RESEARCH IN MATHEMATICS EDUCATIONAL TECHNOLOGY: CURRENT TRENDS AND FUTRUE DEMANDS

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This systematic review of mathematics educational technology literature identified 1356 manuscripts addressing the integration of educational technology into mathematics instruction. The manuscripts were analyzed using three frameworks (Research Design, Teacher Knowledge, and TPACK) and three supplementary lenses (Data Sources, Outcomes, and NCTM Principles) to produce a database to support future research syntheses and meta-analyses. Preliminary analyses of student and teacher outcomes (e.g., knowledge, cognition, affect, and performance) suggest that the effects of incorporating graphing calculator and dynamic geometry technologies have been abundantly studied; however, the usefulness of the results was often limited by missing information regarding measures of validity, reliability, and/or trustworthiness.

Educational technology (i.e., digital technology, as opposed to other forms of educational tools such as overhead projectors or physical manipulatives) is promoted to mathematics teachers as a research-based strategy for improving student outcomes. Although research on mathematics educational technology appears at first glance to be ubiquitous, the usefulness of this research to practitioners and researchers is limited by lack of attention to research design and validity, reliability, and threats to validity (Rakes et al., 2011). Additionally, much of the research appears to be unorganized, with topics such as graphing calculators studied often, while other topics such as virtual manipulatives understudied (Ronau et al., 2010). The purposes of this systematic review were to (1) examine the evidence of technology impact on the teaching and learning mathematics in K-13, graduate, teacher development, and adult education using three frameworks (Comprehensive Framework of Teacher Knowledge [CFTK], Research Design, and Technology, Pedagogy, and Content Knowledge [TPACK]) and three supplementary lenses (Data Sources, Outcomes, and NCTM Principles) and (2) assess the utility of each framework for guiding the synthesis of mathematics educational technology research.

Theoretical Framework and Background

Three frameworks were applied to the analysis in the set of mathematics educational technology studies discovered by the systematic review: Research Design, CFTK, and TPACK. The research design framework was used to guide the investigation of the types of research approaches used in mathematics educational technology research. The complex nature of questions pertaining to educational technology effectiveness requires a variety of research designs such as (1) experimental or quasi-experimental studies, (2) large-scale studies, (3) studies with sufficient statistical information to be included in meta analysis and mixed-methodology studies, (4) studies with rich analysis of student content knowledge, and (5) studies that address the complexities of learners, classrooms, and schools (Bell, Schrum, & Thompson,

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2008; Means, Wagner, Haertel, & Javitz, 2003). However, without explicit attention to the alignment of the research design to the questions of interest, the validity and reliability of the measures used, and the threats to validity within the chosen design, the reported outcomes will be less likely to have been founded on scientific principles or to be replicable (Shadish, Cook, & Campbell, 2002). The usefulness of such studies to practitioners and researchers will be, therefore, limited without robust attention to research design issues. The Research Design framework (Ronau et al., 2010) was compiled from several sources to address pertinent issues across a wide range of research types (e.g., Creswell, 2009; Shadish et al., 2002; Shavelson & Towne, 2002; Teddlie & Tashakorri, 2009). For a detailed description of the Research Design framework, see Rakes, Wagener, and Ronau (2010).

Within the past few years, two new teacher knowledge frameworks have been proposed that have the potential to support the research community in responding to questions on the impact of technology on learning. The Comprehensive Framework of Teacher Knowledge (CFTK; Figure 1) provides a three-dimensional model for addressing multiple aspects of teacher knowledge and their interactions (Rakes, Ronau, & Niess, 2010; Ronau, Rakes, Wagener, & Dougherty, 2009; Ronau, Wagener, & Rakes, 2009). This model transforms current understanding of teacher knowledge from a linear structure to a three dimensional model, as shown in Figure 1, by pairing six inter-related aspects into three orthogonal axes: 1) Field, comprised of Subject Matter and Pedagogy; 2) Mode, comprised of Orientation and Discernment; and 3) Context, comprised of Individual and Environment. For a detailed description of the CFTK aspects and dimensions, see Ronau and Rakes (in press).

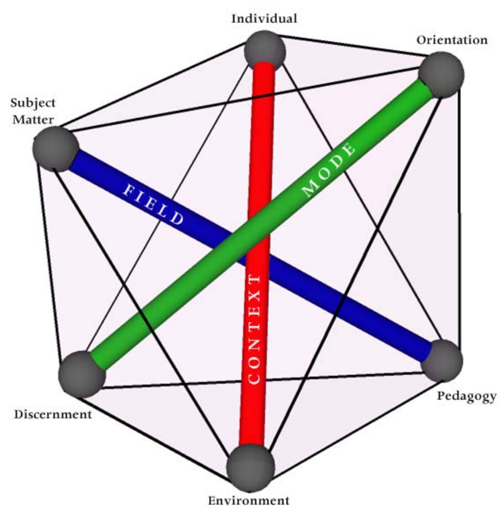

Figure 2. CFTK framework of teacher knowledge as a three-dimensional structure.

The Technology, Pedagogy, and Content Knowledge (TPACK) framework defines the knowledge needed by teachers to integrate technology into the pedagogy of particular subject matter (e.g., Mishra & Koehler, 2006; Niess, 2005). In its entirety, TPACK consists of a set of descriptive knowledge components embedded in an educational Context, Content Knowledge (CK), Pedagogical Knowledge (PK), and Technological Knowledge (TK), and a series of interactions, Pedagogical Content Knowledge (PCK), Technological Pedagogical Knowledge (TPK), Technological Content Knowledge (TCK), and TPACK. The initial TPACK framework has been extended to provide benchmarks of the development of this knowledge as shown in

Figure 2, including recognizing, accepting, adapting, exploring, and advancing (Niess, Lee, & Sadri, 2007).

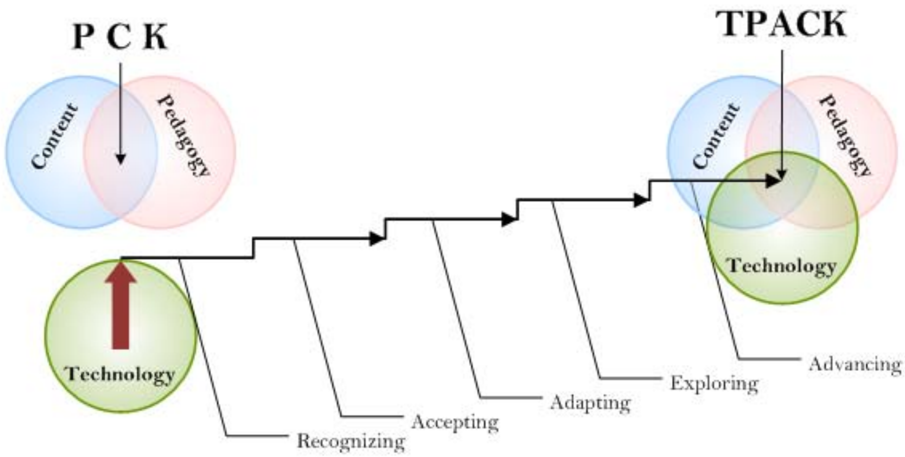

Figure 3. Model of teacher thinking and understanding as that knowledge develops toward the intersection identified as important by TPACK.

Based on feedback through peer debriefing (Rakes et al., 2010), three additional lenses (Data Sources, Outcomes, and NCTM Principles) were added to provide a more comprehensive snapshot of the research landscape, guiding practitioners to choose best practices and for guiding future research directions.

Using these frameworks and lenses, we began our investigation with two overall questions: (1) To what degree do the three frameworks, Research Design, CFTK, and TPACK, capture the scope of mathematics educational technology research? (2) What Data Sources, Outcomes, and NCTM Principles are addressed in mathematics educational technology research? To what degree, and how, implicit/explicit?

Method

A research synthesis (Cooper & Hedges, 2009) was conducted to address the two overall questions. To identify the most representative sample that was relevant to the questions of interest (i.e., construct validity), a wide array of databases were searched using terms to restrict the sample based on three inclusion criteria: (1) The study needed to examine a technology-based intervention; (2) The intervention needed to target the learning of a mathematics concept or procedure; (3) The manuscript needed to be available in the English language. The database platforms and individual databases included EBSCOWeb (ERIC, Academic Search Premier, PsychInfo, Primary Search Plus, Middle Search Plus, Educational Administration Abstracts), JSTOR (limited to the following disciplines: Education, Mathematics, Psychology, and Statistics), OVID, ProQuest (Research Library, Dissertations & Theses, Career & Technical Education), and H. W. Wilson Web (Education Full Text). From these databases, 1356 manuscripts (journal articles, book chapters, technical reports, conference proceedings, master's theses, and doctoral dissertations) were identified as being potentially relevant to the questions of interest.

The initial coding database was pilot tested with three articles and two coders to help refine the coding database. Refinements based on the results of this pilot test were examined with all six researchers coding the same, original three articles. This process was repeated through three more iterations of refinement and coding of 27 more articles (i.e., 30 articles were group coded).

After the analysis of 473 manuscripts, a number of coding issues emerged that required attention. Extensive team discussions led to a number of coding clarifications to improve team alignment, including how to: code studies with meta-analyses and/or systematic reviews, mixed methodology designs and single subject designs, action research, and survey research; code purposive and convenience sampling, subject dialog data, and modified and validated instruments; and record evaluative comments when deemed necessary. Finally, a number of coding form issues was addressed. The existing database of 473 studies was aligned with this new set of procedures and understandings, and the team developed a new process of coding the remaining studies that paired each of the six coders with all the other coders to provide a mixed set of double coding for the remainder of the studies. The new coding design created a completely counter-balanced design with all six coders that provided greater inter-rater reliability and content validity of the coding. With this plan, every manuscript was coded by two members of the coding team, and each member coded 59 studies with every other member. Any discrepancies between coder and re-coder were recorded and discussed by the pair and by the full team as needed.

Preliminary Results

At the time of the writing of this paper, 473 manuscripts have been coded and cross-validated (i.e., double coded and checked for accuracy). Twenty four of these manuscripts were screened out because they were not relevant to the questions of interest (i.e., did not address the learning of mathematics concepts and procedures, did not involve technology, or was not available in English), leaving 449 manuscripts in the sample. Initial results were examined by grouping the manuscripts into four categories (not mutually exclusive) of outcomes: Student Achievement and Learning; Student Orientation, Discernment, and Learning Behavior; Teacher Knowledge; and TPACK. The manuscripts and their 449 characteristics were analyzed through descriptive statistics as an initial method for interpreting the landscape of mathematics educational technology research.

The Role of Educational Technology in Student Achievement and Learning

Of the relevant manuscripts, 218 addressed educational technology in mathematics with a view of improving student achievement and learning. As shown in Table 1, over half (N=113) were dissertations and many of the remainder (N=69) were journal articles. Over half (N=118) were purely quantitative studies. The remaining studies were qualitative (N=36), mixed methods (N=43), non-research (N=9), meta analysis/systematic review (N=6), literature driven (N=5), or single subject (N=1). Performance assessments (e. g., tests, performance tasks, grades, GPA, etc.) were the most common sources of data used in these manuscripts, while journals (all types), focus groups, and non self-report surveys were the least used.

The manuscripts in this subsample most commonly addressed the Algebra NCTM Content Standard (N=159) and the Problem Solving Process Standard (N=89). Graphing calculators (N=43), tutorial software (N=39), and dynamic geometry software (N=25) were the more regularly studied technologies. In regards to information on measures of reliability and validity for the quantitative and mixed methods studies, approximately 41% of the manuscripts addressed reliability, 30% addressed validity, and 57% addressed threats to validity. For the qualitative and mixed methods studies, 60% attended to trustworthiness where approximately 62% of these studies attended to only one form of trustworthiness.

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Type of Manuscript by Research Design	Non-research	Quali-tative	Quanti-tative	Mixed Methods	Single Subject	Meta-Analysis/ Sytematic Review	Liter-ature	Total
Book Chapter	0	1	1	0	0	0	1	3
Conference Paper	1	2	1	2	0	0	1	7
Disserta-tion	0	15	59	34	1	4	0	113
Journal	8	16	35	6	0	1	3	69
Master's Thesis	0	2	18	1	0	0	0	21
Report	0	0	4	0	0	1	0	5
Grand Total	9	36	118	43	1	6	5	218

Table 1. Student achievement and learning manuscripts by research design.

The Impact of Educational Technology on Student Orientation

Of the relevant manuscripts, 126 had examined the impact of educational technology on student orientation (i.e., the affective domain), discernment (i.e., the cognitive domain), and learning behaviors (e.g., student dialog and collaboration). The manuscripts consisted of 71 dissertations and 39 journal articles. Of these, 62 used purely quantitative analyses, 28 used purely qualitative methodologies, and 27 used mixed methodology. Self-report orientation survey data and performance assessment data were the two most common types of data sources; the top seven data sources are listed in Table 2. The Algebra NCTM Content Standard (N=32) and the Problem Solving Process Standard (N=23) were the most commonly addressed NCTM standards. Graphing calculators (N=24) were the most common type of calculator-based technology, followed by non-scientific calculators (N=16). The three most frequently used nonweb-based software were tutorial software (N=15), dynamic geometry (N=13), and algebra (N=12). Distance learning stood out among the web-based technologies (N=10) as these other technologies were often not addressed or addressed in only one or two manuscripts. Only 27% of the quantitative and mixed methods studies addressed issues surrounding validity, 61% addressed threats to validity, and 42% addressed reliability. Of the qualitative and mixed methods studies, 73% attended to trustworthiness, with 55% that attended to only one form of trustworthiness.

Data Sources	Number of Studies
Self-Report Orientation Survey Data	83
Performance Assessment Data	76
Observation Data	42
Interview Data	37
Content Analysis Data	28
Self-Report Polls and Census Survey Data	13
Researcher Journal Data	8

Table 2. Top seven data sources for student orientation.

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The Interaction of Teacher Knowledge Aspects in Educational Technology Research

Teacher Knowledge was examined as an outcome in 72 manuscripts, of which 39 were journal articles and 26 were dissertations. The most common research design was qualitative (N=35), followed by non-research (N=15), mixed methods (N=11), and quantitative (N=8). The four most frequently used data sources were observation data (N=42), interview data (N=30), content analysis data (N=29), and self-report orientation survey data (N=24). Graphing calculators, dynamic geometry software, and spreadsheets were the most commonly studied technologies. The Algebra Content Standard (N=20) and the Problem Solving Process Standard (N=11) were the most commonly addressed NCTM standards. The distribution of CFTK aspects and interactions from this sample was compared to the distribution reported in Ronau and Rakes (in press) for teacher knowledge studies across multiple subject matter domains. The average number of aspects examined in mathematics educational technology ($\bar{x}$ = 1.53, SE = 0.207) appeared to be smaller than the average number of aspects examined across multiple subject matter domains ($\bar{x}$ = 2.16, *SE* = 0.119). This difference appeared to be statistically significant ($t_{df=71}$=3.74). This result may indicate that the research field in mathematics education technology may be considering less complex perspectives of teacher knowledge than other subject matter domains. Reliability was attended to in 32% of the quantitative and mixed methods studies, with validity and threats to validity attended to in 11% and 53%, respectively. Trustworthiness was addressed in 65% of the qualitative and mixed methods studies, where 60% addressed only one form of trustworthiness.

	Graphing Calculators	Dynamic Geometry	Spread-sheets	Graphing Software	Algebraic Software	Statistics Software	Tutorials
Number of Studies	22	19	14	7	5	5	5

Table 3. Top seven technologies for teacher knowledge.

The Use of TPACK to Guide Educational Technology Research

TPACK, as a guiding framework of the knowledge teachers need for integrating educational technology in mathematics, was employed either explicitly or implicitly, in 219 manuscripts, of which 102 were journal articles and 85 dissertations. Of these manuscripts, 72 used purely quantitative methodologies, 48 used purely qualitative methodologies, 27 used mixed methodologies, and 61 did not employ any type of research design (i.e., anecdotal support of hypotheses or descriptions of techniques). Performance assessment was the most commonly used data source (N=86). The NCTM Content Standards considered most often were Algebra (N=67), Geometry (N=45), and Number & Operations (N=37), while Problem Solving (N=35) was the most commonly considered Process Standard. Graphing calculators (N= 54) and dynamic geometry software (N=49) were the two most common types of technology used. Only 24% of the quantitative and mixed methods studies addressed validity issues, 81% addressed threats to validity, and 39% addressed reliability. Of the qualitative and mixed methods studies, 65% attended to trustworthiness, with 63% that attended to only one form of trustworthiness.

Summary

Several patterns were common among all four outcome groups. Dissertations and journal articles were the two most common types of manuscripts, with quantitative studies being the most prevalent research design among three of the four areas (all except teacher knowledge outcomes). Also among these three areas, performance assessment and self-report orientation survey were the two most often used data sources. The most common NCTM Content and Process Standards addressed in all four areas were Algebra and Problem Solving, respectively. Graphing calculators were consistently the most frequently used calculator-based technology, while dynamic geometry was either the most commonly used or second most commonly used non-web-based technology for all four areas. Web-based technologies were the least frequently used type of technology among all four areas.

Missing information regarding measures of validity, reliability, and/or trustworthiness was prevalent. Overall, approximately 40% of the quantitative and mixed methods studies addressed reliability, 27% addressed validity, and 64% addressed threats to validity. Trustworthiness was attended to in approximately 65% of all qualitative and mixed methods studies.

Discussion

The completion of the study will provide a searchable database of educational technology studies from 1968 to 2010, containing key information organized by three frameworks and four lenses. With this data, we will be able to better describe the landscape of educational technology research in mathematics, providing significant detail about the type, quality, content, and alignment of the studies. Doctoral students and advisors will benefit from an analysis of the 600+ dissertations in the sample, providing a guide to over- and under-studied dissertation topics (e.g., impact of graphing calculators in algebra). The research team will be able to identify gaps in the research base with respect to a number of study characteristics organized by the frameworks and lenses described above, as well as the depth and quality of areas well-studied. Detailed coding of research design features will allow for rigorous examination of the evidence currently available to the field in the form of meta-analysis and qualitative research syntheses. The systematic nature of this review will provide a foundation for future investigations and replication. Additionally, once the initial coding is completed, the task of updating the database with newly released manuscripts can easily be accomplished. Finally, this study will also include an evaluation of the utility of each of the three frameworks and four lenses used in the analysis to capture the perspective and the critical details of educational technology research.

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