RESEARCH IN MATHEMATICS EDUCATIONAL TECHNOLOGY: TRENDS IN PROFESSIONAL DEVELOPMENT OVER 40 YEARS OF RESEARCH

Shannon O. Driskell
University of Dayton
sdriskell1@udayton.edu

Sarah B. Bush
Bellarmine University
sbush@bellarmine.edu

Margaret L. Niess
Oregon State University
niessm@onid.orst.edu

David Pugalee
University of North Carolina-Charlotte
david.pugalee@uncc.edu

Christopher R. Rakes
University of Maryland, Baltimore County
rakes@umbc.edu

Robert N. Ronau
University of Cincinnati
bobronau@gmail.com

The effective use of digital technologies in school settings calls for appropriate professional development opportunities for inservice teachers. How has professional development shifted in support of mathematics teachers integrating these technologies in their teaching? This study explored the impact of digital technologies in mathematics inservice professional development over the past four decades and examined how various technologies, content strands, grade-level bands, teacher outcomes, and student outcomes were being used to design mathematics professional development on integrating technology. This study provides recommendations to mathematics teacher educators as they transform professional development to meet the challenges faced in integrating new and emerging technologies in their instruction.

Keywords: Teacher Education-Inservice; Teacher Knowledge; Technology

What it means to teach mathematics has changed over the past four decades. The development and availability of mathematics educational technology is a key factor in how the mathematics classroom looks different than 10, 20, 30, or 40 years ago. Professional development provides opportunities for inservice teachers to experience new methods of both teaching and learning mathematics with technology and to collaborate with colleagues about pedagogical strategies they use when implementing these technologies.

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), which is the definition used in this study. Professional development can be short-term or ongoing and may take many forms such as workshops, sessions during teacher inservice training, institutes and sessions in the summer, individual classroom interactions, lesson study, professional learning community models, online sessions, or video-series. When professional development is effective, teachers may take new ideas back to their classrooms and implement new strategies and use technology in different and/or new ways.

To address ongoing challenges in mathematics educational professional development, we sought to examine extant literature in the field, analyze trends therein, and facilitate present and future improvements to both teaching and learning. The research questions that guided the present study were: (1) What types of technology and content areas have been the focus of professional development research over time? (2) What types of technology and grade bands have been the focus of professional development research over time? (3) What types of outcomes are used to measure effectiveness of mathematics educational technology professional development; have they changed over time, and how do they vary across grade levels?

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Conceptual Framework

Two frameworks were applied to the analysis of a database of mathematics educational technology studies identified by a systematic review: Technological Pedagogical Content Knowledge (TPACK) and Comprehensive Framework of Teacher Knowledge (CFTK). The TPACK framework (Mishra & Koehler, 2006; Niess, 2005) describes the unique set of knowledge needed to effectively integrate technology into the classroom in conjunction with appropriate pedagogical content knowledge (as in Ball, Thames, & Phelps, 2008; Shulman, 1986). TPACK extends beyond knowledge of how to use the technology proficiently and encompasses a deeper and transformed knowledge for understanding how subject matter, pedagogy, and technology are integrated to provide richer learning experiences. Subsets of the TPACK framework include Technological Knowledge (TK), Pedagogical Knowledge (PK), Content Knowledge (CK), Technological Pedagogical Knowledge (TPK), Technological Content Knowledge (TCK), and Pedagogical Content Knowledge (PCK). TCK was used to support research question one while TK was used to support research question two.

CFTK (Ronau & Rakes, 2011) describes an all-encompassing structure for studying and understanding the complex nature of knowledge required for teaching as a highly complex interaction of multiple aspects of teacher knowledge across three dimensions: Subject Matter and Pedagogy (Field dimension), Discernment and Orientation (Mode dimension), and Individual and Environment (Context dimension). These teacher knowledge outcomes and an extension of these outcomes to student outcomes were applied in the analysis of research question three.

Method

The present study is part of a larger, more comprehensive study that analyzed mathematics educational technology papers published between 1968 and 2009. For the literature search of the comprehensive study, we followed a systematic process based on the techniques outlined by Cooper, Hedges, and Valentine (2009) and Lipsey and Wilson (2001); for example, we defined constructs before coding, defined keywords before conducting the literature search, defined a coding process, trained coders, and cross-checked results. To obtain the overall sample, a wide array of databases were searched using terms to restrict the sample, based on two criteria for inclusion: (1) The paper must examine a technology-based intervention (e.g., technology, calculators, computers), and (2) The paper must be focused on the learning of a mathematics concept or procedure (e.g., mathematics, algebra, geometry, visualization, representation). We searched the following database platforms (and the databases within those platforms): EBSCOWeb (ERIC, Academic Search Premier, PsycINFO, Primary Search Plus, Middle Search Plus, Education Administration Abstracts), JSTOR (restricted to the disciplines of Education, Mathematics, Psychology, and Statistics), OVID, ProQuest (Research Library, Dissertations & Theses, Career & Technical Education), and H. W. Wilson Web (Education Full Text). We also examined the bibliographies of the papers we identified through this search in order to identify potentially relevant papers that were missed in our searches. For further details about this process, see Ronau, Rakes, Bush, Driskell, Niess, & Pugalee (2014). Altogether, our literature search of the comprehensive study resulted in 1,210 papers.

In order to code the 1,210 papers, we created a Microsoft Access database with over 200 variables, with each coder paired with each of the other coders (i.e., six coders = 15 coding teams) so that each paper was both coded and cross-checked. The new 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. Our overall inter-rater agreement was 91.5% (Number of Agreements out of the Total Number of Possible Agreements), from which we concluded that the inter-rater reliability for the comprehensive study was high. Upon completion of coding for the comprehensive study, a filter was applied to the database to extract the papers that were coded as teacher development. Next,

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each paper was read to make certain it aligned with Guskey's (2000) definition of professional development and to verify that the professional development was non-credit bearing (not part of a degree program) and took place after initial teacher certification (preservice education was not included). Using this criterion, 21 of the 1,210 papers were retained for the present study.

Results

None of the papers in our subsample of 21 professional development papers were found in the 1960's or 1970's. For each subsequent decade, the ratio of professional development papers per total number of technology papers in mathematics education was 2/48 in the 1980's (4.14%), 3/320 in the 1990's (.94%), and 16/818 in the 2000's (1.96%). To answer research question one, the number of times each technology type was used as compared to content strand per decade was analyzed (see Table 1).

Table 1: Technology Type Compared to Content Strand by Decade

Decade and Content Strand	Calculator	Computer Software	Interactive Whiteboards	Internet	Probeware & Motion Detectors	Other Technology
Total for 1980	**2**	**0**	**0**	**0**	**0**	**1**
Number	1	-	-	-	-	-
Not Specified	1	-	-	-	-	1
Total for 1990	**0**	**3**	**0**	**1**	**1**	**0**
Algebra	-	3	-	1	1	-
Total for 2000	**7**	**13**	**1**	**3**	**5**	**2**
Algebra	2	3	-	-	2	-
Algebra, Geometry, Data Analysis	1	-	-	-	1	-
Algebra, Probability & Statistics	1	2	-	1	-	-
Algebra, Geometry, Calculus	-	1	-	-	-	-
Number	-	-	-	-	-	1
Probability & Statistics	-	2	-	-	-	-
Not Specified	3	5	1	2	2	1
Technology Type Total	**9**	**16**	**1**	**4**	**6**	**3**

Note. N = 21 papers. The number of papers per decade is not always the sum of the row because some papers addressed more than one technology type and/or content strand area. The Other Technology consisted of computer programming, personal digital assistants, and video clips.

The content strands addressed within the professional development papers in the 1980's were limited to number content or was not specified, with calculators used in both studies. Algebra content was the only content strand addressed in the 1990's, and the technology for all three papers was computer software, specifically graphing software in two papers and presentation software in the

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third paper. In the 2000s, there were six different reported content strands. The algebra content strand was addressed most often (six of 13 papers). In the three papers that solely included algebra content, one paper discussed using graphing software and two papers discussed using spreadsheet software. One of the two papers coded as algebra and probability and statistics content discussed using geometry software while the other paper used spreadsheet software. The paper coded as algebra, geometry, and calculus content discussed using geometry software. The computer software used in the two probability and statistics content papers was statistics software. Professional development papers written in the 2000's displayed the greatest variety in technology use, with a growing use of the Internet. Many papers (n = 6; 37.5%) however, did not specify the content addressed in the professional development.

To answer research question two, the technology used and teacher participants' grade-level band reported in the papers was analyzed (see Table 2). Across all three decades, two papers included K-5 teachers; one included a combination of K-5, 6-9, and 10-12 teachers; seven included 6-8 teachers only; five included both 6-8 and 9-12 teachers; five included 9-12 teachers only; and one did not specify the grade-level band.

Table 2: Technology Type Compared to Grade Band by Decade

Decade and Grade Band	Calculator	Computer Software	Interactive Whiteboards	Internet	Probeware & Motion Detectors	Other Technology
Total for 1980	**2**	**0**	**0**	**0**	**0**	**1**
K-5	1	-	-	-	-	-
K-5, 6-8, 9-12	1	-	-	-	-	1
Total for 1990	**0**	**3**	**0**	**1**	**1**	**0**
Unspecified Grade	-	1	-	-	-	-
6-8, 9-12	-	1	-	1	1	-
9-12	-	1	-	-	-	-
Total for 2000	**7**	**13**	**1**	**3**	**5**	**2**
K-5	-	-	1	-	-	-
6-8	2	7	-	2	1	2
6-8, 9-12	2	4	-	-	2	-
9-12	3	2	-	1	2	-
Technology Type Total	**9**	**16**	**1**	**4**	**6**	**3**

Note. N = 21 papers. The number of papers per decade is not always the sum of the row because some papers addressed more than one technology type and/or grade band. The Other Technology consisted of computer programming, personal digital assistants, and video clips.

The most common technology used was computer software, followed by graphing calculators, probeware, Internet, other technology, and interactive whiteboards. Technology for grades 6-8 and 9-12 teachers varied more widely compared to grades K-5. Professional development for grades K-5 in the papers was limited to either calculators or interactive whiteboards. Professional development for

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grades 6-8 or 9-12 teachers, on the other hand, included calculators, computer software, the Internet, probeware and motion detectors, and other technology, including computer programming, personal digital assistants, and video clips.

To answer research question three, we analyzed outcomes (student and teacher) being addressed in the professional development papers, organized by grade band and decade (see Table 3). While the total number of professional development studies was21, the total count of outcomes as shown in Table 3 was51, as many studies had more than one outcome. Teacher outcomes were measured more often than student outcomes. Teacher orientation was the most common outcome measured, which was measured in 15 studies (2, 3, and 10 from the 1980's, 1990's, and 2000's respectively), followed by 10 studies (0, 2, and 8 across the three decades) which measured teacher knowledge of pedagogy, and 9 studies (1, 2, and 6 across the three decades) that measured teacher knowledge of subject matter.

Table 3: Outcomes Compared to Grade Band by Decade

Decade and Grade Band	Student Achievement	Student Orientation	Student Behavior	Teacher Knowledge Subject Matter	Teacher Knowledge Pedagogy	Teacher Knowledge Discernment	Teacher Knowledge Orientation	Teacher Knowledge Individual	Teacher Knowledge Environment	Teacher Orientation
Total for 1980	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**2**
K-5	1	-	-	-	-	-	-	-	-	1
K-5, 6-8, 9-12	-	-	-	1	-	-	-	-	-	1
Total for 1990	**1**	**1**	**0**	**2**	**2**	**0**	**1**	**0**	**2**	**3**
Unspecified Grade	-	-	-	1	1	-	1	-	1	1
6-8, 9-12	-	-	-	1	1	-	-	-	1	1
9-12	1	1	-	-	-	-	-	-	-	1
Total for 2000	**1**	**2**	**1**	**6**	**8**	**3**	**1**	**2**	**1**	**10**
K-5	1	-	-	1	1	1	-	-	1	1
6-8	-	-	-	2	3	1	-	-	-	4
6-8, 9-12	-	1	-	-	1	1	-	1	-	2
9-12	-	1	1	3	3	-	1	1	-	3
Outcome Total	**3**	**3**	**1**	**9**	**10**	**3**	**2**	**2**	**3**	**15**

Note. $N = 21$ 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.

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Teacher knowledge of Discernment or Individual Context in relation to technology was not addressed in professional development research until the 2000's.Both of these knowledge constructs tend to be student-centered and are not as easily observed or measured. Since only three studies included K-5 teachers, there were no trends to describe how the outcomes varied across grade level. With regard to student-related outcomes, student achievement (n = 3 out of 21 papers, 14%) and student orientation (n = 3 out of 21 papers, 14%) were studied most often. As the numbers for student outcomes were so small, there were not clear patterns or trends through the decades.

Discussion

This study found very little published research on professional development focused on technology in teaching and learning mathematics, which was surprising given the long-standing calls from professional organizations such as the National Council of Teachers of Mathematics (1989, 2000) for mathematics teachers to incorporate new technologies in the classroom. Only 21 studies of 1,210 total studies in our sample of mathematics educational technology papers addressed professional development. Limited published professional development research impairs the ability to advance the field of mathematics educational technology professional development. Shavelson and Towne (2002) stated, "Scientific studies do not contribute to a larger body of knowledge until they are widely disseminated and subjected to professional scrutiny by peers" (p. 22). Therefore, a reasonable direction for researchers who conduct mathematics educational technology professional development is to measure the outcomes of their efforts and publish the results of their work. Also, researchers might focus on conducting and publishing further research on professional development with K-5 teachers as only three of the 21 studies included these teachers. Since many students are currently required or will be required to take a computer-based state standardized assessment, some K-5 classrooms now have some sort of 1:1 structure in place (e.g., laptop carts, chromebooks, iPads). Research is needed on how to use these resources to enhance mathematics learning effectively, and professional development research is needed to help providers improve teachers' ability to integrate technology in their classrooms effectively. Furthermore, how technology can enhance learning is content-specific, and too few of the published studies reported the content area that was addressed during the professional development. Future studies need to explicitly identify the content area being studied so that teachers and researchers can build on the work appropriately. Also, the effectiveness of the professional development with any explicit measure related to student knowledge, orientation, or behavior was often omitted. These results align with Sztajn's (2011) concerns, who argued that norms and standards for reporting on professional development studies are needed. Still, consistent with Supovitz and Turner (2000), such standards must include the specific content area(s), grade band(s), and technology type addressed in the professional development. The constructs of the study must be clearly and explicitly stated, threats to validity discussed, and research methodologies clearly articulated as purported in the scientific principles 3 and 4 (Shavelson & Towne, 2002).

Future Directions

The historical data we analyzed in mathematics educational technology literature denotes a clear need for future research measuring the effectiveness of professional development focused on technology in teaching and learning mathematics. Professional development efficacy can be measured by using observational tools, teacher knowledge assessments, and teacher surveys to assess teachers' change in practice. These changes should evaluate instructional activities and practices, classroom discourse, the fidelity in which the curriculum is implemented, teacher knowledge, and teachers' beliefs. Another reasonable direction is to measure changes in student learning/achievement, although we recognize the challenge in collecting such data and the necessity of an extensive length of professional development to gather the data to evaluate this change.

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Research analyzing technology-focused professional development in mathematics education could make great strides in mitigating the field's traditional challenges by pointing to specific research-supported methods for improving future professional development.

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