	—	2	2	—	—	4	10
Pedagogy	—	—	0	1	—	4	—	1	—	6	2	2	3	3	—	1	11	17
Subject Matter	—	1	1	1	—	5	—	1	—	7	1	2	3	2	—	—	8	16
Total Teacher Orientation Outcomes	1	1	2	1	2	3	4	0	1	11	1	4	7	3	0	1	16	29
Total Teacher Behavior Outcomes	0	0	0	0	1	2	2	1	1	7	5	2	4	4	0	1	16	23
Professional Activities	—	—	0	—	—	1	1	—	—	2	2	1	1	—	—	1	5	7
Teaching Choices Reflect Best Practices	—	—	0	—	1	1	1	1	1	5	3	1	3	4	—	—	11	16
Grade-Level Band Total	2	2	4	5	6	18	11	3	2	45	12	12	24	19	1	5	73	122

Note. N = 47 papers. The number of papers per decade is not always the sum of the row because some papers addressed more than one outcome and/or grade band.

and 2000s respectively) with teacher orientation measured in exactly 29 papers; teaching choices reflect best practices and professional activities, in exactly 21 papers.

SOLUTIONS AND RECOMMENDATIONS

The goal of this study was to examine the contents of mathematics education technology professional development published papers to determine whether and how professional development experiences have changed over several decades to help teachers implement current and emerging digital technologies in their classrooms. This analysis, although limited by a small sample size ($n = 47$), found a wide variation among the contents reported in these published papers. To address Sztajn's (2011) call that standards for reporting mathematics professional development are needed, we offer both a framework and process for reporting such standards.

Indeed, a major finding of this study is that there are few published papers on mathematics education technology professional development as only 47 of 1,210 papers (3.9%) in our overall sample of mathematics education technology papers addressed professional development. As we previously stated, this percentage is low but not unexpected, as Sztajn contends that most mathematics professional development programs "are never studied or reported on in research journals" (p. 222). Even though 47 papers is a small sample, it may be highly generalizable to all mathematics education technology professional development literature. Shavelson and Towne's (2002) fifth principle of scientific research is that quality research must be replicated and generalized across studies. We recognize that no single study can capture the breadth and depth needed to fully explore mathematics education technology professional development. However, having only 47 mathematics education technology professional development papers across four decades (0% in 1970s, 6.25% in 1980s, 4.38% in the 1990s, 3.67% in the 2000s) represents a striking lack of attention in published papers. With leading professional organizations in mathematics education, such as AMTE (2006), ISTE (NETS●S, 2008; NETS●T, 2009), and NCTM (2011, 2014), calling for further implementation of technology in the teaching and learning of mathematics, it would seem appropriate that publications on professional development programs supporting this call would appear more often.

A second major finding of our study is the wide variation in the contents reported in our sample of mathematics education technology professional development published papers. These variations were in the analysis of RQ1, which addressed Sztajn's (2011) standards for reporting mathematics professional development. In our sample of published papers, the learning theory that guided the design of the professional development was explicitly addressed in 20 (42.6%) papers. The percentage of papers that explicitly addressed the learning theory increased across the decades from the 1980s to the 2000s, which is promising as it helps practitioners make purposeful decisions about professional development to create more effective experiences for teachers in local settings.

There was a wide variation in what information authors chose to report about participants. The two most common characteristics reported were their teaching grade level ($n = 43$) and the number of participants ($n = 37$). Surprisingly, only one or two specific participant details were reported in 16 papers (approximately 34%). Reporting little information about the participants does not allow the mathematics education community to fully interpret the impact of the professional development, as details about participants and their schools may affect the professional development program goals. We support Sztajn's

(2011) claim that a discussion is needed as to what participant information should be shared. Sztajn stated that teachers' "professional experiences, the grade levels at which they teach, the socioeconomic background of their students, and whether the schools are private or public and rural, suburban, or urban" (p. 228) should be reported. We contend that teachers' professional experiences and the grade levels at which they teach should be expanded to include details about teachers' certification level, mathematical content background, total number of years teaching, number of years teaching specific mathematics content and when these experiences occurred, number of years teaching in the current school/district, experience teaching with mathematics education technology, whether the participation was compulsory or voluntary, and whether incentives were given. Shadish, Cook, and Campbell (2002) suggest that understanding the sample is critical. Therefore, to more clearly interpret the professional development, including its results, further details about the participants must be provided.

Change initiatives in participants' schools or districts were reported in 14 of the 47 papers (30%). With little information provided on change initiatives, it is difficult to determine the school's or school district's level of investment with the professional development program goals. Because teachers are often aware of this level of investment, it may in turn affect their personal commitment to the professional development. Therefore, we support Loucks-Horsley et al.'s (1998) and Sztajn's (2011) claim that there should be an expectation to report aspects that affect the design of the professional development.

Along with change initiatives, program goals must be reported. From our analysis of the mathematics education technology professional development program goals, 36 of the 47 programs goals attempted to enhance teachers' knowledge of technology integration for mathematics, which we coded as TPACK. Seven of the 47 papers also focused on developing teachers' content knowledge (CK). Consistent with recommendations made by Corcoran (1995), Cohen and Hill (2000), Kennedy (1998), and Garet et al. (2001), these papers attempted to enhance teacher knowledge as a mechanism for improving teacher practice and student outcomes.

Within the design and implementation of the mathematics education technology professional development programs, all 47 papers included mathematics content and at least one mathematics-related technology tool, which we viewed as a curriculum material. In 11 papers, additional curriculum materials were reported, and analysis of student thinking was evident in four papers, which aligns with Loucks-Horsley et al. (2010), who posited that professional development should improve student learning and extend teachers' knowledge as it relates to their teaching practices. Furthermore, Garet et al. (2001), Carey and Frechtling (1997), Darling-Hammond (1997), and Lieberman (1996) advocate for professional development programs to include teachers reviewing student work to analyze students' thinking. Hence, there is need for professional development that integrates mathematics content, technology, additional curriculum materials, and student thinking in order to transform teachers' knowledge for integrating technologies as mathematics learning tools to enhance student learning.

Collective participation was addressed in less than half of the professional development papers (*n* = 20, 43%). Collective participation "provides time and opportunities for teachers to collaborate and build strong working relationships" (Loucks-Horsely et al., 2010, p. 5). Bryk et al. (2011) goes further, suggesting that such collaboration should include small research trials to collectively answer classroom effectiveness questions. With groups of teachers from the same school working collaboratively, the effectiveness of the professional development may be more profound (Bryk et al., 2011; Garet et al., 2001). Including teachers' voices in the professional development decision-making will also increase the effectiveness of the professional development. The dramatic increase of teachers' voices in the papers between the 1990s (7%) and 2000s (80%) is evidence that teachers' voices are beginning to be heard.

The professional development time differed widely with respect to duration, span, and organization, including one day, one week, three weeks, one year, etc. Garet et al. (2001) found that duration had a positive influence on engaging teachers in active learning and conducting coherent professional development. Longer activities encouraged active learning, as they provided more opportunities for teachers to plan classroom instruction, observe other teachers, be observed teaching, analyze student work, and give presentations or demonstrations. Considering the benefits provided by longer activities, which may require at least 35 hours (Garet et al., 2001), professional development programs should be designed to allow for activities of such length.

Although technology was used as an artifact in each instance of professional development, 33 of the 47 papers included non-technology artifacts. The technology artifacts most frequently reported in the papers were graphing calculators (in 14 papers), spreadsheets (in 13 papers), dynamic geometry software (in 10 papers), and graphing software (in 7 papers). The number of technologies increased across decades, with 12 new technologies reported in the 2000s.

Typically, authors did not specify in their papers which technology was used to explore each mathematics content strand addressed. For example, one professional development included teachers learning how to use dynamic geometry software and spreadsheet software to teach algebra and geometry. However, we were unable to determine whether participants were exploring ways to teach geometry with only the dynamic geometry software or with both the dynamic geometry software and spreadsheet software. The technology used to explore each mathematics content strand should be clearly stated. Providing specific examples of how these technologies were used will also assist the reader in understanding the design and implementation of the professional development.

Of the content reported in the published mathematics education professional development papers, algebra was the content that appeared most often ($n = 27$), followed by geometry ($n = 14$) and statistics ($n = 8$). Garet et al. (2001) found that when professional development focuses on specific content, teachers are more likely to change their teaching practices, while Cohen and Hill (2000) and Kennedy (1998) noted that student achievement is positively affected when professional development has a specific content focus aligned with practice. Therefore, a specific content focus seems to be necessary to help teachers change their mathematics teaching practice and/or enhance student achievement.

RQ2 examined the types of outcomes addressed in the current literature on mathematics education technology professional development. Our results show that professional development on mathematics education technology has focused on teacher outcomes (40 of 47 papers), with teacher orientation addressed in 30 papers, teacher knowledge pedagogy in 21 papers, and teacher knowledge subject matter in 18 papers. Although teaching that exemplifies what the authors described as "best practices" was the focus of 17 papers, all professional development should define and emphasize best practices. Furthermore, eight papers addressed both teacher and student outcomes with student achievement, student behavior, and/or student orientation addressed in seven of these eight papers. With few published papers focused on both teacher and student outcomes, we recommend that professional development include experiences for teachers to assess the effectiveness of the strategies they are learning and measure this effectiveness through their students' learning when they employ these new teaching practices.

Overall, the results of our study revealed a number of recommended standards for professional development that are not consistently addressed in published papers but are important components in the professional development process, as determined by this study's literature review and conceptual framework. The inconsistency in reporting standards illuminates a need to more explicitly address professional development as a treatment. Therefore, we developed a new model for professional development:

the *Professional Development Implementation and Evaluation Model* (PDIEM) (see Figure 1). Because Sztajn's standards for reporting professional development, which were a component of the conceptual framework of our study, were informed by Loucks-Horsely et al.'s (2010) Professional Development Design Framework (PDDF), our PDIEM expands upon the ideas expressed in the PDDF by emphasizing continuous interaction among and between phases, components, and inputs within the model; collaboration among communities of practice; the implementation of improved classroom instruction; and cyclical evaluation of the professional development.

The Design and Development phase contains three major components that require in-depth analysis in the design of professional development. These components—Common Vision and Standards; Needs Assessment; and Set Goals, Design Strategies, and Design Activities—are interconnected and inform each other. These components interact and continue to inform each other, evolving during this phase and throughout subsequent phases. Current levels of Knowledge, Orientation, Context, and Critical Issues (KOCCI) among stakeholders serve as a lens to focus the professional development. The KOCCI inform the three major components, including delineation of a challenge space, specified by Bryk, Gomez, and Grunow (2011) as the challenges at the instructional, institutional, and system/field levels. The challenge space provides a structure by which individual, specific interventions are focused on a larger, common problem space. Common Vision, guided by the appropriate standards, is important for systemic and systematic change, and a necessity for both professional development designers and participants. Needs Assessment emphasizes that the professional development goals must focus on the common vision and KOCCI based on the teachers', schools', and school districts' needs—that is, the context in which professional development participants teach. Set Goals, Design Strategies, and Design Activities provides a collective focus on the KOCCI, including critical issues (e.g., implementing state standards, school accountability, achievement gap, technology implementation, etc.) among participants, providers, and other stakeholders. This component also emphasizes the importance of specifying measureable goals and designing strategies and activities that are aligned with the vision, needs, and goals that will be used to support the professional development.

The Whole Group Engagement phase integrates elements of effective professional development engagement with specific content and practices. This phase is guided by the design of the professional development, develops the knowledge and skills of the participants, creates a community of learners,

Figure 1. Professional development implementation and evaluation model
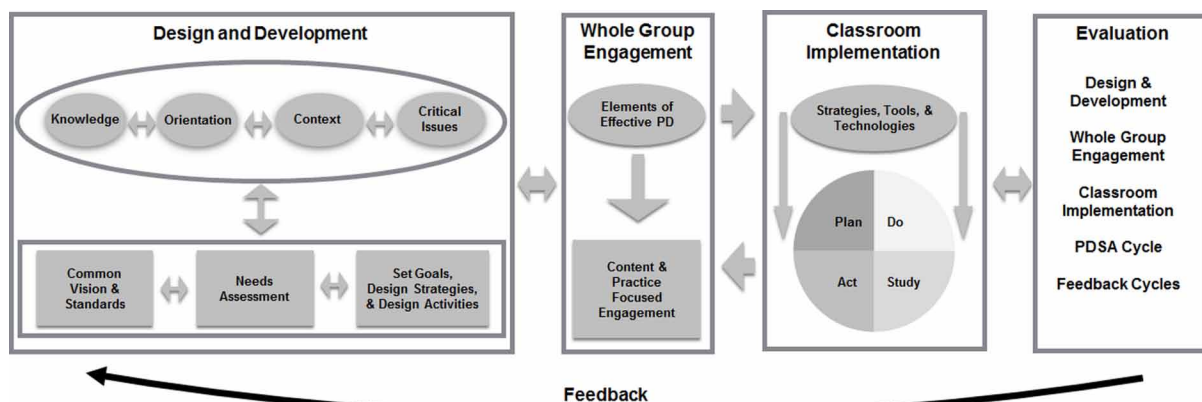
and serves as a catalyst for united efforts toward teacher-led research in the classroom. The Classroom Implementation phase draws from the Networked Improvement Communities' (NIC) Plan, Do, Study, Act cycles (PDSA) (Bryk, Gomez, & Grunow, 2011; Martin & Gobstein, 2015). For example, individual teachers can begin testing an idea with individual or small groups of students, then the results from these trials can be scaled up to the entire classroom. Moreover, multiple teachers try out the idea in their classrooms and share results among themselves. In this model, research is both accessible to teachers and powerful for generating knowledge. Whole group engagement should be cyclically integrated with classroom implementation (see also Collaboration, Enactment, Reflection, and Adaptation as in Blumenfeld et al., 2000). The integration of whole group engagement and classroom implementation more naturally provides opportunities for developing, practicing, reflecting on, and examining the challenge space as an integral part of the professional development, as well as part of the normal classroom instruction. Professional development that included classroom implementation and whole group engagement was rare in the present study ($n = 3$). However, the integration of these two phases into a strong professional development framework has the potential to transform professional development: it can engage teachers in inquiry about their practice by bringing research into the classroom and supporting immediate, positive change in classroom instruction and student learning.

Evaluation in PDIEM informs the design and development of the professional development. Evaluation is a continuous process throughout the professional development; it has both a formative and summative aspect to its assessment of the professional development. The evaluation feedback within and between phases and components fuels the evaluation of whether the goals or challenge space were addressed throughout the professional development, as well as whether the strategies and mechanisms are working as intended.

Networked Improvement Communities (NICs) can provide an overarching structure for the execution of the professional development (Bryk et al., 2011; Martin & Gobstein, 2015). NICs are intentionally-designed social organizations that are:

Focused on a well-specified common aim; guided by a deep understanding of the problem, the system that produces it, and a shared working theory to improve it; disciplined by the methods of improvement research to develop, test, and refine interventions; and organized to accelerate interventions into the field and to effectively integrate them into varied educational contexts (Carnegie Foundation, 2015).

NICs help solve complex educational problems through an infrastructure with a sustained focus on common goals and continuous improvement.

Creating and delivering appropriate and effective professional development is important for supporting teaching and learning; however, of almost equal importance is sharing the results. We draw from the analysis of the professional development papers in this study, in which a number of research reporting components were missing. Reporting on professional development using robust research designs is critical to building a knowledge base on the effective components of professional development. Professional development for teachers typically has two outcomes that are overriding concerns of stakeholders: teacher outcomes and student outcomes. Only ten professional development papers in our study reported on student outcomes, and of those ten, eight also reported teacher outcomes. As a guide for integrating both teacher and student outcomes, we introduce a model for research on professional development, *Education Professional Development Research Framework* (EPDRF), in Figure 2.

Figure 2. Education Professional Development Research Framework
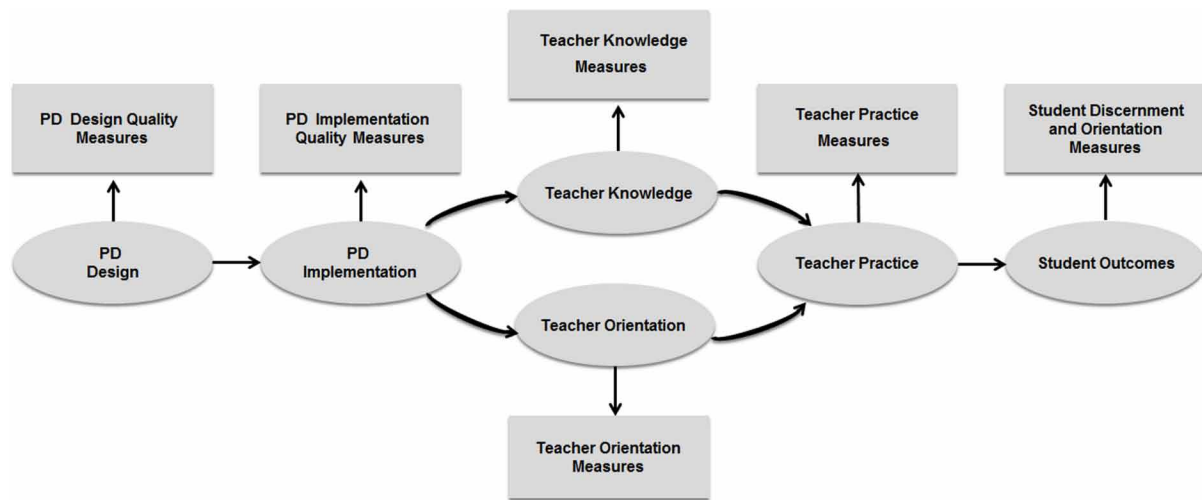
The ovals represent latent constructs and the rectangles represent manifest variables or measures. This is a modeling system that comes from path analysis and structured equation modeling (SEM), a helpful structure when trying to describe relationships between variables in studies (Burne, 2012). Note that the meaning of the ovals, rectangles, and arrows is very specific when using this model. For example, the construct of teacher knowledge predicts the measure of teacher knowledge; that is, the more a teacher knows (Knowledge), the higher the score on a test (Measure). The latent construct of Professional Development Design influences Professional Development Implementation, which influences teacher knowledge, etc., and this influence is represented by the arrow connecting two latent constructs. In SEM, these arrows represent equations with numerical solutions that describe the strength of the relationships in the model. For example, the differential influence of Teacher Knowledge and Teacher Orientation on Teacher Practice can be determined. Each of the relationships, as represented by the arrows, can be tested; and, the results not only may reveal strong and weak relationships, but also negative values. Examples of Professional Development Design Quality Measures may include alignment (with CCSSM, across professional development components, with stakeholder needs); connections to classroom and student work; or structures that support change, inquiry, or collaboration. Professional Development Implementation Quality Measures may include focus on specific content, technology, or grade band(s); activities that engage participants in meaningful work, collaboration, or leadership; duration, span, and organization; or level of engagement during activities. Teacher knowledge measures may include mathematics content assessments (DTAMS, MKT), assessments of teacher knowledge of student thinking and learning, teaching practices, or classroom environment. The TPACK five-stage developmental process (recognizing, accepting, adapting, exploring, and advancing) (Niess, Sadri, & Lee, 2007) has also been used. Teacher Orientation measures commonly used include assessments of attitude, anxiety, and efficacy. A number of classroom observation tools are now available to capture teacher practice; however, other measures have been used, such as teacher engagement in the professional community, leadership in schools, or participation in professional learning activities. Some studies have also used state tests and/or departmental tests.

When conducting research on professional development, attending to a strong, explicit research design is critical—whether quantitative, qualitative, or mixed methods ("Quality Measures" in Figure 1; Ronau et al., 2014, 2015), which include a conceptual framework, clear purpose, research questions, research methodology, and validity and analysis. Furthermore, research on professional development should be designed to provide valid and reliable information about key constructs of the study (represented by the ovals in Figure 2). A research study may analyze only one or two relationships (represented by arrows in Figure 2) to gain a deeper understanding of professional development. Such research studies by themselves, however, paint an incomplete picture of the professional development research field.

FUTURE RESEARCH DIRECTIONS

To further the field on reporting professional development programs, we offer both the *Professional Development Implementation and Evaluation Model* (PDIEM) and the *Education Professional Development Research Framework* (EPDRF). It is not always the case that the designers of a mathematics education professional development will conduct research on their professional development. Nor is it the case that the researchers who study a mathematics education professional development also designed it (Sztajn, 2011). The PDIEM can be used to support the design of professional development, and thus to support the Professional Development Design Quality Measures of the EPDRF. The Design and Development phase of the PDIEM suggests that researchers should report the common vision among the stakeholders, including their vision of teacher knowledge and/or orientation and student knowledge and/or orientation, as it pertains to the professional development (see for example, Sztajn, 2011). Details about the needs assessment conducted (i.e., current school initiatives, teachers' voices in decision making, participation of other stakeholders) and critical issues that influence the goals of the professional development based on the needs assessment (Sztajn, 2011), such as implementing state standards, school accountability, achievement gap, or technology implementation, along with the specific professional development measurable goals, must be provided (Desimone, 2009). A description of the activities and strategies used to design the professional development should be a component of the report, and include the specific mathematics content (Supovitz & Turner, 2000), reform curriculum (Cohen & Hill, 2000), and, when appropriate, the technology (Supovitz & Turner, 2000) and the specific content explored with each technology. Also embedded in the Design and Development phase is a description of the professional development participants (i.e., years of teaching experience; grade level and courses taught; teacher's certification level; mathematical content background; number of years teaching specific mathematics content and when these experiences occurred; number of years teaching in the current school/school district; experience teaching with mathematics education technology; whether the participation was compulsory or voluntary; whether incentives were given; demographic information about the participants, school, and school districts; information about the curriculum used in the school; and information about collective participation—see examples in Garet et al., 2001; Guskey & Sparks, 2002; Sztajn, 2011; and Supovitz & Turner, 2000), the professional setting (location, contact hours, and days offered; see Garet et al., 2001), funding, the professional development facilitators (i.e., the content, pedagogical, and technological expertise), perspectives on K-12 student learning and instruction, and perspectives on teacher learning and adult learning (see Garet et al., 2001).

We advocate that researchers who study professional development should support the entire professional development program. Researchers should then study whether the professional development was implemented in a way that aligns with its design (see the Professional Development Implementation in the EPDRF)—that is, its fidelity of implementation. The facilitator's ability to explicitly connect what the participants are learning with their own classroom practice, the facilitator's preparation level, and the atmosphere and environment of the professional development are examples of factors that influence the implementation. Additionally, quality professional development is implemented in ways that are sustained and focused on specific topics (Garet et al., 2001).

To inform the field about effective activities, strategies, and structures that contribute to effective professional development, the results of the professional development must include measurable and meaningful outcomes, including teacher-related outcomes (e.g., knowledge, orientation, and practice) and ideally, a measure of their K-12 students' outcomes. The teacher knowledge and teacher orientation measurements may include those suggested in the CFTK model (Ronau & Rakes, 2011), such as content knowledge, pedagogical knowledge, knowledge of student orientation, knowledge of student behavior, knowledge of the classroom environment, and/or knowledge of discernment. Other suggestions for measuring teacher-related outcomes include teacher knowledge instruments such as DTAMS (Saderholm, Ronau, Brown, & Collins, 2010), Mathematical Knowledge for Teaching (Ball et al., 2008), TPACK levels instrument (Niess et al., 2009), TPACK Levels Rubric (Lyublinskaya & Tournaki, 2011), teacher orientation instruments such as Mathematics Teaching Efficacy Beliefs Instrument (MTEBI) (Enochs et al., 2000), Conceptions of Mathematics Inventory-Revised (CMI-R) (Briley, Thompson, & Iran-Nejad, 2009), or Fennema and Sherman Mathematics Attitude Scales (Fennema & Sherman, 1976).

Teacher Practice can be studied by using different data collection methods including: observation of lessons; analysis of syllabi, lesson plans, or other documents; etc. Researchers may consider focus groups or interviews with participants, facilitators, and other parties involved in capturing different perspectives on the organization and quality of the professional development implementation. Teacher practice observation instruments, such as the Reformed Teaching Observation Protocol (RTOP) (Piburn et al., 2000; Sawada et al., 2002), or the Instructional Quality Assessment (2006) are possible instruments for evaluating teacher practice. An important goal of professional development is to change teacher practice by influencing teacher knowledge and orientation. In the EPDRF, this relationship is expressed in the path from the construct Professional Development Implementation to the constructs of Teacher Knowledge and Teacher Orientation and from those two constructs to that of Teacher Practice. Identifying which factors of professional development implementation have strong impact on teacher knowledge and orientation and how those changes can influence teacher practice is necessary. This model shows that with appropriate measures, the relationships between constructs can be studied, but only if the measures for the constructs are valid and reliable.

Student outcomes can be measured by assessments such as standardized assessments, review of student work, observations, interviews, surveys, or other forms of analysis of learning. When researchers study professional development, the measures of student outcomes should be aligned with the goals of the professional development, along with both valid and reliable to permit comparisons across studies. Only when professional development is reported with enough detail that others can replicate successful models will the practice of mathematics teachers and the field of mathematics education improve widespread.

CONCLUSION

The effective use of digital technologies in school settings calls for appropriate professional development opportunities that will transform inservice teachers' knowledge for integrating technologies as mathematics learning tools. To inform such opportunities, this study examined the contents of published mathematics education technology professional development papers over several decades using Sztajn's (2011) standards for high-quality reporting in mathematics professional development research studies, the TPACK framework, and the CFTK framework. The low number of published mathematics education technology professional development papers that were in our sample suggests a needed area of attention for the mathematics education community. Although mathematics education technology professional development is a common practice, too few of these efforts are reported in mathematics education literature. Nevertheless, we are encouraged that most mathematics education technology professional development papers were focused on TPACK. We recommend both the *Professional Development Implementation and Evaluation Model* (PDIEM) and the *Education Professional Development Research Framework* (EP-DRF) for further guidance on reporting key features of mathematics education technology professional development. The PDIEM, adapted from Loucks-Horsely, et al. (2010) and Sztajn (2011), accounts for the intricacy of the professional development process and its critical phases of design and development, whole group engagement, classroom implementation, and evaluation, along with the interactions that occur within each phase and between phases. To help promote effective research standards that support quality professional development, we presented the EPDRF. Although the EPDRF may appear as a road map toward quality professional development research, researchers should also attend to a strong, explicit research design, which includes conceptual framework, clear purpose, research questions, research methodology, and validity and analysis. Only through strong, explicit theoretical connections among multiple studies, across different settings, conducted with different populations, on well-defined goals and topics, will research on professional development have the potential to contribute to improvement of the field.

REFERENCES

Association of Mathematics Teacher Educators. (2006). *Preparing teachers to use technology to enhance the learning of mathematics: A position of the Association of Mathematics Teacher Educators*. Retrieved December 14, 2014 from http://amte.net/sites/all/themes/amte/resources/AMTETechnology-PositionStatement.pdf

Ball, D. L., Thames, M. H., & Phelps, G. (2008). Content knowledge for teaching: What makes it special? *Journal of Teacher Education*, *59*(5), 389–407. doi:10.1177/0022487108324554

Blumenfeld, P. C., Fishman, B. J., Krajcik, J., Marx, R. W., & Soloway, E. (2000). Creating usable innovations in systemic reform: Scaling up technology-embedded project-based science in urban schools. *Educational Psychologist*, *XXXV*(3), 149–164. doi:10.1207/S15326985EP3503_2

Briley, J. S., Thompson, T., & Iran-Nejad, A. (2009). Mathematical beliefs, self-regulation, and achievement by university students in remedial mathematics courses. *Research in the Schools*, *16*(2), 15–28.

Bryk, A. S., Gomez, L. M., & Grunow, A. (2011). *Getting ideas into action: Building networked improvement communities in education*. Stanford, CA: Carnegie Foundation for the Advancement of Teaching.

Bush, S. B., Driskell, S. O., Niess, M. L., Pugalee, D., Rakes, C. R., & Ronau, R. N. (2015). The impact of digital technologies in mathematics pre-service teacher preparation over four decades. In M. L. Niess & H. Gillow-Wiles (Eds.), *Handbook of Research on Teacher Education in the Digital Age* (pp. 1–27). Hershey, PA: IGI Global.

Capraro, M. M., & Joffrion, H. (2006). Algebraic equations: Can middle-school students meaningfully translate from words to mathematical symbols? *Reading Psychology*, *27*(2-3), 147–164. doi:10.1080/02702710600642467

Carey, N., & Frechtling, J. (1997, March). *Best practice in action: Follow-up survey on teacher enhancement programs.* Arlington, VA: National Science Foundation.

Carnegie Foundation. (2015). *Carnegie Foundation: For the advancement of teaching*. Retrieved November 2, 2015 from http://www.carnegiefoundation.org/our-ideas/

Cohen, D. K., & Hill, H. C. (2000). Instructional policy and classroom performance: The mathematics reform in California. *Teachers College Record*, *102*(2), 294–343. doi:10.1111/0161-4681.00057

Cooper, H., Hedges, L. V., & Valentine, J. C. (2009). *The handbook of research synthesis and meta-analysis* (2nd ed.). New York, NY: Russell Sage Foundation.

Corcoran, T. (1995). *Helping teachers teach well: Transforming professional development*. Washington, DC: CPRE Policy Briefs.

Darling-Hammond, L. (1997). *The right to learn: A blueprint for creating schools that work*. San Francisco: Jossey-Bass.

Desimone, L. N. (2009). Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. *Educational Researcher*, *38*(3), 181–199. doi:10.3102/0013189X08331140

Edwards, T. G. (2000). Some "big ideas" of algebra in the middle grades. *Mathematics Teaching in the Middle School*, *6*(1), 26–31.

Enochs, L. G., Smith, P. L., & Huinker, D. (2000). Establishing factorial validity of the mathematics teaching efficacy beliefs instrument. *School Science and Mathematics*, *100*(4), 194–202. doi:10.1111/j.1949-8594.2000.tb17256.x

Erbas, A. K. (2005). Predicting turkish ninth grade students' algebra performance. *Mathematics Educator*, *15*(1), 25–34.

Fennema, E., & Sherman, J. A. (1976). Fennema-Sherman mathematics attitudes scales; instruments designed to measure attitudes towards the learning of mathematics by females and males. *Catalog of Selected Documents in Psychology*, *6*(1), 31.

Garet, M. S., Porter, A. C., Desimone, L., Birman, B. F., & Yoon, K. S. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal*, *38*(4), 915–945. doi:10.3102/00028312038004915

Guskey, T. (2000). *Evaluating professional development*. Thousand Oaks, CA: Corwin Press.

Guskey, T., & Sparks, D. (2002). *Linking professional developments to improvements in student learning.* Paper presented at the Annual Meeting of the American Education Research Association. New Orleans, LA.

International Society for Technology in Education. (1998). *National Educational Technology Standards for Students*. Eugene, OR: Author.

International Society for Technology in Education. (2000). *National Educational Technology Standards for Teachers*. Eugene, OR: Author.

International Society for Technology in Education. (2007). *National Educational Technology Standards for Students* (2nd ed.). Eugene, OR: Author.

International Society for Technology in Education. (2008). *National Educational Technology Standards for Teachers* (2nd ed.). Eugene, OR: Author.

Junker, B., Weisberg, Y., Matsumura, L. C., Crosson, A., Wolf, M. K., Levison, A., & Resnick, L. (2006). *Overview of the instructional quality assessment (CSE Technical Report No. 671)*. Los Angeles, CA: University of California, National Center for Research on Evaluation, Standards, and Student Testing (CRESST).

Kennedy, M. M. (1998). *Form and substance in in-service teacher education (Research Monograph No. 13)*. Arlington, VA: National Science Foundation.

Koehler, M. J., & Mishra, P. (2008). Introducing TPCK. In AACTE Committee on Innovation and Technology (Ed.), The handbook of Technological Pedagogical Content Knowledge (TPCK) for educators (pp. 3-29). Mahwah, NJ: Lawrence Erlbaum Associates.

Lieberman, A. (Ed.). (1996). Practices that support teacher development: Transforming conceptions of professional learning. In M. W. McLaughlin & I. Oberman (Eds.), Teacher learning: New policies, new practices (pp. 185-201). New York: Teachers College Press.

Lipsey, M. W., & Wilson, D. B. (2001). *Practical meta-analysis*. Thousand Oaks, CA: Sage.

Lopez, A. M., & Hymel, G. M. (1981). *The effect of computer instruction on computer literacy in a mathematics teacher development program.* Paper presented at the Annual Meeting of the Mid-South Educational Research Association, Lexington, KY.

Loucks-Horsely, S., Stiles, K. E., Mundry, S. E., Love, N. B., & Hewson, P. W. (2010). *Designing professional development for teachers of science and mathematics*. Thousand Oaks, CA: Corwin.

Lyublinskaya, I., & Tournaki, E. (2011). The effects of teacher content authoring on TPACK and on student achievement in algebra: Research on instruction with the TI-Nspire handheld. In R. Ronau, C. Rakes, & M. Niess (Eds.), *Educational technology, teacher knowledge, and classroom impact: A research handbook on frameworks and approaches* (pp. 295–322). Hershey, PA: IGI Global.

Martin, W. G., & Gobstein, H. (2015). Generating a networked improvement community to improve secondary mathematics teacher preparation: Network leadership, organization, and operation. *Journal of Teacher Education*, *66*(5), 482–493. doi:10.1177/0022487115602312

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record*, *108*(6), 1017–1054. doi:10.1111/j.1467-9620.2006.00684.x

National Council of Teachers of Mathematics. (2000). *Principles and standards for school mathematics*. Reston, VA: Author.

National Council of Teachers of Mathematics. (2011). *Technology in teaching and learning of mathematics: A position of the National Council of Teachers of Mathematics*. Retrieved December 14, 2014 from http://www.nctm.org/about/content.aspx?id=31734

National Council of Teachers of Mathematics. (2014). *Principles to actions: Ensuring mathematical success for all*. Reston, VA: Author.

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. doi:10.1016/j.tate.2005.03.006

Niess, M. L. (2013). Central component descriptors for levels of technological pedagogical content knowledge. *Journal of Educational Computing Research*, *48*(2), 173–198. doi:10.2190/EC.48.2.d

Niess, M. L., Ronau, R. N., Shafer, K. G., Driskell, S. O., Harper, S. R., Johnston, C., & Kersaint, G. et al. (2009). Mathematics teacher TPACK standards and development model. *Contemporary Issues in Technology & Teacher Education*, *9*(1). Retrieved from http://www.citejournal.org/vol9/iss1/mathematics/article1.cfm

Niess, M. L., Sadri, P., & Lee, K. (2007). *Dynamic spreadsheets as learning technology tools: Developing teachers' technology pedagogical content knowledge (TPCK).* Paper presented at the meeting of the American Educational Research Association Annual Conference, Chicago, IL.

Piburn, M., Sawada, D., Turley, J., Falconer, K., & Benford, R. B. I. (2000). *Reformed teaching observation protocol (RTOP): Reference manual (ACEPT Technical Report No. IN00-3)*. ACEPT.

Ronau, R. N., & Rakes, C. R. (2011). Aspects of teacher knowledge and their interactions: A comprehensive framework for research. In R. N. Ronau, C. R. Rakes, & M. L. Niess (Eds.), *Educational technology, teacher knowledge, and classroom impact: A research handbook on frameworks and approaches* (pp. 59–102). Hershey, PA: IGI Global.

Ronau, R. N., Rakes, C. R., Bush, S. B., Driskell, S., Niess, M. L., & Pugalee, D. (2014). A systematic study of dissertations in mathematics educational technology and its implications for doctoral programs. *American Educational Research Journal*, *51*(5), 974–1006. doi:10.3102/0002831214531813

Ronau, R. N., Rakes, C. R., Bush, S. B., Driskell, S. O., Niess, M. L., & Pugalee, D. (2015). The quality of mathematics education technology literature. *Journal of Multidisciplinary Evaluation*, *11*(24), 12–36.

Saderholm, J. C., Ronau, R. N., Brown, E. T., & Collins, G. (2010). Validation of the Diagnostic Teacher Assessment of Mathematics and Science (DTAMS) instrument. *School Science and Mathematics Journal*, *110*(4), 180–192. doi:10.1111/j.1949-8594.2010.00021.x

Sawada, D., Pilburn, M. D., Judson, E., Turley, J., Falconer, K., Benford, R., & Bloom, I. (2002). Measuring reform practices in science and mathematics classrooms: The reformed teaching observation protocol. *School Science and Mathematics*, *102*(6), 245–253. doi:10.1111/j.1949-8594.2002.tb17883.x

Shadish, W. R., Cook, T. D., & Campbell, D. T. (2002). *Experimental and quasi-experimental designs for generalized causal inference*. Boston, MA: Houghton Mifflin.

Shavelson, R. J., & Towne, L. (Eds.). (2002). *Scientific research in education*. Washington, DC: National Research Council, National Academy Press.

Stephens, A. C. (2005). Developing students' understandings of variable. *Mathematics Teaching in the Middle School*, *11*(2), 96–100.

Supovitz, J. A., & Turner, H. M. (2000). The effects of professional development on science teaching practices and classroom culture. *Journal of Research in Science Teaching*, *37*(9), 963–980. doi:10.1002/1098-2736(200011)37:9<963::AID-TEA6>3.0.CO;2-0

Sztajn, P. (2011). Research commentary: Standards for reporting mathematics professional development in research studies. *Journal for Research in Mathematics Education*, *42*(3), 220–236.

United States Department of Education. (2001). *No child left behind act of 2001*. Retrieved from http://www2.ed.gov/policy/elsec/leg/esea02/pg34.html

KEY TERMS AND DEFINITIONS

Coding Tool: A Microsoft Access database created and used to code all papers, which were a part of the larger, more comprehensive study.

Comprehensive Framework of Teacher Knowledge: A model used to organize teacher outcomes which includes three components with two outcomes each: Field (composed of two outcomes: Subject Matter and Pedagogical Knowledge), Mode (composed of two outcomes: Knowledge of Orientation and Knowledge of Discernment Knowledge), and Context (composed of two outcomes: Knowledge of Individual and Knowledge of Environment Knowledge).

Content Strands: The different subject areas within mathematics (e.g., algebra, calculus, data analysis, geometry, probability, statistics).

Technological Pedagogical Content Knowledge (TPACK): A model that addresses the specialized set of knowledge needed to effectively integrate technology into the mathematics classroom integrating appropriate technological, pedagogical, and content knowledge.

Technology: Both mathematics-specific and general instructional technology materials that teachers use to teach and students use to learn mathematics.