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Educational Technology, Teacher Knowledge, and Classroom Impact

A Research Handbook
on Frameworks and Approaches



Robert N. Ronau, Christopher R. Rakes & Margaret L. Niess

Educational Technology, Teacher Knowledge, and Classroom Impact:

A Research Handbook on Frameworks and Approaches

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Section 1

Strategies for Conducting Educational Technology or Teacher Knowledge Research

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Technology, pedagogy, and content knowledge (TPACK) is a dynamic lens that describes teacher knowledge required for designing, implementing, and evaluating curriculum and instruction with technology. TPACK strategic thinking incorporates knowing when, where, and how to use domain-specific knowledge and strategies for guiding students' learning with appropriate digital, information and communication technologies. This chapter maps historical responses to the question of the knowledge teachers need for teaching amid the emerging views of and challenges with TPACK. A review of empirical progress serves to illuminate potential insights, values, and challenges for directing future research designed to identify a teacher's learning trajectory in the development of a more robust and mature TPACK for teaching with current and emerging information and communication technologies.

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How Do We Measure TPACK? Let Me Count the Ways	16
<i>Matthew J. Koehler, Michigan State University, USA</i>	
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In this chapter we reviewed a wide range of approaches to measure Technological Pedagogical Content Knowledge (TPACK). We identified recent empirical studies that utilized TPACK assessments and determined whether they should be included in our analysis using a set of criteria. We then conducted a study-level analysis focusing on empirical studies that met our initial search criteria. In addition, we conducted a measurement-level analysis focusing on individual measures. Based on our their measure-

ment-level analysis, we categorized a total of 141 instruments into five types (i.e., self-report measures, open-end questionnaires, performance assessments, interviews, and observations) and investigated how each measure addressed the issues of validity and reliability. We concluded our review by discussing limitations and implications of our study.

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Results from Classroom-Based TPACK Research 32

Thomas C. Hammond, Lehigh University, USA

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The TPACK framework provides researchers with a robust framework for conducting research on technology integration in authentic environments, i.e., intact classrooms engaged in standards-aligned instruction. Researchers who wish to identify the value added by a promising technology-supported instructional strategy will need to assess student learning outcomes in these environments; unfortunately, collecting valid and reliable data on student learning in classroom research is extremely difficult. To date, few studies using TPACK in K-12 classrooms have included student learning outcomes in their research questions, and researchers are therefore left without models to guide their development, implementation, and analysis of assessments. This chapter draws upon the literature and our own research and assessment experiences in technology-integrated, standards-aligned classroom instruction to give examples and advice to researchers as they develop, analyze, and write up their observations of student learning outcomes. In particular, we focus on standard items, specifically multiple choice items, as an accepted (if limited) method for assessing student understanding. We seek to fill an existing gap in the literature between assessment advice for educational psychologists (who typically work outside of classroom settings) and advice given to teachers (who have lower thresholds for issues such as validity and reliability). Classroom researchers will benefit from this advice to develop, validate, and apply their own objective assessments. We focus on the content areas of science and social studies, but this advice can be applied to others as well.

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A Comprehensive Framework for Teacher Knowledge (CFTK):Complexity of Individual Aspects and Their Interactions 59

Robert N. Ronau, University of Louisville, USA

Christopher R. Rakes, Institute of Education Sciences, USA

In this chapter, we examine the validity of the Comprehensive Framework for Teacher Knowledge (CFTK) through a systematic review and meta-analysis. This model, developed through a series of exploratory studies, transforms current understanding of teacher knowledge from a linear structure

to a three dimensional model by pairing 6 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. The current study analyzes the way interactions of these aspects appear in literature across a wide domain of subject matters. These interactions have direct implications for future research on teacher knowledge as well as policies for guiding professional development and pre-service teacher training.

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The TPACK of Dynamic Representations	103

Lynn Bell, University of Virginia, USA

Nicole Juersivich, Nazareth College, USA

Thomas C. Hammond, Lehigh University, USA

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Effective teachers across K-12 content areas often use visual representations to promote conceptual understanding, but these static representations remain insufficient for conveying adequate information to novice learners about motion and dynamic processes. The advent of dynamic representations has created new possibilities for more fully supporting visualization. This chapter discusses the findings from a broad range of studies over the past decade examining the use of dynamic representations in the classroom, focusing especially on the content areas of science, mathematics, and social studies, with the purpose of facilitating the development of teacher technological pedagogical content knowledge. The chapter describes the research regarding the affordances for learning with dynamic representations, as well as the constraints—characteristics of both the technology and learners that can become barriers to learning—followed by a summary of literature-based recommendations for effective teaching with dynamic representations and implications for teaching and teacher education across subject areas.

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Jeanine Beatty, Rutgers, USA

This chapter informs teacher educators and individuals involved in teacher professional development about the tensions that frequently arise when K-12 teachers integrate technology into their classrooms. Suggestions for how individuals can help teachers confront and overcome these challenges are presented. In order to describe the various tensions that exist, findings are organized around concerns that are related to the innovator (e.g., the teacher), the technological innovation, and the contextual factors that arise from the environment in which teaching and learning occur. To describe ways to assist teachers as they confront the challenges of technology integration, recommendations are framed around the Cognitive Apprenticeship Model (CAM) and the four dimensions that constitute a successful learning environment: content, method, sequencing, and sociology.

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John K. Lee, North Carolina State University, USA

Meghan M. Manfra, North Carolina State University, USA

To address the myriad effects that emerge from using technology in social studies, we the authors introduce in this chapter the concept of vernaculars to represent local conditions and tendencies, which that arise from using technology in social studies. The chapter includes three examples of TPACK vernaculars in social studies. The first explores a theoretical TPACK vernacular where Web 2.0 technologies support social studies and democratic life. The second example is focused on a three-part heuristic for seeking information about digital historical resources from the Library of Congress. Example three presents personalized vernacular TPACK developed by teachers planning to use an online gaming website called Whyville. Research and theorizing on vernacular forms of TPACK in social studies can aid teachers as they reflect on their own experiences teaching with technology.

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Classroom Connectivity Technology (CCT) can serve as a tool for creating contexts in which students engage in mathematical thinking leading to understanding. We The authors theorize four principles of effective mathematics instruction incorporating CCT based on examination of teachers' use of CCT within their Algebra I classrooms across four years. Effective implementation of CCT is dependent upon (1) the creation and implementation of mathematical tasks that support examination of patterns leading to generalizations and conceptual development; (2) classroom interactions that focus mathematical thinking within students and the collective class; (3) formative assessment leading to teachers' and students' increased knowledge of students' present understandings; and (4) sustained engagement in mathematical thinking. Each of these principles is discussed in term of its implications for teacher knowledge.

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Christopher J. Johnston, American Institutes for Research, USA

Patricia S. Moyer-Packenham, Utah State University, USA

Multiple existing frameworks address aspects of teachers' knowledge for teaching mathematics with technology. This study proposes the integration of several frameworks , including TPACK (Mishra & Koehler, 2006), MKT (Ball, Thames, & Phelps, 2008), and technology evaluation criteria (Battey, Kafai, & Franke, 2005), into a new comprehensive model for interpreting teachers' knowledge of the use of technology for teaching mathematics. The study employed quantitative and qualitative methods to examine 144 pre-service elementary teachers' evaluations of technology for future mathematics teaching. The proposed model and its application to this group of pre-service teachers suggest that there are multiple dimensions to understanding teachers' knowledge of uses of technology for mathematics teaching, and that teachers' self-identified evaluation criteria reveal the dimension in which their knowledge resides. Understanding teachers' progressions through these dimensions may provide insights into the types of experiences that support teacher development of the knowledge necessary to teach mathematics using appropriate technologies.

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Joseph M. Piro, Long Island University, USA

Nancy Marksby, Long Island University, USA

With the continuing shift of instructional media to digital sources occurring in classrooms around the world, the role of technology instruction in the pre-service curriculum of K-12 teachers is acquiring increasing salience. However, barriers to its inclusion continue to exist. In this chapter we focus on a model of hybridity designed to embed technology instruction into pre-service education. This model is known as the WebQuest, and involves the development of a technology-driven learning activity that scaffolds the building of skills in content, pedagogy, and technology integration in pre-service teachers. We discuss data from an exploratory project conducted within a class of graduate pre-service teachers experiencing instruction in creating a WebQuest, and offer some preliminary findings. We place these results within a larger perspective of the CFTK and TPACK frameworks and their application to issues germane to pre-service teacher education.

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Travis K. Miller, Millersville University of Pennsylvania, USA

This chapter details a theoretical framework for effective implementation and study of technology when used in mathematics education. Based on phenomenography and the variation theory of learning, the framework considers the influence of the learning context, students' perceptions of the learning opportunity, and their approaches to using it upon measured educational outcomes. Elements of the TPACK framework and the CTFK model of teacher knowledge are also addressed. The process of meeting learn-

ing objectives is viewed as leading students to awareness of possible variation on different aspects, or dimensions, of an object of mathematical learning.

Chapter 12

Successful Implementation of Technology to Teach Science: Research Implications 271

David A. Slykhuis, James Madison University, USA

Rebecca McNall Krall, University of Kentucky, USA

In this review of recent literature on the use of technology to teach science content, 143 articles from 8 science education journals were selected and analyzed for the use of technologies in teaching science, pedagogies employed, and successes of the implementations. The resultant data provides a snapshot on how technology is being used in the teaching and learning of science, and the research methods used to explore these issues. Levels of research and levels of success were developed and applied to the article data set to characterize the types of research and technology implementations described in the literature. Articles that showed high levels of successful implementation of technology along with a high level of research were explored and explained in greater detail. The review underscores the research trend toward using technology to illustrate abstract concepts and make objects that are invisible to the naked eye, visible and malleable in computer modeling programs. Implications for successful use of technology to teach science are discussed.

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The Effects of Teacher Content Authoring on TPACK and on Student Achievement in Algebra:

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Irina Lyublinskaya, College of Staten Island/CUNY, USA

Nelly Tournaki, College of Staten Island/CUNY, USA

A year-long PD program was provided to four NYC integrated algebra teachers. The PD comprised of teacher authoring of curriculum that incorporated TI-Nspire™ technology. Teacher TPACK levels were measured through a TPACK Levels Rubric, created and validated by the authors. The rubric was used to assess the teachers' written artifacts (lesson plans and authored curriculum materials) and observed behaviors (PD presentations and classroom teaching through observations). Results indicated that, first teachers' TPACK scores for written artifacts paralleled those of PD presentations. Second, the classroom teaching was either at the same level or lower than written artifacts. Third, teachers did not improve with every lesson they developed; instead, their scores vacillated within the two or three lower TPACK levels. Finally, the students taught by the teachers with higher TPACK level had higher average score on the NYS Regents exam and higher passing rates.

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Making the Grade: Reporting Educational Technology and Teacher Knowledge Research 323

Robert N. Ronau, University of Louisville, USA

Christopher R. Rakes, Institute of Education Sciences, USA

This chapter examines issues surrounding the design of research in educational technology and teacher knowledge. The National Research Council proposed a set of principles for education research that has not been applied consistently to teacher knowledge and education technology research. Although some

studies address reliability of measures, few adequately address validity or threats to validity or the trustworthiness of their designs or findings. Special attention is given to the need for explicit connections between the study purpose and guiding theoretical frameworks and previous research. This volume provides examples of studies addressed these design issues and includes a checklist of questions and additional resources to aid future researchers in developing rigorous, scientific research.

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Preface

Education Technology, Teacher Knowledge, and Classroom Impact: A Research Handbook on Frameworks and Approaches provides a compilation of strategies that can be used to conduct research, a description of the current research field, and an examination of the role of research in guiding practice. This book began with a review of literature (Ronau et al., 2010) whose original purpose to conduct a meta-analysis was de-railed as we examined the quality of evidence presented and found major gaps in the content and validity of findings that appeared to be the result of inconsistencies in design and reporting of results such as: application and alignment with clearly articulated theoretical frameworks, quality of validity evidence to justify the development of new theoretical frameworks, and quality of validity and reliability evidence provided to justify claims from primary and secondary analyses. We therefore set out to compile a guide to provide structural models and example studies for researchers and practitioners as they develop, implement, and interpret future research. The book is divided into three sections to address this purpose.

The first section begins the handbook by reviewing strategies that have been used to conduct research on teacher knowledge for integrating educational technology. Niess discusses conceptions of Technology, Pedagogy, and Content Knowledge (TPACK), a leading conceptual framework for examining teacher knowledge for educational technology. Koehler, Mishra, and Shin conduct a systematic review of ways that have been used to measure TPACK. Hammond, Alexander, and Bodzin wrap up this section by discussing measurement issues associated with the development of value added models for TPACK on student achievement.

The second section examines the current landscape of educational technology and teacher knowledge research. Ronau and Rakes focus on teacher knowledge, conducting a systematic review of literature to develop the representativeness and relevance of the Comprehensive Framework of Teacher Knowledge (CFTK). Bell, Juersivich, Hammond, and Bell focus on the benefits and challenges of integrating dynamic representation software in mathematics, science, and social studies. Boling and Beatty conclude this section by concentrating on the challenges of preparing new teachers to integrate technology through the Cognitive Apprenticeship Model (CAM).

The third section considers the role of research in guiding practice. Lee and Manfra begin this section by discussing how vernaculars for TPACK arise in social studies. Pape, Irving, Bell, Shirley, Owens, Owens, Bostic, and Lee present principles of effective instruction in mathematics for the integration of classroom connectivity technology. Johnston and Moyer-Packenham compile three frameworks to present a model for examining preservice teacher knowledge of integrating technology in mathematics. Piro and Marksbury discuss the benefits and challenges of implementing WebQuests in the classroom through the lenses of CFTK and TPACK. Miller examines the role of knowledge of context in the effective imple-

mentation of technology in the study of mathematics. Slykhuis and Krall conducted a systematic review of literature to examine the use of educational technology to teach science concepts. Lyublinskaya and Tournaki developed a rubric to assess TPACK based on evidence from a year-long professional development program. Ronau and Rakes conclude the handbook by examining research design issues that have inhibited the field from constructing high quality evidence to guide future research and practice.

DUALITY OF TEACHER KNOWLEDGE FRAMEWORKS

This preface would not be complete without some discussion of the dual nature of teacher knowledge frameworks such as TPACK and CFTK. Theoretical frameworks of teacher knowledge are often used as models to guide and interpret studies by naming and describing the knowledge being represented. The same models are also often used as a guide to break apart components of the knowledge that they represent, measure those individual components, interpret the measures and the measures of the interactions of those parts, and then employed as a map to form these results into an overall outcome. This duality of purposes may lead to a particularly potent threat to validity as teacher knowledge research progresses to ways of measuring teacher knowledge and examining links between teacher knowledge and student achievement. For example, Mathematics Knowledge for Teaching (MKT) (Hill, Schilling, & Ball, 2004), one of the most prominent teacher knowledge frameworks in mathematics, has been used to name and describe the types of subject matter knowledge teachers need to teach mathematics and how that knowledge interacts with pedagogical knowledge and sometimes knowledge of students. Hill, Ball, Blunk, Goffney, & Rowan (2007) recognized, however, that the achievement measures created as proxies are not always representative of the targeted underlying constructs (i.e., achievement does not always equal knowledge). As a result of their studies, they recommended that studies proposing to measure teacher knowledge need to be concerned not only with content validity of the items developed, but also with convergent validity of the achievement measure with observational measures.

TPACK and CFTK are relatively new frameworks compared to MKT; they represent important advances to the field of teacher knowledge research, because they describe and define teacher knowledge not accounted for by other frameworks (i.e., TPACK describes the interaction of technology knowledge with pedagogical content knowledge; CFTK describes complex interactions of teacher knowledge). Measures for TPACK have begun to emerge, but the items developed have typically measured TPACK achievement or behavior as proxies for TPACK. The rigorous application of content validity considerations coupled with convergent validity considerations has not yet been applied to the measurement of TPACK. For example, although some studies have parsed TPACK into measures of its subcomponents (i.e., technological knowledge (TK), content knowledge (CK), pedagogical knowledge (PK), pedagogical content knowledge (PCK), technological content knowledge (TCK), and technological pedagogical knowledge (TPK)), the convergent validity between the subcomponents and the overall TPACK construct has not yet been explored. Similarly, the CFTK framework has begun to re-define conceptualizations of teacher knowledge; as this line of research matures, instruments will need to be developed to measure its constructs in valid, reliable ways and be able to interpret the measures in terms of the overall construct (i.e., concurrent and convergent validity). Such considerations are a step beyond the issues presented in this volume. We hope that this handbook challenges and supports this future research direction.

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Section 1

Strategies for Conducting Educational Technology or Teacher Knowledge Research

Chapter 1

Teacher Knowledge for Teaching with Technology: A TPACK Lens

Margaret L. Niess
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ABSTRACT

Technology, pedagogy, and content knowledge (TPACK) is a dynamic lens that describes teacher knowledge required for designing, implementing, and evaluating curriculum and instruction with technology. TPACK strategic thinking incorporates knowing when, where, and how to use domain-specific knowledge and strategies for guiding students' learning with appropriate digital, information, and communication technologies. This chapter maps historical responses to the question of the knowledge that teachers need for teaching amid the emerging views of and challenges with TPACK. A review of empirical progress serves to illuminate potential insights, values, and challenges for directing future research designed to identify a teacher's learning trajectory in the development of a more robust and mature TPACK for teaching with current and emerging information and communication technologies.

TEACHER KNOWLEDGE: A HISTORICAL VIEW

What knowledge do teachers need for teaching? Responses to this question have evolved over the past centuries, with significant changes at the

beginning of the 20th century (Parkay & Stanford, 2008). Up through the 19th century, the prevailing notion was that teachers needed to know the content they were to teach. This view shifted to the importance of knowing how to teach; teachers needed to be prepared to implement new teaching and learning (or pedagogical) practices along with an even more in depth understanding of the

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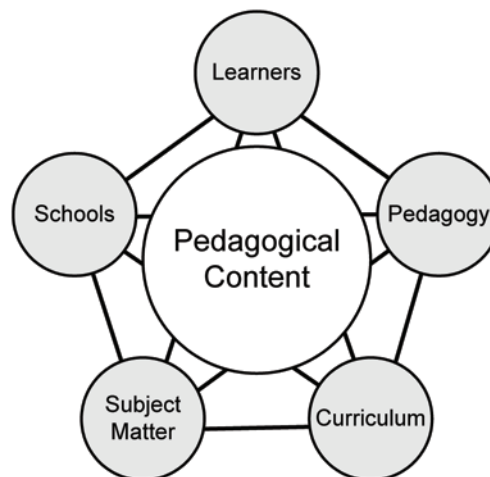
content they were planning on teaching (Grimmett & MacKinnon, 1992; Parkay & Stanford, 2008). The late 1980s signaled another significant shift in views on this question. Shulman (1987) challenged teacher educators and researchers to reconsider the knowledge that teachers need indicating that, at a minimum, teacher knowledge included:

- Content knowledge
- General pedagogical knowledge
- Curriculum knowledge
- Pedagogical content knowledge
- Knowledge of learners
- Knowledge of educational contexts
- Knowledge of educational ends, purposes, and values

Among these more extensive knowledge domains, pedagogical content knowledge (or PCK) was identified as the knowledge that represented “that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of understanding ... of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction” (Shulman, 1987, p. 8).

This identification of teacher knowledge (Wilson, Shulman, & Richert, 1987) was markedly different from previous views, resulting in extensive research and scholarly discussion about the nature of PCK and the types of programs needed to adequately prepare teachers such that they develop this knowledge (Gess-Newsome, J., 2002; Niess, 2005). At my institution, this change encouraged the faculty to redesign the science and mathematics teacher preparation program to explicitly develop this more comprehensive teacher knowledge called PCK. Figure 1 provides the visual description we used to guide the program redesign. This visual recognized the importance of multiple knowledge domains of teacher knowledge - learners, pedagogy, curriculum, subject matter, and schools (describing the

Figure 1. Visual display of the relationships and interactions of the six teacher knowledge domains



educational contexts, ends, purposes and values) - as being a complex and interconnected whole with PCK at the hub connecting all the domains. As a result, this graduate level, content-specific teacher preparation program was focused on an integration of the multiple domains of knowledge viewed as integral to teaching and learning science and mathematics (Niess, 2001). Courses contained subject-specific pedagogical modeling rather than a generic pedagogy class. The emphasis was to have the preservice teachers think about and reflect upon the multiple domains as they investigated each topic or assignment. The overall goal was to guide the preservice teachers in developing an integrated, interconnected knowledge for teaching that incorporated PCK.

Amid the evolving views on the knowledge teachers need for teaching, a technological knowledge explosion significantly enhanced humans' abilities “to change the world” through the invention of computer-based technologies (American Association for the Advancement of Science, 1989). While iron horse technologies fueled the Industrial Age of the 20th century (Hillstrom & Hillstrom, 2005), the invention of the computer and the Internet paved society's way into the

Information and Communication Age of the 21st century (Parkay & Stanford, 2008). As the computer technologies advanced, they became more and more accessible for educational purposes (Roblyer & Doering, 2009). Even though most of the digital technologies emerging by the 1980s were developed for different tasks, some educators were beginning to visualize how these technologies might be used as learning tools. The expansion of the Internet and the proliferation of millions of interconnected computer networks began impacting everyday lives as early as the 1990s. This dynamic shift toward the dependence on more and more information and communication technologies for everyday life quickly challenged the basic idea of what knowledge and skills were needed for productive citizenship (Niess, Lee & Kajder, 2008).

TEACHER KNOWLEDGE: A TECHNOLOGICAL VISION

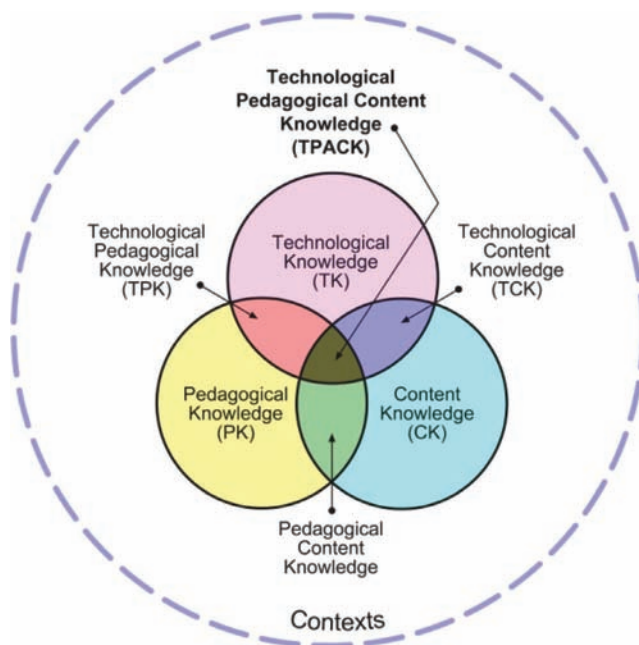
Teachers today are faced with challenges and questions of how and when to incorporate new and emerging digital technologies for teaching and learning various subject matter topics. With few exceptions, their precollege and college education have not prepared them with these digital technologies. Yet, as “digital immigrants,” their students are “digital natives” with significantly different experiences with digital technologies (Prensky, 2001). Therefore, teacher educators have been engaged in the search for preservice, inservice, and professional development experiences to reshape teachers’ thinking in ways that incorporate new and emerging digital technologies as learning and teaching tools. What experiences do teachers need so they are able to reform education in their classrooms as these technologies are used as learning and teaching tools? Is learning about the capabilities of the technologies sufficient for applying these technologies in teaching and learning in various content areas? Does knowledge

of subject matter automatically transfer to knowledge for incorporating appropriate technologies as learning tools for specific content topics? How do teachers need to be prepared to teach content in a way they have not learned? Today’s teacher educators are confronted with such “wicked problems” (Rittel & Webber, 1973)—complex problems with incomplete, contradictory, and changing requirements that they must recognize and respond to within the realm of teacher education in the 21st century (Koehler & Mishra, 2008).

While teacher educators have struggled in response to the many complexities presented, a new lens for envisioning the knowledge needed for teaching with these new and emerging technologies has emerged. Recognizing the need for a broader perspective, numerous scholars and researchers proposed thinking about the integration of technology, pedagogy, and content in much the same way that Shulman (1986, 1987) did in proposing PCK. Technological pedagogical content knowledge (TPCK) was proposed as the interconnection and intersection of technology, pedagogy (teaching and student learning), and content (Margerum-Leys & Marx, 2002; Mishra & Koehler, 2006; Niess, 2005; Pierson, 2001; Zhao, 2003). Over time with some difficulties in naming this construct, the acronym of TPCK was recast as TPACK (pronounced “tee – pack”) to direct attention to the total package required for teaching that integrates technology, pedagogy, and content knowledge (Niess, 2008a, 2008b; Thompson & Mishra, 2007). TPACK is proposed as a dynamic framework for describing the knowledge that teachers must rely on to design and implement curriculum and instruction while guiding their students’ thinking and learning with digital technologies in various subjects.

Koehler and Mishra (2008) described this wicked problem confronting teachers and teacher educators for integrating new and emerging digital technologies in the classroom as “a complex and ill-structured problem involving the convoluted interaction of multiple factors, with few hard and

Figure 2. TPACK logo depicting the multiple domains and their intersections



fast rules that apply across contexts and cases” (p. 10). They presented TPACK as “a flexible knowledge framework that teachers need to develop in order to successfully integrate technology in their teaching” (p.10). As they described TPACK, they illuminated multiple subsets in the intersection of content, pedagogy and technology: content knowledge (CK), pedagogical knowledge (PK), technological knowledge (TK), pedagogical content knowledge (PCK), technological content knowledge (TCK), technological pedagogical knowledge (TPK), and finally TPACK for technology, pedagogy, and content knowledge which continues to be referred to as technological pedagogical content knowledge (Koehler & Mishra, 2008) as shown in TPACK logo in Figure 2.

In addition to the individual knowledge domains and their intersections displayed in the TPACK construct, the vision is that these domains are embedded within important contexts including “knowledge of particular students, school social networks, parental concerns, etc.” (Mishra & Koehler, 2008, p. 23). These multiple contexts

are consistent with those identified in the PCK model in Figure 1, where PCK was interconnected not only with content and pedagogy but also with learners, curriculum, and schools (describing the educational contexts, ends, purposes and values) (Niess, 2001; Shulman, 1987).

A Cognitive Perspective of TPACK

The TPACK framework and its knowledge components present a different view on teacher knowledge than previously envisioned in earlier centuries. Now, teacher knowledge is represented as a dynamic equilibrium among the multiple domains of knowledge (technology, pedagogy, and content) and skills that a teacher needs for teaching specific content at specific grade levels. Unpacking this conception of knowledge for teachers is a challenge beginning with an understanding of knowledge as “the amount of information necessary to function and achieve goals; the capacity to make information from data and to transform it into useful and meaningful

information; the capacity with which one thinks creatively, interprets and acts; and an attitude that makes people want to think, interpret and act” (uit Beijerse, 2000, p. 94). Therefore, the knowledge displayed by the TPACK model is an integrated knowledge and form of strategic thinking: knowing when, where, and how to use domain-specific knowledge and strategies (Shavelson, Ruiz-Primo, Li, & Ayala, 2003) when guiding student learning with appropriate information and communication technologies. In essence then, teachers’ TPACK supports them in organizing, implementing, critiquing results, and abstracting plans for specific subject matter content and student needs when integrating appropriate technologies.

Expanding upon Grossman’s (1989, 1991) four central components of PCK helped me analyze extensive preservice teacher observation data of their plans, implementations, assessments, and reflections when integrating appropriate technologies as they learned to teach with technologies. This view extended the description of TPACK to the knowledge, thinking, and beliefs using these four cognitive components that more specifically described the reasoning and processes through which the teachers operated when integrating technologies (Niess, 2005):

1. *An overarching conception about the purposes for incorporating technology in teaching subject matter topics.* This conception is what the teacher knows and believes about the nature of the subject and its selected topics, what is important for students to learn, and how technology supports that learning. This foundation serves as a basis for instructional decisions.
2. *Knowledge of students’ understandings, thinking, and learning in subject matter topics with technology.* In this component, teachers rely on and operate from their knowledge and beliefs about student’ understandings, thinking, and learning with technologies in specific subject matter topics.
3. *Knowledge of curriculum and curricular materials that integrate technology in learning and teaching subject matter topics.* With respect to the curriculum, teachers discuss and implement various technologies for teaching specific topics and how subject matter concepts and processes within the context of a technology-enhanced environment are organized, structured, and assessed throughout the curriculum.
4. *Knowledge of instructional strategies and representations for teaching and learning subject matter topics with technologies.* Teachers adapt their instruction toward guiding students in learning about specific technologies as they are learning subject matter topics with those technologies. They employ content-specific representations with technologies to meet instructional goals and the needs of the learners in their classes.

These four components suggest that current teachers need more than simply learning about the technologies. They need to be engaged in reconsidering content specific concepts and processes along with the impact of the specific technology on the development of those ideas as well as on teaching and learning the content. These results challenge prior assumptions that (1) in depth knowledge in the content area is sufficient for teaching with technology and (2) developing PCK with no attention to teaching with technology is sufficient for learning to teach with technology. Shreiter and Ammon (1989) view teachers’ adaptation of new instructional practices when integrating appropriate technologies to support learning as a process of assimilation and accommodation resulting in changes in their thinking and personal experiences. Developing TPACK is, thus, posed as a “constructive and iterative” process where teachers need to reflect on and carefully revise multiple experiences and events for teaching their content with appropriate technologies based on their “existing knowledge, beliefs, and disposi-

tions” (Borko and Putnam, 1996). In essence, teacher preparation programs need to attend to the knowledge, beliefs and dispositions that these teachers bring to the programs if the programs are to guide the development of their TPACK for teaching with technologies.

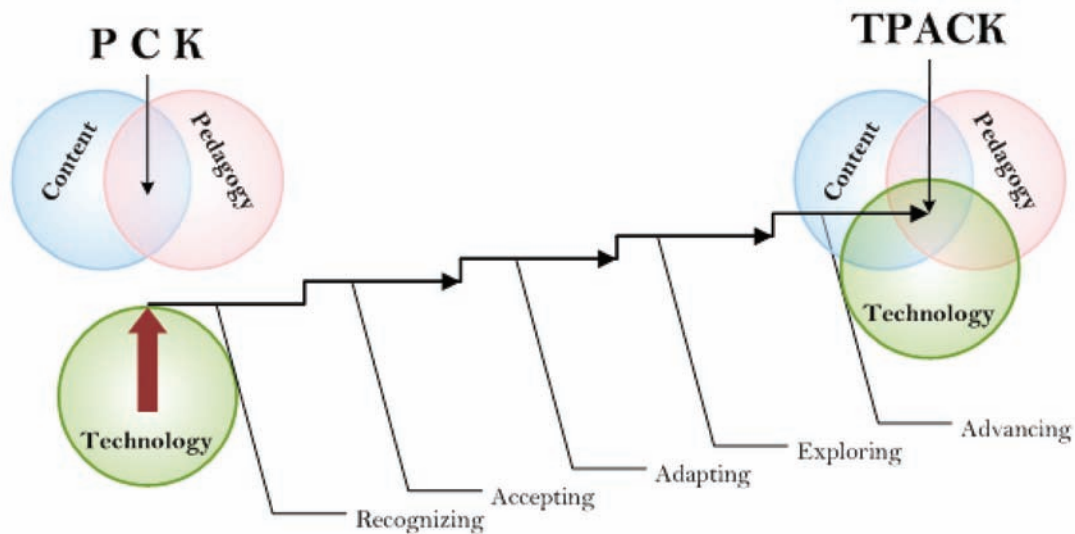
Through continuing research with preservice and inservice teachers in learning to teach with technologies, significant differences in teachers’ actions when learning to teach with technologies were observed (Niess, 2005; Niess, Suharwoto, Lee, & Sadri, 2006). Neither in-service nor preservice teachers demonstrated that they either had or did not have TPACK for teaching their content with technology. They differed in their actions with respect to each of the four components as they were confronted with whether to accept or reject the use of various technologies in teaching their content. These differences seemed to be a function of their knowledge of the content, their knowledge of the particular technologies, and their knowledge of pedagogy (teaching and learning).

Everett Rogers (1995) identified potential differences in his vision of innovators when working with technological innovations much as teachers are when considering teaching with technologies. He proposed a five-step process in the ultimate decision of whether to accept or reject a particular innovation such as teaching mathematics with spreadsheets. My research group (Niess, Suharwoto, Lee, & Sadri, 2006) used Rogers’ lens for framing a description of the differences observed in teachers’ TPACK levels for teaching with technologies. These levels were described as:

1. *Recognizing* (knowledge) where teachers are able to use the specific technology and recognize an alignment of its capabilities with content specific topics. Teachers at this level rarely think about incorporating the technology, and only consider the technology as a low level tool for learning the content
2. *Accepting* (persuasion) where teachers form a favorable or unfavorable attitude toward teaching and learning subject matter topics with the technology. Teachers at this level practice with the technology but do not consistently think about how the technology might support teaching in their content area.
3. *Adapting* (decision) where teachers engage in activities that lead to a choice to adopt or reject teaching and learning the content topics with the technology. Teachers at this level try ideas for incorporating the technology in teaching the content but at best have students do more low-level thinking activities with the technology. For the most part, these teachers manage the activities through the use of prepared worksheets that specifically guide students toward the intended ideas.
4. *Exploring* (implementation) where teachers actively integrate teaching and learning of subject matter topics with the technology. Teachers at this level investigate different ways of teaching the content and are willing to demonstrate new ways of thinking about concepts with the technology. They also are more apt to allow students to explore with the technology through a more student-centered pedagogy.
5. *Advancing* (confirmation) where teachers evaluate the results of the decision to integrate teaching and learning mathematics topics with spreadsheets. Teachers at this level willingly consider using the technology in a variety of ways in building content concepts and ideas. They consciously encourage students’ hands-on explorations and experimentation where the students direct the ideas that are explored. They also incorporate the technology in student assessment of the content.

With this understanding, teachers’ development of TPACK for teaching subject matter top-

Figure 3. Visual description of teacher levels as their thinking and understanding merge toward the interconnected and integrated manner identified by TPACK



ics with technology is envisioned as a cognitive, developmental process. As depicted in Figure 3 (Niess et al., 2009), these levels depict how the teacher's thinking and understandings merge toward the interconnected and integrated ideas described by TPACK. Using this perspective suggests that the development of TPACK should be recognized as a dynamic, fluid process, rather than as a static view of teachers having or not having TPACK. These teachers are confronting an innovation – an innovation that integrates a digital technological tool, new teaching and learning pedagogical strategies, and revision of how they know their subject matter content as a result of the availability of the new digital technology.

A Social Constructivist Perspective of TPACK

Much of the research and scholarly work in describing TPACK has emphasized a cognitive constructivist approach where teachers actively

engage in transforming, organizing and reorganizing their previous knowledge for teaching in order to more effectively guide student learning with appropriate technologies (Koehler & Mishra, 2008; Mishra & Koehler, 2006; Niess, 2005, 2008a, 2008b). Meanwhile, social constructivists have highlighted the importance of the social contexts of learning with recognition that knowledge is mutually built and constructed in a social environment (Bearison & Dorval, 2002; Woolfolk, 2008).

With a Vygotskian social constructivist view, knowledge is constructed through social interactions with others; this view represents a conceptual shift from a more Piagetian cognitive constructivist view of knowledge development as a cognitive process where learners organize and make sense of their explorations (Santrock, 2006). A social constructivist perspective comes from an important assumption that thinking is *situated* in social and physical contexts, rather than within the individual learner's mind (as in the Piagetian

perspective) (Santrock, 2006; Woolfolk, 2008). This situated perspective postulates that *how* and *where* a person learns an idea is fundamental to *what* is learned (Greeno, Collins, & Resnick, 1996). In essence then, this perspective contends that investigations of *what is learned* must reflect multiple contexts that include the learners as well as the physical and social systems in which they participate in the process of learning.

Descriptions and discussions of TPACK are based largely on a cognitive view of individual learning (Koehler & Mishra, 2008; Mishra & Koehler, 2006; Niess, 2005, 2008a, 2008b). The situated perspective instead is directed toward the social context and how participation in that context impacts personal understanding. Cobb and Yackel (1996) provide a means for resolving these seemingly conflicting perspectives. In their work, they describe an *emergent* perspective. This perspective views the social and cognitive constructivist ideas as reflexive rather than in conflict with one another (Cobb & Bowers, 1999; Cobb, Stephan, McClain, & Gravemeijer, 2001; Gravemeijer & Cobb, 2006; McClain & Cobb, 2001).

In recognition of this reflexive connotation, Harrington (2008) revealed the importance of situational and social learning perspectives in developing TPACK. Harrington's study investigated preservice teachers' learning using both a social and a cognitive perspective of teacher learning. The preparation of mathematics preservice teachers in her study was specifically focused on the experiences designed to prepare them for full-time student teaching. Through the Technology Partnership Project, the preservice teachers were working in collaborative groups composed of a school-based cooperating teacher and two preservice students. Through these collaborations, the pre-service teachers shared ideas that gave insight into their reasoning about teaching with technology, their overarching conception of teaching mathematics with technology and their knowledge of students' understanding, thinking, and learning in mathematics with technology.

The cooperating teachers provided the curricular perspectives on teaching middle school mathematics and the pedagogical strategies that were most effective in working with middle school students. Collaboratively, all members of each group gained experiences in designing, implementing and reflecting on teaching mathematics with appropriate technologies.

Since the impacts of the social interactions and the various learning situations had on the preservice teachers' learning were not effectively captured by the TPACK framework, Harrington searched for additional tools to understand the social and situative learning evident in the data she had gathered. She ultimately proposed an addition to the cognitive view of individual learning in TPACK in much the same way as with Cobb and Yackel's (1996) emergent perspective. She proposed a view of TPACK from a lens that incorporated both the social and cognitive constructivist perspectives of learning to teach with technology as identified in Table 1. Aligning a combination of the four components of TPACK (Niess, 2005) and an additional component (resulting from her data) with three components from the social perspective, she proposes an *emergent* TPACK perspective showing how both social and cognitive perspectives are aligned.

Harrington (2008) proposed that future examinations involving TPACK consider the combination of the social perspective with the cognitive perspective as a tool for framing and characterizing the teacher's developing knowledge for teaching with technology. As both preservice and inservice teachers are engaged in teaching with technology, they are continuing to develop their TPACK. And, this knowledge that is developing is being impacted by a combination of the cognitive and social engagements within the classroom. Thus an *emergent* TPACK perspective provides an important view for understanding TPACK within the dynamic of technology integration in the classroom.

Table 1. Harrington's (2008) proposed integrated social and cognitive perspectives of learning to teach with technology.

Social Perspective	Cognitive Perspective
Pedagogical Social Norms	A teacher's beliefs about the teacher's own role, others' role and the general nature of technology
Norms of Pedagogical Reasoning about Technology	A teacher's overarching conception of teaching mathematics with technology
	A teacher's knowledge of student understandings, thinking, and learning mathematics with technology
Classroom Pedagogical Practices With Technology	A teacher's knowledge of instructional strategies and representations for teaching with technologies
	A teacher's knowledge of curriculum and curricular materials

ADVANCING TEACHERS' KNOWLEDGE FOR TEACHING WITH TECHNOLOGY

Over the past decade, new technologies have emerged and become increasingly accessible for educational purposes. Meaningful integration of these technologies, however, requires more than skill and knowledge with the technologies. Mishra and Koehler (2006) recognized this situation in their descriptions of TPACK:

There is no single technological solution that applies for every teacher, every course, or for every view of teaching. Quality teaching requires developing a nuanced understanding of the complex relationship [among technology, content, and pedagogy], and using this understanding to develop appropriate, context-specific strategies and representations. (p. 1029).

TPACK (both from a cognitive and social perspective) describes a dynamic framework for describing teachers' knowledge for designing, implementing, and evaluating curriculum and instruction with technology. Within this TPACK framework, teacher educators and researchers have been actively engaged in exploring instructional methods to incorporate when redesigning teacher

education programs to focus on the development of this newly described knowledge.

Teacher Preparation-Instructional Experiences

What is a TPACK-based teacher preparation program? What are the essential experiences needed for integrating pedagogy, content, and technology? What learning trajectories are supportive in developing TPACK? When considering experiences to include in preservice programs, ideas have been proposed similar to Harrington's (2008) Technology Partnership Project. Angeli and Valanides (2009) investigated Technology Mapping (TM) and peer assessment learning experiences on the development of TPACK competency. The TM activities required the students in peer-assessment groups to engage in strategic thinking around that integration of technologies in lessons where they were expected to map software affordances with content representations and pedagogical uses. Angeli and Valanides recognized the importance of the social exchanges in the students' thinking during these peer-assessment experiences by calling for more examination of the impact of these exchanges on the development of TPACK, essentially supporting Harrington's hypothesis of the development of TPACK from an emergent perspective.

Mishra, Koehler, Shin, Wolf, and DeSchryver (2010) proposed a learning-by-design trajectory for TPACK development. They proposed spiraling stages of more complex instructional design activities where TPACK reflection is completed at the end of the process. After explorations with micro-design problems followed by macro-design problems, preservice and inservice teachers reflect on pedagogy, technology, and content and their interrelationships when considering specific difficult instructional problems.

Additional researchers have identified content and technology-based approaches, such as instructional modeling (Niess, 2005), collaborative lesson studies (Groth, Spickler, Bergner, & Bardzell, 2009), and meta-cognitive exploration of TPACK emerging from curricula and technologies shifts (Hughes & Scharber, 2008). Dawson (2007) and Pierson (2008) described action research activities. Mouza and Wong (2009) proposed a TPACK-based case development strategy to guide teachers learning from their practice. The challenge for teacher educators and researchers is to continue to investigate methods and learning trajectories for integrating the development of TPACK amid the entire teacher preparation program. The instructional methods, lesson planning, classroom management, and even student practicum experiences need to be re-examined with a recognition of the impact and influence of technologies as well as other teaching resources on the knowledge teachers need for teaching.

Since inservice teachers are actively engaged in teaching their content at specific grade levels, their instruction in the development of TPACK must recognize and take advantage of their more advanced teacher knowledge gained through their teaching experiences. My research groups' work with inservice teachers found that mentoring teachers as they engage in implementing their developing ideas for integrating the technologies with their students provided essential experiences for elevating their TPACK levels (Lee et al., 2006). Harris and Hofer (2009) recognized that

inservice teachers had a more developed PCK and needed a program directed toward extending that PCK to TPACK. As the teachers were engaged in implementing their learning about teaching with technologies, Harris and Hofer mentored them in (1) selecting and using learning activities and technologies in a more conscious, strategic, and varied manner; (2) instructional planning that is more student-centered, focusing on students' intellectual, rather than affective, engagement; (3) and making deliberate decisions for more judicious educational technology use.

Assessing TPACK

Koehler and Mishra (2008) provided a warning when engaging in TPACK development: "While attempting to solve a wicked problem, the solution of one of its aspects may reveal or create another, even more complex problem" (p. 111). This conundrum has certainly been presented as teacher educators and researchers have explored the design of instructional methods leading to the development of TPACK. How is TPACK recognized? What should be assessed? How can it be assessed? Since TPACK is described as an integrated knowledge construct of related domains (TK, CK, PK, PCK, TCK, TPK, and TPACK), how are these individual knowledge domains assessed? Do changes in one of the domains result in changes in TPACK? How is a teacher's knowledge affected with the introduction of new technological possibilities for teaching and learning? Such questions are and will continue to challenge researchers as they work to clarify the knowledge that teachers rely on for teaching with technologies while identifying and developing effective assessment instruments of teachers' knowledge.

Research that involves assessment of TPACK is in its infancy for good reason. Validity and reliability of assessments are essential considerations with assessing TPACK. Without this evidence, the question of what the assessment is measuring is challenged. Yet, the clarification of what is meant

by TPACK is critical to the identification of assessments to measure the construct. Schmidt et al. (2009) undertook the task of developing and validating an instrument to gather preservice teachers' self-assessment of their TPACK and its related knowledge domains. Harris, Grandgenett and Hofer (2010) developed a valid and reliable rubric for teacher educators to assess teaching artifacts such as lesson plans to judge the teachers' TPACK. They are currently engaged in developing an observation instrument for assessing teachers' TPACK while teaching.

FUTURE DIRECTIONS

What knowledge do teachers need for teaching today and in the future where digital technologies are significantly impacting the ways that citizens work, play and interact? Given the current state, current and future teachers must be prepared to rethink, learn, and relearn, change, revise and adapt as they work to plan, implement, and assess teaching with these new technologies. The salient question for teacher preparation programs is: What experiences and how should the experiences be arranged so that preservice teachers develop the appropriate knowledge identified in the TPACK lens given that they bring to the program a lack of experiences in learning the content with these new and emerging technologies, along with a recognition of a shifting set of curricular outcomes knowledge expectations of a more technological society? Add to this situation, emerging learning environments toward more student-centered, performance-focused learning and learner-constructed knowledge in collaborative activities (International Society for Technology in Education, 2008) with implications for the implementation of social constructivist approaches when teaching with technologies.

The research efforts to date provide important approaches for designing learning trajectories and developing tools that more directly describe the

teacher knowledge leading to improved student and teacher outcomes in a technology-enhanced learning environment. The challenges for advancing TPACK as the knowledge teachers rely on for teaching with technology call for careful and thoughtful continued empirical research investigations with a clear understanding of the theoretical framework that frames the research questions, methodology, analysis, and conclusions. More specifically, the identification of TPACK provides (1) a theoretical framework or lens for thinking about teacher knowledge and (2) as a knowledge construct – the knowledge teachers rely on for teaching with technology. This duality of purposes for TPACK presents multiple research directions for future understanding and uses.

Research is needed to clarify TPACK as a framework for thinking about teacher knowledge. Is TPACK the intersection of the multiple domains or the sum of the multiple domains that represent the total knowledge that teachers need for teaching with technology? Should the research focus be on a holistic knowledge view of TPACK or on parsing out the multiple subsets – TK, CK, PK, PCK, TCK, TPK, and TPACK? Is the interaction between these multiple subsets captured in the subset descriptions? Is the essence of TPACK captured through these multiple subsets?

The research to date has considered proxy measures to capture TPACK as a knowledge construct describing the knowledge that teachers need for teaching with technology. What is the most appropriate way for measuring TPACK as a knowledge construct? Which measures of TPACK have the potential of aligning with increased student learning and achievement? Research is needed to assess teachers' beliefs and experiences that direct how they think about their content and how that content is learned in connection with using appropriate technologies for engaging students in learning the content. Research is needed to describe teachers' learning trajectories in developing the knowledge, skills, and dispositions for incorporating new and emerging technologies as learning and teaching

tools in various subject areas such that children's knowledge is strengthened and enhanced.

The TPACK lens offers a cognitive perspective, a social constructivist perspective, and the emergent perspective (a combined lens of the two perspectives). How do these different perspectives help to explain TPACK as a knowledge construct? Each perspective has implications for the research questions, methodology, analysis, and conclusions drawn.

When considering the duality presented in the discussion of TPACK, the research must be clear about which view is being used and then use systematic, empirical methods to provide believable evidence and more appropriately direct and support policy and large-scale changes in teacher education. Research studies must reflect the intersection of technology, pedagogy, and content – technology, pedagogy, and content knowledge or TPACK – amidst quality teaching and learning in the 21st century, where information and communication technologies have become increasingly accessible and valued for educational purposes.

This research handbook proposes to identify and highlight important considerations as researchers and teacher educators work to advance the recognition of the dynamic TPACK framework for describing the knowledge that teachers must rely on to design and implement curriculum and instruction while guiding their students' thinking and learning with digital technologies in various subjects. In words from Koehler and Mishra (2008), "We need to develop better techniques for discovering and describing how knowledge is implemented and instantiated in practice, and just as importantly, how the act of doing influences the nature of knowledge itself" (p. 23).

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Chapter 2

How Do We Measure TPACK? Let Me Count the Ways

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ABSTRACT

In this chapter we reviewed a wide range of approaches to measure Technological Pedagogical Content Knowledge (TPACK). We identified recent empirical studies that utilized TPACK assessments and determined whether they should be included in our analysis using a set of criteria. We then conducted a study-level analysis focusing on empirical studies that met our initial search criteria. In addition, we conducted a measurement-level analysis focusing on individual measures. Based on our measurement-level analysis, we categorized a total of 141 instruments into five types (i.e., self-report measures, open-end questionnaires, performance assessments, interviews, and observations) and investigated how each measure addressed the issues of validity and reliability. We concluded our review by discussing limitations and implications of our study.

INTRODUCTION

I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind.— William Thompson Kelvin

(Popular Lectures, Vol. I, “Electrical Units of Measurement,” p. 73, 1883).

In this chapter we review a wide range of approaches to measure Technological Pedagogical Content Knowledge (TPACK). In the first section we provide a brief overview of the TPACK framework and discuss the need for the current review. In the second section, we identify recent empirical studies that utilized TPACK assess-

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ments. We categorize these approaches into five types, and investigate how the researchers address issues of validity and reliability. We end the chapter with a set of summary conclusions, a discussion on limitations and implications of our review for future research on TPACK assessment.

Research on the role and impact of technology in education has often been criticized for being a-theoretical in nature, driven more by the possibilities of the technology than broader or deeper theoretical constructs and frameworks. Accordingly, the preponderance of work in educational technology has consisted of case studies and examples of best practices and implementation of new tools. Though such case studies can be informative, the lack of broader theoretical or explanatory conceptual frameworks prevents us from identifying and developing themes and constructs that would apply across cases and examples of practice. Over the past few years there has been a considerable interest in the Technological Pedagogical Content Knowledge (originally TPACK, now known as TPACK, or Technology, Pedagogy, and Content Knowledge) Framework for effective technology integration (American Association of Colleges for Teacher Education (AACTE), 2008; Koehler & Mishra (2009); Mishra & Koehler, 2006; Niess, 2007). The TPACK framework connects technology to curriculum content and specific pedagogical approaches and describes how teachers' understandings of these three knowledge bases can interact with one another to produce effective discipline-based teaching with educational technologies. The TPACK framework has had a significant impact on both research and practice in the area of educational technology.

Theoretical frameworks, such as TPACK, play an important role in guiding observation. Quoting Chalmers, a philosopher of science, Mishra and Koehler (2006) write:

... "Precise, clearly formulated theories are a prerequisite for precise observation statements." (p.27) In other words, observation statements cannot be made without using the language of

some theory and in turn, these theories determine what is investigated. Thus, frameworks play an important role by guiding the kinds of questions we can ask, the nature of evidence that is to be collected, the methodologies that are appropriate for collecting this evidence, the strategies available for analyzing the data and finally interpretations we make from this analysis. (p.1039)

The TPACK framework functions as a "conceptual lens" through which one views educational technology by drawing attention to specific aspects of the phenomena, highlighting relevant issues, and ignoring irrelevant ones. In this view, the framework functions as a classification scheme providing insight into the nature and relationships of the objects (and ideas and actions) under scrutiny.

Providing a framework, however, is not enough. Frameworks have to be examined within the real world, where it becomes critical to develop sensitive instruments and measures that are both consistent with the theory *and* measure what they set out to measure. Since the TPACK framework was first published in *Teacher College Record* (Mishra & Koehler, 2006), researchers have been developing a wide range of TPACK instruments to measure whether their TPACK-based interventions and professional developments efforts have developed teachers' TPACK (Graham et al., 2009; Guzey & Roehrig, 2009). The move towards measuring TPACK is notable as a shift from the conceptual to the empirical. As researchers began to focus on empirically testing the effect of their TPACK-based treatments, the issue of how to accurately capture their subjects' levels of understanding in TPACK became more important.

Despite the abundance in studies involving the use of TPACK measures in recent years (Graham, Cox, & Velasquez, 2009; Jamieson-Proctor et al., 2007; Mueller, 2010; Robertshaw, 2010; Schmidt et al., 2009), little effort has been made to provide a comprehensive account of TPACK measures in a systematic manner. This situation

is somewhat understandable given the infancy of the field. Without a full understanding of the repertoire of TPACK assessments and the strengths and weaknesses of each, there is a danger of an overreliance on one measure over the others. This state, in turn, can lead to missed opportunities in accurately assessing and measuring the multiple components of TPACK.

Our goal is not only to identify a wide range of TPACK measures, but also scrutinize each TPACK measure in terms of its *reliability* and *validity*. Reliability refers to the extent to which a measure yields stable and consistent results when repeated over time (Gall et al., 2007). A reliable measure should address the question of “Does the measure yield the same result if we follow the same measurement process?” Validity, on the other hand, refers to the extent to which a measure accurately reflects or assesses the specific concept that the researcher is set out to measure. A valid measure should address the question of “Does the instrument measure what it is supposed to measure?” Whether it is a self-report survey or an interview, a good measure needs to be reliable *and* valid.

PURPOSE OF THIS REVIEW

In this chapter, we present a review of various techniques of measuring TPACK, specifically addressing the following two questions: (1) What kinds of measures are used in the TPACK literature? (2) Are those measures reliable and valid?

We begin with a detailed review of existing measures of TPACK, focusing on five commonly used techniques: self-report measures, open-ended questionnaires, performance assessments, interviews, and observations (Duke & Mallette, 2004; Gall et al., 2007). Then, we examine the reliability and validity of each instrument. Specifically, we look for evidence that the instrument developers address the issues of reliability and validity in an appropriate manner.

Method

Search Strategies and Procedure

To ensure that this literature review provided a comprehensive overview of a wide range of TPACK measures, we conducted literature searches (Cooper, Hedges, & Valentine, 2009), in the PsychINFO, Education & Information Technology Digital Library (EdITLib), and Education Resources Information Center (ERIC) online databases using the keywords “technological pedagogical content knowledge,” “TPACK,” and “TPCK.” We also sought to include grey literature in our search (i.e., documents other than journal articles in widely known, accessible electronic databases) to reduce the impact of a potential publication bias with well known, indexed journal articles (Rothstein & Hopewell, 2009). We also reviewed other types of publications, including existing conference papers, dissertations, and unpublished manuscripts that were listed on the reference list of www.tpack.org. After cross-checking the reference lists in these data sources, we created a master reference list of articles on TPACK. A total of 303 articles were identified through our initial search process.

Inclusion Criteria

Once we collected all the manuscripts using the sampling procedures described above, we then evaluated each research study against the following criteria:

- a. The study used TPACK measures
- b. The study was of empirical nature
- c. The study was published between 2006 and 2010
- d. The study was written in English

Out of 303 articles we identified, a total of 66 studies met our inclusion criteria. A total of 237

Table 1. Categories and descriptions for coding articles in the review

Category	Description	% Agreement
Authors	We listed the author(s) of the publication.	100%
Publication Type	We listed the type of publication (Journal article, Conference proceeding, Dissertation, Conference presentation)	100%
Type of TPACK Measure	Gall, Gall, and Borg (2007) identified five different ways of collecting research data: self-report measures, open-ended questionnaires, performance assessments, interviews, and observations. We used their categorization of measures in our coding as it was deemed comprehensive and commonly used in educational research. All measures fit into our categorization.	96.92%
Target Audience	Each measure was developed for a specific population. Some instruments targeted pre-service teachers while others were specifically designed for online educators. We listed who the primary target was for each measure.	84.62%
Evidence of Reliability	We checked whether the particular TPACK measure addressed the issue of reliability. We then reported how the study tested the reliability of its TPACK measure.	100%
Evidence of Validity	We checked whether the particular TPACK measure addressed the issue of validity. We then reported what kind of validation process the TPACK measure underwent.	100%

studies were excluded from our analysis for the following reasons:

- The study was a conceptual piece with no empirical data
- The study was not directly related to TPACK
- The study provided insufficient information on the TPACK measures
- The study was grounded within the TPACK framework but did not measure participants' TPACK
- The study was a literature review
- The study was a conference paper or dissertation that was later published in a refereed journal

Data Coding Scheme

We entered the information about each publication into our database: author(s), publication type, type of TPACK measure, target audience, evidence of reliability, and evidence of validity. See Table 1 for a description of these categories and possible values for each.

Coding was done by one of the authors who had experience in meta-analysis. When there was an ambiguous case, the other authors participated

in an extensive discussion until a final decision was made on whether to include the particular case or not. Rationale for each decision were documented and entered into our master database. A total of 66 studies were identified for inclusion.

For the purposes of determining the robustness of the coding scheme, a random sample of 19 studies (of the 66 total) were coded independently by another author. Percentage agreement for each of the coding categories is presented in Table 1. Disagreement was resolved in all cases by consensus.

Many of the studies we reviewed implemented multiple measures to assess TPACK. Therefore, we allowed each study to be coded multiple times when two or more types of TPACK measures were used. For instance, Niess et al. (2006) used a performance assessment, an interview, and an observation to accurately document changes in their subjects' level of TPACK. In this case, the study was coded three times even though the three measures were used in the same study.

Analysis

We conducted two levels of analysis: study- and measurement-levels. First, we examined the char-

Table 2. Characteristics of the ($N=66$) studies in the review

Category	Number of studies	Percentage
Source of the studies		
Journal articles	30	46%
Conference proceedings	32	48%
Doctoral dissertation	3	5%
Conference presentation	1	1%
Year of publication		
2010*	22	33%
2009	28	42%
2008	7	11%
2007	6	9%
2006	3	5%
Number of TPACK measures used in a study		
1	25	38%
2	14	21%
3	19	29%
4	8	12%

* Only studies published prior to June 2010 were included in our analysis.

acteristics of each study by reporting the source, year of publication, and a total number of TPACK measures used in the study. The study-level analysis was necessary as it gave a broader picture of various measures implemented in TPACK studies.

Once the study-level analysis was completed, the foci of our analysis shifted to the measurement-level. Here we focused on individual TPACK measures rather than on the studies themselves. Specifically, we were interested in who the target population of the measure was and whether the measure provided evidence of reliability and validity.

Study-level analysis. A majority of the studies we investigated were published in journals and conference proceedings (a total of 62 out of 66 studies). The other four publications were unpublished doctoral dissertations and conference

presentations. As shown in Table 2, the number of publications implementing TPACK assessments has increased each year, mirroring the extent to which the TPACK framework has become an integral part of the educational technology research literature. We also counted the number and type of TPACK measurements used in individual research studies. The results show that a total of 41 out of 66 studies used more than two different types of TPACK instruments (see Table 2).

Measurement-level analysis. Once the study-level analysis was done, our analysis focused on the individual TPACK measures. First we counted the number of TPACK instruments by the type of measure. Notably, all five types of measures were used fairly evenly across studies. Self-report measures (31 out of 141) and performance assessments (31 out of 143) were most frequently used while open-ended questionnaires (20 out of 141) were the least popular TPACK instruments (see Table 3). Note that the number of measures does not total to 66 because a majority of research studies involved the use of multiple measures.

Self-Report Measures

Self-report measures, which ask participants to rate the degree to which they agree to a given statement regarding the use of technology in teaching, are one of the most frequently used methods to measure participants' TPACK. A total of 31 studies implemented self-report measures to assess the level of their participants' TPACK. Most self-report measures were aimed at measuring pre- or in-service teachers (29 out of 31 measures). The other two instruments were developed for K-12 online educators (Archambault & Crippen, 2009) and faculty instructors (Koehler, Mishra, & Yahya, 2007) (see Table 3).

In most cases, self-report measures included multiple sub-scales of TPACK. For instance, Lee and Tsai (2010) used the Technological Pedagogical Content Knowledge-Web (TPCK-W) Survey

Table 3. Frequency and Percentage Summary of TPACK measures for Intended Audience, Evidence of Reliability, and Evidence of Validity

Category	Self Report-Measures N=31, 23%		Open-Ended Questionnaires N=20, 13%		Performance Assessments N=31, 23%		Interviews N=30, 21%		Observations N=29, 20%	
	N	%	N	%	N	%	N	%	N	%
Target Audience										
Pre-service only	14	44%	9	45%	17	55%	13	43%	10	34%
In-service only	13	42%	10	50%	12	39%	15	50%	17	58%
Pre- and In-service	2	7%	1	5%	1	3%	0	0%	1	4%
Other	2	7%	0	0%	1	3%	2	7%	1	4%
Evidence of Reliability										
Clearly provided	12	39%	3	15%	6	19%	0	0%	3	10%
Vaguely provided	0	0%	3	15%	5	16%	5	17%	7	24%
Not provided	19	61%	14	70%	20	65%	25	83%	19	66%
Evidence of Validity										
Clearly provided	11	35%	1	5%	1	3%	0	0%	0	0%
Vaguely provided	0	0%	0	0%	0	0%	0	0%	0	0%
Not provided	20	65%	19	95%	30	97%	30	100%	29	100%

to assess teachers' self-efficacy regarding the use of Web in teaching. Although the TPCK-W Survey consists of the six sub-scales, only the following five sub-scales were based on the TPACK framework: (1) Web-general: Teachers' confidence in their general use of Web, (2) Web-communicative: Teachers' confidence in their general knowledge about the Web, (3) Web-Pedagogical Knowledge (WPK): Teachers' confidence in their knowledge about the Web specifically related to educational settings, (4) Web-Content Knowledge (WCK): Teachers' confidence in their knowledge about the use of Web in enhancing content knowledge, and (5) Web-Pedagogical Content Knowledge (WPCK): Teachers' confidence in using the Web to fit the needs of a particular course and the practice of appropriate pedagogies to enhance student learning.

For reliability, out of 31 self-report measures, a total of 12 studies presented evidence of reliability. Except for one study that reported Raykov's reliability rho (Burgoyne, Graham, & Sudweeks,

2010), all eleven studies reported Cronbach's Alpha as their reliability index. For example, Lee and Tsai (2010) reported the reliability coefficient (Cronbach's Alpha) for each of the five sub-scales ranging from .92 to .99.

For validity, only 11 studies presented evidence that they addressed the issue of validity. The most frequent way to establish validity of a self-report measure was to conduct either an exploratory or confirmatory factor analysis. For instance, Jamieson-Proctor et al. (2007) developed 45 items to measure in-service teachers' confidence in using Information and Communication Technology (ICT) for teaching and learning. They conducted an exploratory factor analysis on responses of 929 Australian in-service teachers and reduced the number of items based on factor loadings. With the shortened version, they ran a confirmatory factor analysis to come up with the best fitting structural equation model with 20 items that can be categorized into two factors (see Table 3).

Open-Ended Questionnaires

Open-ended questionnaires ask participants to record written or typed responses to a set of prompts prepared by researchers. Twenty TPACK instruments were coded as open-ended questionnaires. All of the open-ended questionnaires were aimed at pre- or in-service teachers' TPACK (see Table 3).

A typical TPACK open-ended questionnaire asks pre- or in-service teachers to write about their overall experience in an educational technology course or professional development program that emphasizes the TPACK. For instance, So and Kim (2009) asked pre-service teachers, who were enrolled in an ICT integration for teaching and learning course, to write brief responses to prompts such as "What do you see as the main strength and weakness of integrating ICT tools into your PBL lesson?" The authors then coded students' responses specifically focusing on the representations of content knowledge with relation to pedagogical and technological aspects.

For reliability, only three out of twenty open-ended questionnaires presented evidence of reliability (e.g., inter-rater reliability). For validity, except for one instrument (Robertshaw & Gillam, 2010), none of the open-ended questionnaires explicitly addressed the issue of validity (see Table 3).

Performance Assessments

Performance assessments evaluate participants' TPACK by directly examining their performance on given tasks that are designed to represent complex, authentic, real-life tasks. Researchers can assess their subjects' performance in completing a task, or the product resulting from such performance (Gall et al., 2007). A total of 31 TPACK instruments were coded as performance assessments. Except for one performance assessment targeted at faculty instructors (Koehler, Mishra, & Yahya, 2007), almost every instrument was

designed to measure pre- or in-service teachers (see Table 3).

Some TPACK performance assessments ask participants to create and maintain a set of artifacts such as portfolios and reflective journals (Suhawoto, 2006), while others consist of scenario- or problem-based questions that require deeper levels of TPACK for solutions (Graham, Tripp, & Wentworth, 2009).

Individual products or responses are typically evaluated either by experts in the field or researchers, based on a set of specific criteria framed within the TPACK model. For example, Harris, Grandgenett, and Hofer (2010) developed a rubric to measure the quality of a TPACK-based technology integration in teaching by incorporating the TPACK framework into the Technology Integration Assessment Instrument (TIAI) that was initially designed by Britten and Cassady (2005). Harris and her colleagues collaboratively worked with local technology-using teachers, administrators, and TPACK experts and revised the rubric's items. They then engaged in multiple rounds of revisions while testing the rubric on lesson plans created by 15 experienced technology-using teachers.

Only six performance assessment measures provide evidence of reliability by presenting the inter-rater reliability or test-retest reliability to show how their measures were stable over time. Except for one instrument (Harris, Grandgenett, & Hofer, 2010), none of the performance assessments present evidence of validity.

Interviews

Interviews consist of a set of oral questions asked by the interviewer and oral responses by the interviewee (Gall et al., 2007). Usually interviews are recorded in videotapes, audiotapes or notes and later transcribed for researchers to systematically analyze. Out of 66, a total of 30 studies used interviews that were conducted in a semi-structured manner (see Table 3). Except for two cases where

interviews were specifically designed for faculty (Mishra, Peruski, & Koehler, 2007; Williams, Foulger, & Wetzel, 2010), most interviews were geared toward measuring the TPACK of pre- or in-service teachers.

Typically, during an interview, participants were asked a series of pre-determined questions and, if needed, were asked follow-up questions by the interviewers. For example, to examine changes in pre-service teachers' TPACK, Ozgun-Koca (2009) asked them to discuss the advantages/disadvantages of calculator usage and the effects on the teaching and learning process and environment. The author then followed up with questions such as "when calculators would be more beneficial."

None of the thirty studies reported concrete evidence that established the reliability of their interview measures. Five studies reported that the interviews were coded by multiple coders but did not present any reliability index. In addition, none of the studies that implemented interviews address the issue of validity explicitly (Table 3).

Observations

Researchers also conducted observations that included video recording or field-note taking of a class or session, to examine how participants' levels of TPACK changed over a certain period of time. Out of 66, a total of 29 studies used observations as a means to measure their participants' TPACK. Except for one instrument (Koehler, Mishra, & Yahya, 2007), all the observations were targeted at measuring development in pre- or in-service teachers (see Table 3). Usually, the researcher observed in the classroom how a teacher integrated technology in her own teaching while videotaping. The videotape was then transcribed into a written form that can be read and coded by researchers based on their coding scheme. For example, in Suharwoto's study (2006) researchers attended and videotaped all the courses taught by internship teachers to examine how they implement technology in their own teaching in the actual

classroom settings. Once the observations were completed, researchers analyzed the transcript of the observation following the TPACK-based coding scheme.

For reliability, only three studies reported the reliability index, which shows the agreement rate between the coders. For validity, none of the studies presented any concrete evidence that the coding schemes of observations were valid other than reporting that they were based on the TPACK framework (see Table 3).

DISCUSSION

As we look across and beyond the studies in this analysis, a few aspects stand out, positive and negative. The most encouraging is that TPACK is a vibrant area of research, indicated by both the number of studies in this area, and the range of methodological approaches used to study its development. Four of the methodologies (Self Report Measures, Performance Assessments, Interviews and Observations) were equally represented in our sample (between 20-23%). Open-ended questionnaires (13%) were used in somewhat fewer studies. It is understandable why researchers would hesitate in choosing this method, given the complexities of coding and analyzing data from open-ended instruments. Another positive aspect revealed by this current survey is the number of studies that went beyond self-reports to performance assessments or observation of teachers (or teacher candidates). The value of any framework of technology integration and teacher knowledge lies in how it manages to influence practice and it is only through actual observation of performance and assessments thereof that this practice can be empirically tested.

These positives aside, we must point to some significant concerns with this research. The biggest weakness in these current studies is the short shrift given to issues of reliability and validity. Over 90% of the studies we looked at provided

no evidence of validity (“the instrument being used measures what it is supposed to measure”), and ought to be of concern to all researchers in this area. This problem is further compounded in that most studies included no evidence of reliability. For instance, our analysis reveals that approximately 69% of the studies had provided no evidence of reliability (the extent to which researchers can be sure the same measurement could be obtained if measured repeatedly). We recommend that future research on TPACK pay a greater attention to these key concerns.

Our survey of the research also reveals important challenges in conducting research about the development and measurement of TPACK. Because TPACK is a complicated construct, lying as it does at the intersection of multiple constructs (which are each complicated in their own way), research on TPACK requires sophisticated understanding of multiple constructs and how they interact with each other. For instance, the fact that the TPACK framework argues for the significant role of content implies that instruments need to be customized to specific content knowledge bases. An instrument designed for a chemistry teacher would be different than one designed for a teacher of music. A bigger challenge to this research comes from the rapid advance of technology. This rapid rate of technological change means that the part of the research instrument that focuses on technology needs to be continually updated as technologies change. For example, a question about email listserv that made sense a few years ago needs to be replaced, possibly by one about RSS feeds!

It is clear from our current survey of the research that each of the studies included in our survey face these issues (frozen as they are in time, technologically speaking) if they wish to be relevant to future research. It is not clear how the instruments used in these studies will have to change in response to the challenge of rapidly evolving technologies. If the instruments do not change they risk losing validity (speaking of Microsoft office tools when the world has moved to

cloud computing), however, if we do change these instruments to reflect new technological realities, we risk losing reliability (i.e., confidence that we are still measuring the same thing). New technologies engender new ways of representing content and new forms of pedagogy, making the idea of TPACK a moving target. It will be interesting to see how research in this domain, as it matures, contends with these issues and concerns.

CONCLUSION

In the 2006 article introducing the TPACK framework, Mishra and Koehler point to three key advantages that such frameworks present to researchers and practitioners: *descriptive*, *inferential* and *application*. First, frameworks (such as TPACK) play an important *descriptive* function, providing researchers with concepts and terminologies with which to describe complex phenomena in a theoretically-grounded manner with methodological precision and rigor. Second, frameworks such as TPACK allow us to make *inferences*, about the educational technology and teacher education. It allows us to make predictions about what approaches may be good for further development, and, as importantly, those, which may not be. Third, frameworks such as TPACK allow us to develop *applications* that bridge the gap between theory and design.

In this paper our focus has been on the first of the three advantages (descriptive), though the many research studies cited clearly inform the other two (inferential and application) as well. The 303 TPACK research publications between 2006 and June 2010 found in our initial search, along with the increasing number of TPACK measures each year (Table 2), strongly indicate that the TPACK framework has indeed provided researchers with a set of conceptual tools with which to articulate precise research questions. The many studies cited also speak to the robustness of the framework and applicability across multiple

contexts and domains. That said, much remains to be done. Although it was encouraging to see various efforts are being made to incorporate the TPACK framework into course or professional development programs, several critical issues emerged from our analysis. For instance, we noticed many of the TPACK instruments did a poor job of addressing the issues of reliability and validity. Most interview and observation instruments failed to present convincing evidence that they were reliable and valid TPACK measures.

Our goal of this chapter was not to categorize each TPACK measure into a dichotomized research tradition of quantitative versus qualitative research. Instead, we sought to identify a wide range of TPACK measures used in the field and, in so far as possible, objectively assess their reliability and validity as psychological instruments. We see this as a key step in establishing a sound, empirical and critically evaluated foundation for future research.

Our approach, however, has limitations. Despite our extensive search, it is possible that some studies may have been excluded from our analysis (Cooper, Hedges, & Valentine, 2009). For instance, studies on Information and Communication Technology (ICT) that were published prior to 2006 were not included in our analysis as our search focused on publications that were grounded within the TPACK framework, which was first published in 2006. Given that the literature on ICT is also concerned with helping teachers successfully integrate technology into their classrooms, future research may want to expand the search by including additional keywords such as “ICT.” Second, we focused on whether or not the TPACK measures explicitly presented evidence of reliability and validity. Some studies may have assumed that triangulating different sources data would automatically resolve the issue of validity. These implicit approaches to establishing reliability and validity were not the scope of our analysis. Instead we sought clear evidence that the measurement property of the instrument itself was of high qual-

ity. Future research should carefully examine this implicit validity assumption associated with the data triangulation processes.

We hope that this chapter makes a significant contribution to the field of TPACK in several different ways. First, we hope that this chapter helps our readers understand the contribution of a variety of research methodologies to measure TPACK. Second, by providing an extensive review of different methods to measure TPACK, the chapter enables the readers to make informed decisions on what types of assessment suit their research questions. Finally, we hope that our comprehensive up-to-date reviews and comparisons of the different types of assessments are useful to anyone wishing to conduct research in the area of TPACK.

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ENDNOTE

- ¹ References marked with an asterisk indicate studies included in the analysis.

Chapter 3

Assessment in Authentic Environments: Designing Instruments and Reporting Results from Classroom– Based TPACK Research

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ABSTRACT

The TPACK framework provides researchers with a robust framework for conducting research on technology integration in authentic environments, i.e., intact classrooms engaged in standards-aligned instruction. Researchers who wish to identify the value added by a promising technology-supported instructional strategy will need to assess student learning outcomes in these environments; unfortunately, collecting valid and reliable data on student learning in classroom research is extremely difficult. To date, few studies using TPACK in K-12 classrooms have included student learning outcomes in their research questions, and researchers are therefore left without models to guide their development, implementation, and analysis of assessments. This chapter draws upon the literature and our own research and assessment experiences in technology-integrated, standards-aligned classroom instruction to give examples and advice to researchers as they develop, analyze, and write up their observations of student learning outcomes. In particular, we focus on standard items, specifically multiple choice items, as an accepted (if limited) method for assessing student understanding. We seek to fill an existing gap in the literature between assessment advice for educational psychologists (who typically work outside of

classroom settings) and advice given to teachers (who have lower thresholds for issues such as validity and reliability). Classroom researchers will benefit from this advice to develop, validate, and apply their own objective assessments. We focus on the content areas of science and social studies, but this advice can be applied to others as well.

INTRODUCTION

Research on the impact of instructional technology on learning outcomes have a history of finding *no significant difference*—the technology did not provide a measureable effect on students' performance (e.g., Clark, 1983; Dynarski et al., 2007). Kozma (1994) provided a counterpoint, noting that the proper focus is not the technology alone but the technology *and* the instructional method employed by the teacher. Mishra and Koehler's framework of Technological Pedagogical Content Knowledge (TPACK; Mishra & Koehler, 2006) provides an even more comprehensive set of variables as it broadens Kozma's interest in instructional method into the richer, more descriptive context of Shulman's Pedagogical Content Knowledge (1987). Researchers can use TPACK to frame studies that attend to the interacting variables of content, pedagogy, and technology in the authentic environment of technology integration: classroom teachers engaged in standards-aligned instruction with intact groups of primary and secondary students. These more fully-contextualized, real-world studies may be able to shed light on which combinations offer no relative advantage and which do, indeed, afford a significant difference in learning outcomes.

As Schrum et al. (2007) noted in their discussion of TPACK, "Until the pedagogical methods that uniquely take advantage of a technology's pedagogical affordances to *achieve content-specific learning objectives* are identified, it will not be possible to prepare teachers to make effective use of current and emerging technologies" (p. 460 [emphasis added]). The goal of this chapter is to review the state of the field in TPACK-related

research to see whether and how this task is being carried out and to offer constructive, specific guidance to future research. Specifically, we will

1. Examine the extent to which TPACK-informed research has sought to observe the relative advantage of technology integration strategies in terms of student learning in elementary and secondary classrooms,
2. Identify and evaluate the methodology used in this research to identify exemplars, and
3. Advise TPACK-informed researchers as they conduct their own assessments of student learning in the authentic environment of technology integration: intact primary and secondary classrooms engaged in standards-aligned instruction.

In the spirit of TPACK's attention to context, we will focus on the content areas of science and social studies—these are the areas of our own instructional and research expertise and are therefore the ones in which we are most competent to review others' work with a critical but constructive lens. Our analysis and advice can inform work in other content areas as well but will directly address only these designated areas.

EXAMINING THE LITERATURE: TPACK-INFORMED STUDIES ON K-12 STUDENT LEARNING

As an initial sampling frame of TPACK-informed literature, we selected the TPACK Reference Library hosted by Koehler and Mishra (2010). The Reference Library contains more than 150

citations covering theory, pre-service teacher education, professional development for in-service teachers, and classroom practices of technology integration. The list is self-maintained by members of TPACK community. The most recent update (as of our analysis) was January 15, 2010. Of the 150 citations provided, fewer than 10 present intact classroom studies. Of these 10, only 3 include student academic performance and/or learning outcomes as one of their targeted variables (Doering & Veletsianos, 2007; Manfra & Hammond, 2008; Warren, 2006). All three studies are qualitative; the researchers did not measure student learning but only described behaviors consistent with academic goals. These goals included meeting language arts and technology standards (Warren, 2006), geography education objectives (Doering & Veletsianos, 2007), and concordance with the classroom teachers' standards-aligned history instruction (Manfra & Hammond, 2008). While these studies can inform future research and practice, they do not provide models for researchers who wish to use TPACK to identify instructional approaches that improve students' learning outcomes relative to other strategies (cf Schrum et al., 2007). Our conclusion from this initial literature review of the Reference Library is that the TPACK community and literature base is currently under-served in terms of models for assessing student learning.

Given this gap in the TPACK literature listed in the Reference Library, and to include more recent material, we turned to the Education Resources Information Center (ERIC—eric.ed.gov) to conduct supplementary searches. ERIC holds more than 1.3 million unique records. A search for the keywords 'TPCK' and 'TPACK' yielded a total of 33 unique records, many of which were not indexed in the TPACK Reference Library. However, we observed the same pattern here as with the Reference Library: of the 33 records, only 1 addressed classroom teachers engaged in standards-aligned instruction with K-12 learners—in this case, middle school history (Hofer & Swan,

2006). However, this study focused solely on the teachers' decision-making process and presented no data regarding students' learning outcomes. Again, this study can inform future research, but does not provide a model for exploring student learning outcomes.

We decided to conduct a second search in ERIC to capture relevant research that may not have been identified by 'TPCK' or 'TPACK'. To approximate the TPACK framing in the least-restrictive terms, we searched for published journal articles indexed under the thesaurus terms 'educational technology,' 'teaching methods,' and our respective areas of curricular expertise ('science instruction' and 'social studies'), limiting our attention to journal articles published within the last ten years. Next, to select for standards-aligned instruction and assessment in intact K-12 classrooms, we added 'elementary and secondary education', 'instructional effectiveness,' and (for the science search), 'science achievement.' (ERIC has no equivalent term for social studies.) For example, a study aimed at researching 'science achievement' would likely refer to the learning outcomes of science students, rather than focus solely on the teachers' attitudes, behaviors or outcomes. The terms were entered one at a time, and at each step we reviewed the articles that were excluded to confirm their removal; when we observed that an article was being excluded for an arbitrary indexing decision, we re-instituted it in the analysis. These searches yielded a total of 10 articles: 6 in the context of science education and 4 in social studies education.

Unfortunately, the majority of these 10 articles provided few models of assessment for TPACK researchers. For example, one provided *no* information about the assessment beyond that it "aimed to evaluate the students' basic knowledge about plants on their campus" (Chu, Hwang, & Tsai, 2009). Another study included the assessment as an appendix but the items are riddled with grammatical errors, calling its usefulness into question (Turkmen, 2009). Two studies identified the

number and type of items used to assess student learning, but did not include descriptions of the assessment development, validity, reliability, and scoring guidelines (Boon, Burke, Fore, & Hagan-Burke, 2006; Boon, Burke, Fore, & Spencer, 2006). Another study identified the number of items on the assessments, explained the scoring, and provided a coefficient of reliability, but offered no validation data or description of item development or piloting (Liu, Peng, Wu, & Lin, 2009). In the inverse, So, Seah, and Toh-Heng (2010) provided information on item development and validation, but no reliability data. One article described the assessments' design (to address three concepts from the state standards), validation (examination for content validity by experienced practitioners and teacher educators), and reliability, but collected no information about teachers' practices when integrating the technological innovation—short, curriculum-aligned clips of streamed video—into their instruction (Boster, Meyer, Roberto, Inge, & Strom, 2006). Accordingly, the pattern of differences they observed hinge upon an unknown factor: exactly how the teachers chose to integrate the technology into their instruction. Heafner and Friedman (2008), as participant observers in their research, provided a detailed description of their implementation. They also used a promising tactic of repeating an assessment after several months to observe students' retention of concepts learned. Unfortunately, they offered no information about the assessment's validity or reliability, meaning that the sizeable differences they observed are not interpretable. While researchers can benefit from carefully observing these studies' design and item development, none provide researchers with models of valid, reliable assessment of student learning during technology-supported, standards-aligned instruction.

Our literature review did yield two studies that stood out as strong examples of assessment of student learning during technology-integrated activities in authentic environments of intact elementary and secondary classes. Kwon and

Cifuentes (2007) studied 74 eighth grade students in 5 classrooms who used concept mapping software to learn science concepts from a set of four readings about astronomy adapted from the textbook. To assess students' learning across three conditions (individually-generated concept maps, collaboratively-generated concept maps, and a control condition of independent, unguided study), the researchers collaborated with the participating teachers to select 40 relevant items from the textbook publisher's test bank. Each item was criterion-referenced to the assigned reading, and the researchers reported on the internal consistency on the entire 40-item assessment, a coefficient alpha of .82. Students' work was carefully observed throughout the study to determine fidelity of treatment, and the analysis was presented thoroughly, including tests of assumptions and effect sizes. Cantrell and Sudweeks (2009) observed students' science achievement in a large-scale study of autonomy and gender effects: nearly 5,000 middle school students in 38 classrooms completed 4 science units, covering topics such as population biology and pulley systems. Each unit contained technology-supported activities requiring students' hands-on use of tools such as models, animations, and spreadsheets, and modified WebQuests. The participating teachers collaborated in designing the units and their corresponding assessments, aligned each item's cognitive domain and level of difficulty based on information provided in the Trends in International Mathematics and Science Study (TIMSS). University experts in assessment and science content participated in item development. The analysis addresses unequal group sizes and unequal variances. While each of the studies has its flaws (Kwon and Cifuentes fail to disaggregate their data across the four readings; Cantrell and Sudweeks provide no data on internal consistency), they do provide useful, working models for TPACK researchers as they observe student learning in classroom studies.

The literature examined above, both within the TPACK Reference Library and in ERIC, is merely a sample of the possible relevant studies. However, the central finding is consistent: the research community interested in using TPACK to explore student learning outcomes from teachers' use of instructional technology in standards-aligned instruction has very few models available for assessing student learning in classroom learning environments. Of the self-identified TPACK literature, studies of intact K-12 classrooms are rare and, to date, only qualitative methods have been used to discuss students' experiences. From literature that does not identify itself as TPACK-informed but does investigate technology and pedagogy in the service of content instruction within the classroom, a wider set of models is available but most are deeply flawed. Furthermore, these flaws are not limited to educational technology research: a review of 173 teacher education studies employing quantitative measures observed that researchers routinely failed to include information about instrument development, did not provide copies of instruments or sample items, and did not report reliability—or worse, reported it incorrectly (Zeicher, 2005; Zientek, Capraro, & Capraro, 2008). Accordingly, as TPACK researchers seek to respond to the call of Schrum et al. (2007) design their studies and select instruments to assess student learning, they will be forced to rely on their own ingenuity and whatever exemplars they happen to find in the literature. Until more and stronger examples emerge, the TPACK-informed research effort to connect teachers' selections of instructional methods and technologies to meet content-specific learning objectives will proceed unevenly.

We acknowledge that the authentic environment of the K-12 classroom is a challenging research environment, particularly when it comes to identifying student learning. The patterns of assessment that are appropriate for teachers—the use of targeted reviews before assessments, extensive reliance on standardized measures, high frequency of basal items—may not be useful for researchers

who need to attend to validity, reliability, and item discrimination. Ethical research practices demand that researchers respect the teachers' purposes in assessment, such as assessment for learning and/or curricular accountability, and not impose their own epistemological paradigm. In some cases, researchers can use established, valid and reliable instruments as part of their data-gathering measures to assess student learning (e.g., Bodzin, 2008; Bodzin, 2011). In other cases, however, a researcher must work with either teacher-designed assessments without external construct validity (Hammond, 2007; Heafner & Friedman, 2008) or researcher-designed assessments that align to the curricular learning goals and objectives but without high levels of internal consistency (Alexander, 2009; Bodzin, 2011) in order to conform to school accountability purposes. In these instances, the research may be hampered by ceiling effects, low coefficients of reliability, narrow or shallow sampling of content, or weaknesses in assessment design. All issues of instrumentation aside, the classroom environment itself provides further complications that cannot provide controlled settings for optimal curriculum implementation conditions—student absences, unanswered assessment items, classroom interruptions or distractions, low internal motivation, demoralization, and so forth. While the existing literature on TPACK will certainly help researchers construct appropriate research designs for classroom studies, capturing useful data on student learning will remain a challenge. Finally, the preparation and training of education researchers may be a weak point. Education doctoral students' research training experiences, particularly in quantitative methods, are often taught by methodologists outside of individual students' fields and may not attend to the rigors or contemporary practices of, for example, classroom-based research. This gap between research training and research practice can contribute to the observed weaknesses in the research literature (Henson, Hull, & Williams, 2010).

DESIGNING INSTRUMENTS AND REPORTING RESULTS FROM CLASSROOM-BASED TPACK RESEARCH

We now turn to our third purpose, to draw upon the literature and our own research and assessment experiences in technology-integrated classroom instruction to give examples and guidance to researchers as they develop and analyze assessments to measure learning, and write up their findings of student learning outcomes. We are limiting our focus to the use of objective, selection response items: multiple-choice, matching, and so forth. We have two reasons for doing so. First, standard items are a staple element of classroom assessment. Researchers hoping to work within teachers' existing assessment practices to explore student learning outcomes will have many opportunities for collecting data—especially if the items can be developed for dual purposes that both suit the needs of classroom teachers for their own assessment purposes and the needs of researchers to carefully observe student learning. Second, the strength of the TPACK framework is its ability to be highly context-specific, attending to the unique circumstances of individual teachers' content knowledge, pedagogical stance, and technology as they are pulled together in the unique circumstances of the classroom—as the teacher's *intended* curriculum becomes transformed into the *enacted* curriculum (Eisner, 2002). Given this deep contextualization, researchers using TPACK can and should use protocols for capturing fidelity of implementation data and include qualitative methods in their research designs. Indeed, the majority of the classroom research citations in the literature are qualitative studies; researchers recognize that fidelity of implementation is not always a given with technology-embedded curriculum and that teachers will adapt an innovation to suit their needs (Rogers, 2003). This chapter seeks to inform researchers as they seek to complement this deep

look into context with data and instruments than can speak across settings and across studies.

We continue to limit our attention to assessments in the areas of social studies and science education. First, these curricular areas represent our own area of experience in teaching and research. Second, social studies and science education researchers wishing to use standardized items have relatively few resources at their disposal. Researchers in language arts and math have a wide body of highly standardized, normed instruments to draw upon—for example, researchers can choose among multiple tests of oral reading fluency, from the National Assessment of Educational Progress (NAEP) scale (<http://nces.ed.gov/pubs95/web/95762.asp>) to the DIBELS Oral Reading Fluency test (<https://dibels.uoregon.edu/measures/orf.php>) to the Gray Oral Reading Test (via psychcorp.pearsonassessments.com). In science education, this work is still in its early stages, such as the assessment work under development by the *Project 2061* initiative of the American Association for the Advancement of Science (AAAS—AAAS—see Hermann-Abell & DeBoer, 2010; Abell & DeBoer, 2007; Project 2061, 2007; Wertheim & DeBoer, 2010; Willard & Rosemann, 2010) or the items used by the Technology Enhanced Learning in Science (TELS) projects (Linn, Husic, Slotta, & Tinker, 2006; Linn, Lee, Tinker, Husic, & Chiu, 2006). In social studies education, the premises of standardized assessment are highly contested (e.g., Grant & Salinas, 2008; Reich, 2009; Wineburg, 2004) and there are no corresponding initiatives to develop valid, standard items aligned to the learning goals in the social studies.

First, however, we must situate this guidance within the context of *measurement* versus *assessment* versus *evaluation*. Education writers often use these terms interchangeably, but they have significant if subtle differences that are vitally important to the education researcher. Unfortunately, these terms and their relationship to one another have been defined inconsistently in the

literature, depending upon the authors' purposes; therefore, we must clarify our use before making further recommendations. *Measurement* is simply "the process of assigning numbers to individuals or their characteristics according to specified rules" (Ebel & Frisbie, 1991, p. 25). Typically, the term is associated with a specific tool (such as thermometers, rulers, and timepieces) and a quantifiable degree of precision (Hopkins, Stanley, & Hopkins, 1990). Given this association, *measures* of student achievement are often associated with the type of highly-refined and standardized instruments such as the afore-mentioned DIBELS Oral Reading Fluency test—its reliability for elementary students ranges from .92 to .97, it uses pre-selected materials, the administration is scripted (and illustrated with a demonstration video), and the scoring is tightly structured (see <https://dibels.uoregon.edu/measures/orf.php>).

Most importantly, the measure is given under controlled conditions: students and test-givers are in an isolated environment, working one-on-one with no overt time constraint. Whereas *measurement* focuses on the amount of a given quantity or attribute (e.g., words read in a minute, a runner's time in the mile, the ratio of computers to students in a school), *assessment* is a process by which information is obtained relative to an established objective or goal (Kizlik, 2010)—either before or after instruction, teachers or researchers collect information for "the purposes of discovering and documenting students' strengths and weaknesses" (Cizek, 1997, p. 10). The positioning of assessment in teachers' or researchers' hands is important—for teachers' purposes, assessment is either used for formative or summative purposes. Formative assessments are used for instructional decision-making. They are embedded in instructional events and serve to inform subsequent steps in the teacher's instructional planning. Summative assessments are used for grading and placement decisions. While researchers can make use of embedded formative assessments (e.g., Slotta, 2004), these are typically qualitative data such as

student responses to specific items on instructional handouts or worksheets, student journal responses, and drawings. Summative assessment measures provide researchers with a more valid form of data measurement than formative assessments since it can provide student achievement data for mastering a concept or skill at that point in time. Three additional comments on classroom assessment versus measurement are required. First, assessment is more often associated with inference rather than explicit 'measurement'—the assessment is an observation of student behavior, but its purpose is to make an inference about some unobservable characteristic of the student (Cizek, 1997). Second, assessments such as end-of-unit tests typically take place within the context of instructional time, such as a given class period or exam period. Third, assessment is commonly applied to groups of learners, such as whole classrooms, not individuals—the teacher and researcher wish to observe how the entire group (and sub-groups) of learners respond to the items. *Evaluation* is the making of judgments, whether about teachers, instructional techniques, curriculum programs, students, classes, materials, or some other element of the classroom context (Ebel & Frisbie, 1991).

To put these three terms into the context of classroom research informed by TPACK, we avoid using the term *measurement*. The formal definition of the term certainly applies to the use of standardized items—based on students' responses to the item, a number can be applied to the item and/or to the students' performance on the knowledge or skills targeted by the item; a specific rule (the scoring guide) applies. However, given the term's association with instrumentation and consistency, we feel that it invites misreading. Rather than *measuring* the amount of knowledge students have attained, teachers typically collect data to better understand each student's progress toward meeting the learning objectives, which aligns with the aforementioned definition of *assessment* (Huitt, Hummel, & Kaeck, 2001). For example, teachers

regularly adapt their assessment protocols based on the characteristics of a given group of students. When administering a summative classroom assessment such as an end-of-the-unit test, teachers may give certain classes or certain students more or less time or choose to conduct a quick review prior to the test. In addition, any given class may be interrupted by visitors, announcements or even a fire drill. Given the unpredictable nature of schools and classrooms, the term *assessment* more closely captures the context of classroom research and aligns with the key elements of instruction and teacher's purposes. If the learning goals of classroom instruction are aligned to state content standards, then one would expect that the assessment items used to measure student learning would also be aligned to these learning goals. When using standard items, the classroom researcher can and should aspire to certain characteristics of measurements (described below), but the more appropriate term for this action is "assessment of student learning." The use or non-use of *evaluation* depends on the researcher's purpose—if a study is meant to be descriptive and not make value judgments, then the term is unnecessary. If, however, the researcher uses standardized items for the purpose of evaluating the use of a technology within a particular content area and within a particular instructional strategy, then the term is entirely appropriate.

GENERAL CONCERNS REGARDING STANDARDIZED ITEMS

Forced-selection type items such as multiple-choice questions are deeply familiar to teachers, students, and researchers. Using forced-selection type assessment items for research purposes has many advantages for faster and reliable scoring purposes and reducing student response omissions that often occurs in classroom contexts with the use of open-ended response items (Hollingworth, Beard, & Proctor, 2007). On the surface, they are

straight-forward micro-tasks: the student reads or interprets a prompt (or stem), surveys the offered answers (the correct answer and several incorrect answers, also known as distractors or alternatives), and matches the correct (or best) answer to the prompt. To item writers of basal curriculum programs, these tasks may appear simple, or even trivial—the writers see the logic undergirding the connection between the stem and the correct answer and the lack of fit between the stem and the distractors; they can articulate the connection between the item content and the overarching goals of the assessment, such as testing students' content knowledge or skills. For research purposes, distractor-based multiple choice testing can be used for diagnostic purposes when distractors are built specifically to illuminate common knowledge deficits or misconceptions student might hold in science-related content domains (Briggs, Alonzo, Schwab, & Wilson, 2006; Sadler, 1998).

For some students, standardized items may also be simple and straightforward, but it is worth considering the characteristics of these students that shape their responses. For students who have strong reading skills (relative to the reading level of the test), who have a working schema of the concept or mastery of the skill, and who can maintain the stem *and* the proffered answers in their working memory, standardized items are sensible, or even trivial. In the context of these students' abilities, standardized items can function as valid, reliable micro-tasks. For other students, however, who may not have the same reading ability, who may have fragmentary schema or emerging skill levels, who may not be able to hold the key components of the question and the answers in their working memory, a standardized item may appear to very different—it may be meaningless, a salad of words and ideas that have no discernable connection to what they thought they were learning. Under these circumstances, the item is not a small, manageable task but a set of snares, whether from tricky wording in the prompt to

shades of difference between the distractors and the correct answer.

The researcher, therefore, must approach the design or interpretation of standardized items with caution. A myriad of seemingly minor aspects of an item (the wording, the visuals associated with the prompts, the ordering of the distractors) can impact students' perception and performance on the item. To prepare research using standard items, researchers should take time to attend to the following issues and pilot items with a sample of diverse target-age learners that include English language learners and students with disabilities prior to use in a classroom implementation study. We have attempted to arrange these issues in a logical sequence for a researcher, moving from broader to more specific concerns.

Content Sampling

Any given item is an attempted sample of a larger domain of conceptual knowledge or skill performance. Some items may sample basic or core concepts in a domain (definitions of key terms, basal skills) while others address complex understandings (e.g., causal relationships) or later-stage conceptualizations (motivations of historical actors, interactive models of dynamic processes). For each item, the content sampled should be (a) clearly identifiable, and (b) aligned with the standards and curriculum that informed the instruction. Depending upon the purposes of the teacher and of the researcher, the items may also need to (c) sample the content evenly—that is, each learning objective or standard should be assessed by roughly equivalent numbers of items. However, some teachers may prefer to sample basic concepts more heavily (because these are critical to later understandings or to allow students multiple chances to show what they know—cf Bol & Strage, 1996) and/or some researchers may prefer to focus on more complex understandings to differentiate among learners or to capture the value-added by an innovative instructional ap-

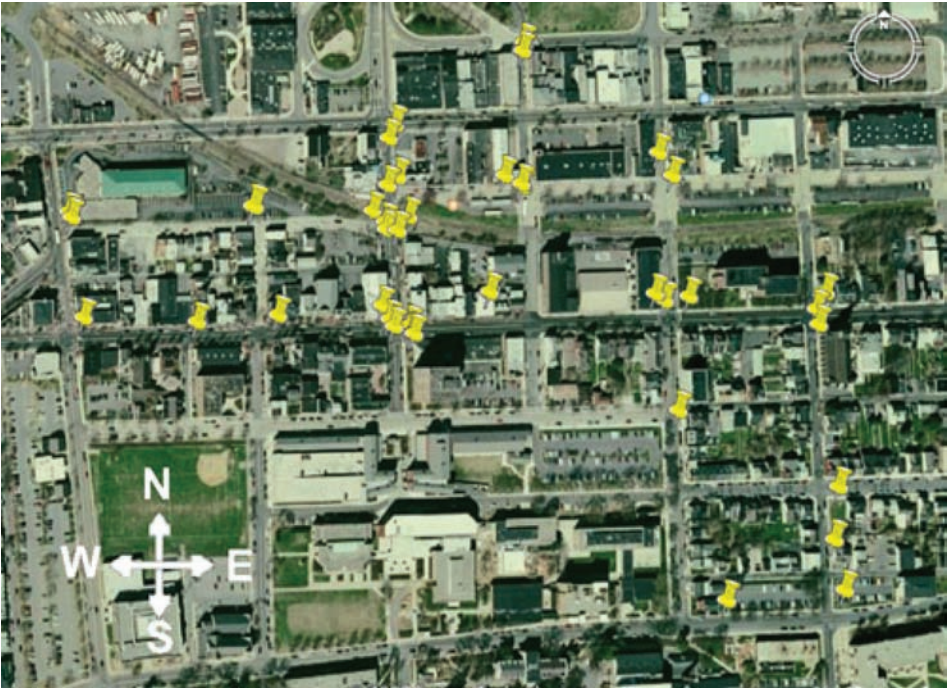
proach. When multiple items sample a concept (e.g., the Harlem Renaissance) or different aspects of a construct (atomic models), these items can be joined into a scale or sub-scale.

Content Alignment with Instruction

Within the context of classroom research with technology, summative assessments arrive after instruction to document students' mastery of the concepts or skills addressed during the lesson. The researcher must therefore take care to examine the items' fidelity to the instruction - including how technology is intended to be used in the classroom to promote learning and not just the curriculum or the standards. In short, were students prepared with appropriate schema or skills to understand the questions and answer them correctly? Did they have an adequate opportunity to learn what the item purported to assess? To properly examine this alignment, researchers must also have a chance to observe the instruction—did the teacher omit certain topics or key instructional sequence details that were represented on the test? At the very least, if daily classroom observations are not feasible, researchers should subject the test content to a member check with the teacher, asking him or her to recall and describe the daily instructional sequence events that include the instructional strategies used for each sampled concept or skill. In our study of a local geospatial inquiry unit, the targeted learning goals included students' ability to analyze geospatial data and determine patterns (Bodzin, Hammond, Carr, & Calario, 2009; Hammond & Bodzin, 2009). During the unit, students surveyed the neighborhood topography and the distribution of sewers along the street grid and created data displays using geospatial tools. (See Table 1.) This task provided students with the opportunity to learn the patterns present in this dataset.

When using standard items that align to learning goals, not all items may align specifically with classroom instruction. For example, items in-

Table 1. Sample True/False Items & Responses From Two Rounds of Implementation of a Middle School Local Geospatial Inquiry Unit

				
Prompt: Look at the map above. The yellow pins mark sewer locations . According to this map, mark each of the following statements True or False .				
Items	Global means			
	Round 1 (n=78)		Round 2 (after modifying instruction; n=86)	
	pretest	posttest	pretest	posttest
A. Sewers are located along streets [<i>True</i>]	.831	.846	.814	.778
B. Sewers are found at intersections [<i>True</i>]	.6	.679	.663	.794
C. More sewers are located on east-west streets than north-south streets [<i>False</i>]	.585	.731	.523	.556

tended to assess students' ability to transfer their knowledge or skills to a new context will by definition have a limited connection to students' instructional experiences. In other cases, the researchers may include items that address enrichment materials that are accessed by some, but not all students. These are valuable items and can be critical to the researcher's purpose, but they must be handled carefully. Depending on the research questions, the researcher may need to interpret this data separately from students' performance

on the items intended to sample their instructional experiences. In our geospatial inquiry example described above, we followed the pattern-recognition items in Table 1 with unfamiliar data displays, such as precipitation maps. For these items, the students had experienced an opportunity to practice the skill but had not rehearsed it with this content. Accordingly, students' performance on these items was judged separately from their performance on the more familiar items in Table 1.

Item Sequencing Relative to Content or Instruction

Human memory works better with a retrieval plan than in random order, and time sequence is one such retrieval plan—memories are encoded within episodes and episodes are accessible in time order. When test content is ordered in the same sequence as during instruction, students are able to recall the sequence of episodes of instruction, providing a pathway to the concepts of instruction. Accordingly, students perform slightly better on content-ordered tests than random order tests (Carlson & Ostrosky, 1992). Furthermore, students perform better on tests that begin with easy concepts (as instruction tends to do) versus tests that begin with the most difficult concepts (Aamodt & McShane, 1992). Given that teachers and researchers are interested in seeing students' best performance on an assessment, items should be arranged in ascending order of complexity and in the same sequence as the topics of instruction; to do otherwise introduces further randomness into students' responses. Beginning tests with exceptionally challenging items can also invite student demoralization, reducing their level of effort and performance on subsequent items.

Item Difficulty and Guessing

Once the researcher has student response data to an item or set of items, the work of analysis begins. A standard component of item analysis is the item difficulty, or *p*-value. In its most basic terms, the *p*-value is the proportion of test-takers who got the item correct divided by the total number of test-takers. If 100 students answer an item and 80 answer it correctly, the *p*-value or item difficulty is 0.8. These values can vary from one sample to the next. If the sample has been randomly constructed, an observed *p*-value may be generalized to the entire population. When using intact groups, as many classroom studies do, any interpretation

based on item difficulty must be limited to the participating group (Osterlind, 1998).

In the absence of other factors, researchers cannot interpret student responses on standardized items below a certain threshold of item difficulty. In the case of a four-choice item, for example, by pure random guessing 25% of the students should select the correct answer. When faced with an item on which 25% the students selected the correct answer, the researcher cannot necessarily infer that this group knew the answer. Instead, the starting premise must be that the probability of correctly guessing the item must be taken as the baseline of student knowledge: on a true-false item, the expected *p*-value for random guessing is 0.5; on a five-choice multiple choice item, it is 0.2 (Haladyna, 1994). Only when student performance rises decisively above these thresholds do the results become interpretable.

When examining item difficulty, we have found that looking at students' answer choices (i.e., option A, B, C, or D) is more informative than looking at right-answer/wrong-answer data (i.e., scores of 1 or 0). In some instances, we have found that a four-choice item was functionally a three- or even a two-choice item. For example, in the context of a study of students' digital documentary making, we asked students to identify the style of music that Louis Armstrong or Duke Ellington is most associated with. The vast majority of students (between 83% and 100%, depending on the group) selected 'Jazz' or 'Blues' as their answer instead of 'Bluegrass' or 'Country.' In essence, we had two non-functional distractors, and the true minimum threshold to compensate for student guessing on this item should be set at 0.5, not 0.25.

Researchers must also keep in mind that guessing can inflate students' performance. Even in a class where 100% of students answer an item correctly, some portion (although probably not more than a few) may have obtained the correct answer by guessing. In cases where researchers need to control more firmly for guessing, they may wish to look at students' performance on

more than one item at a time. In the geospatial inquiry unit described earlier, for example, we asked redundant questions targeting key topics, such as the ability to identify geospatial patterns in a familiar dataset. Answering only one of these items correctly could be the product of guesswork. Only when a student answered all of these items correctly did we categorize them as mastering this particular goal.

Item Discrimination and Ceiling Effects

The flip side of guessing and a low item difficulty index is the ceiling effect: a question on which all (or almost all) of the students answer correctly. An item that 90% of students answer correctly is close to its natural ‘ceiling’—there is not much room for improvement. For example, in Table 1, the Item A pretest means (.831 and .814) are high enough to merit exclusion from the analysis, or at least careful consideration of the students who offered incorrect responses—did they misread the question? Did they have an alternate conception? From a research standpoint, when attempting to compare across groups, an item with a high *p*-value can be a missed opportunity to observe differences in learning outcomes. Of course, it can be appropriate to place easy items (with a concomitant high *p*-value) at the beginning of a test (see above). However, the target is for items to fall far enough below the ceiling to allow for the observation of differences.

In addition to item’s difficulty, researchers can examine an item’s discrimination index. There are multiple methods for calculating a discrimination index, but they all share the fundamental tactic of comparing students’ performance on a single item with their performance across an entire test or sub-scale. An item on which the top-performing students do well and the lower-performing students do poorly may have a high or low *p*-value, but a very high discrimination index: it effectively discriminates between different levels of achieve-

ment. In contrast, an item that is answered correctly at the same rate by all levels of students (as in the case of guessing) has a very low discrimination index. Most measures of item discrimination, such as a biserial correlation coefficient (see Osterlind, 1998, pp. 278-282), range from 1 (highly discriminating) to -1 (negatively discriminating—usually a flawed item or at least unusual item). For research purposes, items should ideally have an item difficulty and an item discrimination index close to 0.5. Items that significantly deviate from these expectations bear further scrutiny and revision. Rasch modeling methods are emerging in science education research to estimate and compare item difficulty and the popularity of each answer choice for students of differing ability (Lee & Liu, 2010). Researchers are using item-response theory to align items to content standards and improve construct validity of items by paying attention to comprehensibility, test-wiseness, and appropriateness of task context (Herman-Abell, DeBoer, & Rosemann, 2009; Liu, 2009).

Again, looking at raw student responses (A, B, C, D, etc.) instead of scored responses can help shed light on the performance of an item. On the previously-mentioned question about the musical genres of Louis Armstrong and Duke Ellington, students who answered either ‘Bluegrass’ or ‘Country’ were mostly within the 25th percentile of the distribution, with a mean test score a full standard deviation lower than students who answered ‘Jazz’ or ‘Blues.’ The item discrimination index was 0.5, meaning that the item, despite its flawed distractors, still effectively discriminated between higher- and lower-scoring students. With improved distractors, however, the item should perform even better.

Student Characteristics: Prior Knowledge, Cultural and Linguistic Differences, and Mediating Variables

Once a researcher is looking at student responses, he or she must consider the range of possibilities

than can influence students' answers beyond the initial assumptions of content understanding or skill. An obvious beginning point is students' prior knowledge—what did students know upon entering rather than what they learned during instruction? Obviously, a pretest can address this concern and confirm whether students had no prior knowledge (given an item difficulty of approximately .25) or do have some previous understanding or skill (given an item difficulty above .25). We wish to flag this seemingly obvious point because under the conditions of standards-aligned instruction, students are very often addressing a topic for a second or even third time in their academic career. This prior knowledge will contribute to their performance on a test, particularly on objective items (Dochy, Segers, & Buehl, 1999). When we asked more than 200 7th grade students across three Virginia school districts, “What was the Great Migration?” their *p*-values ranged from a high of .84 to a low of .75 *on the pretest*. (In this case, the topic did not appear on any of the state-mandated standards prior to 7th grade, but students reported that they were familiar with the event from sources such as the History Channel—see Hammond & Manfra, 2009.) Given the possibility of prior knowledge on curricular concepts, researchers must consider dropping basic items from their analysis and/or adding more open-ended assessments to capture the nuances in students' knowledge or skill.

Another possible impact on students' performance comes from their unique characteristics. In some cases, students may have an alternative understanding of a term from that assumed during item design. In the course of implementing and refining instructional materials for a local geospatial inquiry unit, we discovered that many students were interpreting the term ‘intersection’ (as in where two streets meet) to mean ‘a four-way intersection,’ or ‘where two streets *cross*.’ Accordingly, they were not recognizing three-way or T-shaped intersections as such. We modified the instruction in subsequent iterations of the

study, and the results can be seen in Table 1, Item B: students' gains between the pre- and posttest administration of the item nearly doubled. Researchers must be especially sensitive to students' cultural or linguistic differences influencing their test responses. In a design study on a geospatial technology-integrated science unit on land use change in an urban, high-needs middle school (Bodzin & Cirucci, 2009), one test item on satellite image interpretation showed a persistent, incorrect answer to the question, “Which location is a neighborhood with large houses?” (See Table 2.) In follow-up interviews with participating students, the researcher found that in the students' view, a ‘neighborhood’ was an urban area: a densely-populated region with few green spaces and either adjoined or narrowly separated housing. In the satellite image, the suburban area (Location E) failed to meet these criteria. The researcher then revised the question to read, “Which location is an area with houses that have very large yards?” (To date, no student response data on the revised item has been collected). When evaluating student responses, researchers must bear in mind that on their own, test items are completely insensitive to students' emic constructions of meaning; accordingly, the researcher may want to be present for some or all test administrations to observe the clarifications that students seek about individual items and/or conduct follow-up interviews.

Two final student variables are critical to interpreting students' performance on items: reading ability and test-wiseness. Given the amount of reading comprehension required on a test, it is unsurprising that achievement test results correlate with reading scores. An additional consideration to bear in mind when interpreting test results from students with limited reading ability is that the estimates of reliability will be lowered—the amount of error in their responses (i.e., answer choices made due to some factor other than relevant knowledge/skill) is higher than for students with stronger reading skills (Abedi, 2002). Researchers must carefully examine test items and

Table 2. Sample Multiple Choice Item & Student Responses From a Study of a Middle School Unit on Land Use Change



Prompt: Which location is a neighborhood with large houses? [Correct answer = 'Location E']			
Choices	Student responses (n=110)		
	pretest	posttest	
Location A	0%	0.9%	
Location E	5.2%	4.5%	
Location F	72.2%	83.6%	
Location G	22.6%	10.9%	

student responses whenever they suspect that the language ability demanded by the test exceeds that of the students (American Psychological Association, 1999). Test-wiseness (or test sophistica-

tion) is highly correlated with verbal ability (Sarnacki, 1979) and indicates the student's ability to use cues within the test item or test context to derive the correct answer (or a more probable

guess) without referring to the targeted understanding or skill. Test-wise students can recognize clues within the answer stem or identify patterns within the answer choices—the longest or shortest answer is more likely to be correct, or one of a pair of diametrically opposed choices (Millman, Bishop, & Ebel, 1965). As a result, the test-wise student scores correctly on items on which he or she has no knowledge or only partial knowledge. Researchers must therefore carefully examine item stems and answer choices for test-wise ‘tells’ such as a more carefully qualified distractor.

Item Delivery: Design, Readability, Prompting Media, and Conditions of Testing

The final body of issues when examining items relate to their method of delivery. As survey designers know, the way in which a question is asked can influence the answer. For example, a commonplace among teachers is that questions that use a negative construction (e.g., ‘all of the following except’ or ‘which of the following is not’) confuse students and result in more incorrect answers than a positive construction (‘which of the following’). We have indeed observed this to be true in our own work, although the effect is not always easy to detect. In the study of digital documentary-making, students were asked “Which was NOT a cause of the Great Migration?” On the pretest, between 20 and 30% of our participating students opted for a distractor (e.g., “African-Americans were looking for job opportunities in factories in large cities”). On the posttest, students who selected a distractor either stuck with their initial choice (suggesting that they either again misread the question or maintained an incorrect understanding about the topic) or switched to the correct answer (suggesting that they either read the question correctly this time and/or learned the concept more completely). Fewer than 5% of students selected a distractor

on the pretest and selected a different distractor on the posttest.

The reading level of a question clearly matters, as described above. The *readability* of a question is a related but slightly different issue—reading level focuses on word choice and sentence structure, while readability incorporates typeface, use of color, spacing, and so forth. Whenever we have a question stem or a distractor that hinges upon a single word or phrase (e.g., a map-reading question such as, “Look at the map above. Where are most **CITIES** located?”), we single out the key word in an attempt to ensure that students focus on the key criteria in the stem and apply it to the answer choices as we have intended.

An emerging area of interest for us is the type of media used in the prompt. Most questions are text-driven: students read a sentence or a fragment, decode it, and then apply these understandings to the answer choices. Depending on the targeted content, however, we may use an enhancement—a map, graph, chart, primary source passage, photograph, satellite image, force diagram, or other media as appropriate to the topic and the field of study—to accompany the stem. Each format comes with its own challenges. Primary source documents may use language that is archaic or contain unusual sentence constructions. Students interpreting a graph as part of a prompt are tapping into a set of quantitative skills more closely aligned with math education and therefore further removed from students’ social studies ability, for example. Students’ ability to interpret a force diagram in a science item may hinge upon their spatial thinking, a skill related to many science topics but not necessarily addressed or developed during the classroom instruction being studied. Photographs or paintings come with their own set of affordances—students can and do ‘read’ these images and make inferences much as they do with text, but they may attend to details overlooked by the item designer (cf Barton & Levstik, 1996). We have not yet identified a discernable pattern in students’ responses to different enhancements

that are typically found as part of technology-integrated school curriculum, and the topic has not yet received attention in the research literature on test construction and analysis. Methodologist Thomas Haladyna advises not including illustrated items: “One would have to have a strong rationale for using these items” (1994, p. 56). We argue that in social studies and science education, these enhancements are not only communicative devices about the topic but critical tools of the discipline, especially when one uses learning technologies that take advantage of visualizations and graphic representations to promote effective classroom instruction—assessment items should include whenever they align with the curriculum.

A final concern is the item delivery vehicle, whether a paper-and-pencil test or computer-based. This topic has received attention in the literature (e.g., Russell, 2006, Ch. 5), for example, examining whether students’ test performance will be mediated by their technological proficiency. We have used both formats in our own classroom studies, depending upon the availability of computers. We have not observed a difference emerging by condition; students appear to be equally comfortable with both. If there is an effect on students’ performance, we feel that it is less perceptible than the impact of the issues described above, such as item readability or student reading level. We do have a slight preference for computer-based assessments based on their affordances to students and researchers. Students can follow links to examine large, full-color versions of maps and other graphics; researchers can take advantage of options such as randomizing answer choice sequences. With computer-based tests, we have experienced less ‘leakage’ of data relative to paper-based formats (e.g., from lost or destroyed test sheets, errors in transcription, etc.). The most common error we have experienced in using web-based tools (SurveyMonkey, Google Poll, Zoho, etc.) is multiple submits from students who press the ‘Send’ button more than once. However, each researcher must make the item delivery

choice that best fits the context of the study. In the event that the same test is run in two different settings, one on the computer and one on paper, the researcher should observe for differences by condition by comparing the two sets of results, or at least examining items that are expected to show the greatest degree of difference.

STRATEGIES FOR DEVELOPING NEW ITEMS

When designing a study, a researcher may be fortunate enough to find existing items or even entire assessments that speak to the targeted learning outcomes. However, in many cases, researchers will have to develop their own items and assessments to properly align with the curriculum learning goals and instruction for a given classroom context. Many researchers who conduct technology implementation studies do not have specialized training in test item development—they may rely on selecting available items from basal curriculum test banks or standardized assessments such as TIMSS or NAEP. Fortunately, the literature does provide a process that can be followed to produce useful items, or at least items that are more likely to be useful for data gathering purposes when using technology-embedded curriculum with intact classrooms.

The first step is to carefully define the concept to be assessed. Typically this can be drawn from the state standards and the school or school district’s adopted curriculum. One caution is that these sources offer a starting point to understanding standards-based learning goals, but not a complete description of curriculum implementation details that are required when using TPACK to promote student learning. Content standards, for example, can provide an initial statement of the topic—the National Geography Standards for grades 5-8 state that students are to know “How to make and use maps...to analyze spatial distributions and patterns” (Geography Education Standards

Project, 1994, p. 144). Within the same document, expected competencies are defined: the student should be able to “Develop and use different kinds of maps...as exemplified by being able to use data and a variety of symbols and colors to create thematic maps...of various aspects of the student’s local community” (Ibid.). From this definition, we need to specify what we mean by a map: a map should conform to a map view (top-down, or birds-eye), follow an identifiable orientation (e.g., north toward the top), have boundaries delimiting different areas, have identifiable features with labels or a legend, and so forth. To explore spatial patterns in the community, students need to collect and display data—typically using a GIS or other geospatial visualization tool such as Google Earth—that has a spatial significance: the location of features is purposeful and meets a need at that location that cannot be served from another location. (See Hammond & Bodzin, 2009 for more information on the operationalization of these concepts. For an exhaustive example of developing constructs for science education, see the work of AAAS’ Project 2061, e.g., Abell & DeBoer, 2008, and DeBoer, Lee, & Husic, 2008.) Each step should be evaluated—is this description complete? Are additional clarifications needed? Can any information be omitted without compromising students’ understanding of the key ideas? Note that this step of defining the content is equally critical for constructing more qualitative data collection techniques (such as interviews or performance tasks) as for constructing standardized items.

Once the researchers have defined the content to be assessed, they must examine students’ understandings of these concepts. In some cases, the research literature may provide a starting point, describing students’ conceptualization of force (Watts, 1983), the solar system (Baxter, 1995), lunar cycles (Bell & Trundle, 2008), chronology (Barton & Levstik, 1996), the natural of historical sources (Wineburg, 1991), etc. At some point, however, the researcher must go to the students

themselves. Student input can be sought in a variety of ways: through interviews about the topic, performance tasks, constructed-response answers, think-alouds on closed-ended items, or even examining common student errors on similar items. The goal of this interaction is three-fold: (1) to check the content definition for completeness, (2) to observe alternative conceptions that students may hold, and (3) to identify stumbling blocks to students’ arriving at the desired understanding. When working with students, pay particular attention to their level of prior exposure to the topic—are they arriving at this topic armed only with their naïve conceptions or after instruction? What understandings or models were emphasized during this instruction? We have observed students laboring under misconceptions about, for example, westward expansion during the 19th century that were the product of previous instruction, not a mere accident (Hammond & Manfra, 2009).

After defining the content and exploring the spectrum of student understandings, the researchers can commence with the time-consuming step of formal item development. Many rules exist to guide this process (e.g., Haladyna, 1994, Ch. 4-6; Osterlind, 1998, Ch. 4-5), and many of them are intuitive (allow time for iterative refinement and editing) or obvious (don’t use humor, use plausible distractors). Our advice at this point, beyond bearing in mind the concerns raised in the previous section, is to attend carefully to the cognitive level of the item. For fact-recall items, try to write at least two or more forms of the question, to control for guessing. For items that aim for higher level understandings, consider asking a two-tiered question: an initial question that tests the understanding (e.g., providing a prediction about which objects might float) and a following question that directs the student to select the appropriate chain of reasoning (relative density). In both cases, draw upon the literature and observed student conceptions to carefully frame the correct answer and the distractors to engage students’ schema.

With a set of items in-hand, researchers can begin piloting their performance with students. This step is the one that some classroom researchers tend to skip or under-value, but in our experience it is a make-or-break stage for not just the assessment but perhaps the entire research project. As students answer items, the researchers can evaluate the usefulness of distractors, the readability of the items, the possible impacts of cultural and linguistic differences, etc. Items that are too easy can be omitted (or included for the purposes of avoiding demoralization but excluded from analysis); items that fail to discriminate can be re-written or omitted. Given an opportunity to test items both before and after instruction, look carefully at items that drop between pre and post or fail to show much improvement—they are either flawed items or they do not align with instruction. As groups of useful items are identified, experiment with assembling them into sub-scales—do these five items provide useful information about a unified concept, such as urban heat islands? Looking across items, can instances of student guessing be detected?

Simultaneous with the piloting, researchers should seek to validate the content of the assessment. The most common tactic for validating the content is to submit the assessment and its related curricular documents for review by independent experts familiar with the content area and the targeted population of learners (e.g., Boster et al., 2006). Do these items accurately reflect the content area as represented in the standards or curriculum? Are the ideas being presented comprehensibly to the test takers? Participating teachers can certainly act as one source of content validation, but the review should also include two or more external or impartial judges. A way to buttress this qualitative validation process is to run a factor analysis on the test's pilot data. A factor analysis is merely a massive examination of item correlations. The result is a list of item sets that correlate in the pilot data. For example, if an assessment is designed to cover three topics,

the factor analysis should (in theory) return three sets of items whose correlation with one another is stronger than their correlation with the items in the other sets.

Note that a factor analysis can—and often will—return many more factors than anticipated by TPACK researchers who are attending to curricular standards or other content-organized framing devices. Bear in mind that the factor analysis looks for ANY correlation and can capture differences and similarities that the researcher is not examining, such as reading difficulty or even placement on the test (e.g., items towards the end of a long test may be skipped or guessed, depending on students' time management). Accordingly, use factor analyses sparingly. Carefully examine items that have a low or even negative correlation with their expected peers and explore why this may be the case—is it a result of student misreading? A gap in instruction? However, do not hold items to a rigid threshold, such as a minimum correlation and/or exclusion from competing factors.

The final step in preparing assessment items is evaluating the items' reliability—are students' performance on these items consistent (i.e., repeatable) or do they include a large amount of error (a repeat assessment, *ceteris paribus*, would provide a different result)? For most classroom research, the Kuder-Richardson correlation (or coefficient alpha, or Cronbach's alpha) is the most appropriate measure of reliability, as it requires only a single form of the test and a single testing session. However, the psychometric literature calls for a reliability coefficient of 0.8 or 0.9 (e.g., Anastasi, 1988, p. 115); other sources cite 0.7 as being acceptable (Cortina, 1993). Unfortunately, teacher-designed tests tend to have a reliability coefficient around 0.5 (Ebel & Frisbie, 1991, p. 86)—good enough for instructional purposes, perhaps, but not for research purposes. Part of the aim of piloting and refining items is to craft a test that is responsive to the teacher's needs (assessing curricular concepts, avoiding demoralization) while also approaching the standards

demanding by research (content validity and test score reliability). For the purposes of the classroom researcher, 0.65 can be an acceptable target for making decisions about *groups* of students; decisions about individual students demand a more reliable instrument (Ebel & Frisbie, 1991, p. 85).

STRATEGIES FOR EVALUATING EXISTING ITEMS

In addition to developing original items, researchers will also wish to look for existing items developed by others. There will be two primary sources of items: instructional materials, such as teacher- or publisher-designed items, and released assessment items from valid and reliable large-scale assessments such as NAEP, TIMSS, and the Advanced Placement (AP) exams from the College Board. Often, teacher-designed items have not been subjected to the critical steps of the design process described above, barring unusual circumstances. Most assessment items designed to align to learning standards, on the other hand, have gone through most or all steps of the process. Typically these items are reported with at least some supporting data: student performance statistics, reliability coefficients, content validation, etc.

Regardless of the source, existing items should be subjected to the same level of scrutiny as researcher-developed, original items. First, the researcher should carefully challenge the content of the item to examine its fit both with the curriculum learning goals and the instruction of the research context. Items developed in the context of a large-scale assessment such as NAEP, TIMSS, or the AP exams or items developed to serve another's research agenda, will not necessarily speak to the researcher's own context or purposes. This may be especially true when TPACK is a working framework of interest. Second, researchers should subjectively scrutinize the items' format—does it match the reading level of the intended test-takers? Is the

item culturally biased? Does the item layout and design have high readability? Third, researchers should introduce these items into pilot testing and hold them to the same standards as their own custom items. If an item or scale comes with a high reported reliability, the researcher must keep in mind that this reliability is true only *in the test's original context*. Properly speaking, reliability coefficients belong to test data, not tests (Ebel & Frisbie, 1991)—as a researcher integrates items into classroom assessments, the conditions of student performance change and hence the reliability of the item changes. A highly reliable item on the AP Biology exam may not be highly reliable in the context of a general-level biology classroom.

INTEGRATING STANDARDIZED ASSESSMENTS INTO RESEARCH DESIGNS

Any researcher must approach the use of standardized items in classroom research with a great deal of caution. The critical literature on the interpretability of standardized assessment results is broad and convincing (e.g., Nuthall & Alton-Lee, 1995; Reich, 2009). However, with the proper preparation and analysis, standardized items can shed meaningful light on student learning outcomes as a result of technology-integrated curriculum use (e.g., Bodzin & Cirucci, 2009). We offer several suggestions to maximize researchers' chances of gaining useful data from standardized assessments in classroom studies within the framework of TPACK.

Whenever possible, classroom researchers should seek to pretest students to obtain a baseline reading of their current level of understanding. Some school settings elect to pretest students at the beginning of a semester or a unit as part of their routine documentation (e.g., Hammond, 2007); in other cases the researcher will have to seek special permission from the school authorities to implement a pretest. For most classroom studies

(which are rarely if ever true experiments with randomized control and experimental groups), posttest-only data on standard items is *not* interpretable, in the absence of additional external data such as student classwork or corresponding assessments (e.g., relevant items on a science or social studies proficiency test). If the assessment has been extensively tested on equivalent students (i.e., students within similar contexts with similar levels of experience, technology capabilities, and instructional exposure on a topic), the researcher can argue that the participating group's entry-level knowledge and understanding is equivalent. For example, released NAEP items available through their Questions Tool (<http://nces.ed.gov/nation-reportcard/itmrlsx/landing.aspx>) often include student performance data, including sub-groups by gender, region, race, and free-or-reduced lunch status. However, this argument of assumed equivalence is a poor support upon which to build a case and certainly weakens the careful attention to context that is TPACK's strength.

While useful, pretesting comes with its own set of concerns. Ethically, is the researcher allowed to consume instructional time to ask students questions about which they quite possibly know nothing? As students answer these questions, will they experience demoralization and provide answers that do not reflect their true best effort? In one stage of the digital documentary study, Hammond observed abnormally low scores within a single honors-level classroom. They were far below their peers in another class on this pretest (but not on subsequent assessments), and these low scores occurred on items towards the end of the test. An additional complicating factor was that assessment data was gathered during the last class of the day—might these students not perform as well on the assessment compared with an earlier time during the school day? Or did their performance demonstrate a true lack of prior knowledge about the topics on the second half of the test? Since the researcher was present in the classroom for daily observations for an extended

period of time, he is able to directly observe the conditions of the testing and obtain a contextual understanding of student and classroom affect. Such daily observations are especially important when using learning technologies in curriculum contexts to gauge student engagement and motivation. A final concern about pretesting is testing carryover between the pre- and posttest. When students face a posttest within days or weeks of taking a pretest, part of their performance may reflect familiarity with the item based on the pretest, not the assumed learning during instruction. Researchers concerned with this possibility can control for testing carryover by using alternate forms of tests or by conducting a formal analysis of carryover during the pilot stage. At a minimum, researchers should exclude from the pretest any items targeting transfer of knowledge or skills, since this ability (presumably) rests upon the characteristics already being assessed.

During the study implementation, the researcher must thoroughly document the instructional and assessment processes. This documentation is necessary both to describe the context and to properly interpret the assessment results. Such documentation is important for capturing components of TPACK such as technological content knowledge – how learners use specific software applications and functions, and for understanding ways in which various technology tools afford new and potentially more effective approaches to desired learner understandings. Posttest items should be carefully examined in the light of the observed or documented instruction to check for instructional alignment to learning goals and technological pedagogical knowledge used by the classroom teacher – that is how the teacher implements technology capacity to optimize student learning. Did students experience technology-enhanced instruction addressing the sampled content? If the researcher observes pre- to posttest increases on items that were *not* addressed during instruction, then the change is more likely due to testing carryover or simple variance. Only

those items that were clearly addressed during instruction should be included in the analysis. The participating teachers can also help conduct this examination as a form of member checking.

When writing up the results, we encourage researchers to thoroughly report their assessment development process, including content validation and reliability data. Even when using previously validated instrument, this data should be included; each population is unique and there are no guarantees that the participants in your study are similar to the participants who helped pilot and refine the instrument. Note that when reporting reliability, researchers should report figures for *individual scales*, not merely for the entire test (unless the test happens to be a single scale). Reliability analysis makes the presumption of unidimensionality; a 50-item test of, for example, vocabulary should provide a high reliability because all 50 items are assessing the same domain. Most curricular assessments, however, cover multiple domains: geographic knowledge, map skills, and spatial thinking skills, for example. Piling the entire set of items together will typically provide a higher coefficient of reliability but also violate the underlying premise of unidimensionality (Cortina, 1993). Another consideration is whether to report reliability data based on the pretest, posttest, or the entire pool combined. We recommend using the pretest as the more robust measure of a standards-based assessment, as the posttest will likely have more systematic errors due to testing carryover and the unique conditions of instruction (e.g., exceptionally good or exceptionally poor instruction, patterns of student absences, student misunderstandings of key concepts, etc.).

Limitations

We must offer two sets of qualifiers to the advice offered here. The first is methodological: standardized items are merely one way to assess student knowledge or skill; researchers should avail themselves of the full range of informa-

tion about students via observation, document analysis, performance tasks, interviews, and so on. Standardized items have the virtue of (usually) fitting neatly within the established practices of classroom assessment. However, a single item provides a single, small data point regarding a student's understanding or skill, mediated by many variables beyond the researcher's control (prior knowledge, reading ability, cultural and linguistic differences, etc.). Only an accumulation of items can provide a basis for inference about individual students, and only a large number of students taking any one item can give a sense of the presence or absence of a specific targeted understanding within the group. As a rule, conclusions drawn from student performances on standardized items should be held tentatively and should be compared to other evidence of student understanding.

The second limitation is personal: we are not psychometricians or methodological specialists. We are all researchers and teacher educators (and former classroom teachers) with a particular interest in classroom implementation studies informed by TPACK. In this chapter, we present some key ideas with regards to assessment designs in studies pertaining to TPACK. These ideas are informed by our experiences conducting classroom research with innovative learning technologies. While we present important assessment design ideas for the purposes of research and data interpretation, we suggest that readers consult the references in this chapter to further explore the literature on testing and emerging trends in assessment.

CONCLUSION

Researchers should carefully consider any opportunity to incorporate standardized assessments into their study designs. They are a staple feature of classroom assessment and they can produce useful results under the right circumstances and with extensive development work (e.g., Bodzin & Cirucci, 2009). On the other hand, poorly-

designed items or concepts heavily loaded with prior knowledge can render these assessments largely useless (Alexander, 2009; Hammond, 2007). Producing an interpretable assessment requires sustained focus in developing, testing, and refining items; following naïve assumptions about standardized items in classroom settings can lead to major errors in interpretation.

As researchers interested in applying TPACK to classroom-based studies that examine student learning outcomes in the context of classroom assessment, we encourage others to carefully consider their own assessment and measurement techniques, whether quantitative or qualitative. By sharing our insights and shortcomings, by engaging in a frank dialogue about our shared methodological challenges, we will do ourselves and our field a service. When we can convincingly link teachers' pedagogical decisions with technology, instruction, and their content area to relative increases in student learning, we will be in a position to speak to teachers, administrators, and policy-makers in terms of the 'bottom line' of education: assessment data. In the absence of this careful work by education researchers, standardized assessment will continue to be a blunt tool, poorly used.

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Section 2

The Current Landscape in Educational Technology and Teacher Knowledge Research

Chapter 4

A Comprehensive Framework for Teacher Knowledge (CFTK): Complexity of Individual Aspects and Their Interactions

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ABSTRACT

In this study, we examine the validity of the Comprehensive Framework for Teacher Knowledge (CFTK) through a systematic review and meta-analysis. This model, developed through a series of exploratory studies, transforms current understanding of teacher knowledge from a linear structure to a three dimensional model by pairing 6 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. The current study analyzes the way interactions of these aspects appear in literature across a wide domain of subject matters. These interactions have direct implications for future research on teacher knowledge as well as policies for guiding professional development and pre-service teacher training.

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INTRODUCTION

Teacher knowledge forms the foundation for all the pedagogical decisions that occur in the classroom, drawing upon teachers' personal experiences, education, and other teacher preparation (Borko & Putnam, 1995). Several teacher knowledge frameworks have been put forward to explain components of teacher knowledge (e.g., Cochran & Conklin, 2007; Even, 1990; Jacobson, 1997; Salhi, 2006; Sankar, 2010), and some frameworks have gone so far as to hypothesize interactions among these components, most noticeably, Pedagogical Content Knowledge, or PCK (Shulman, 1986). Yet no single framework exists to encapsulate the complexity of teacher knowledge. A new framework clarifying the nature of teacher knowledge could provide a structure for more precise research on the nature of teacher knowledge and its impact on student learning and achievement (Ball, Thames, & Phelps, 2008; National Council of Teachers of Mathematics (NCTM), 2000). Similarly, Wilkinson (2005) described the need for formal understanding of teacher knowledge to avoid the erosion of teacher autonomy and the professionalization of teaching. Korthagen and Lagerwerf (2001) considered a broader, all-encompassing teacher knowledge framework to be a necessary component for diagnosing and correcting gaps between theory and practice.

The Comprehensive Framework for Teacher Knowledge (CFTK; Ronau et al., 2010; Ronau, Rakes, Wagner, & Dougherty, 2009; Ronau, Wagener, & Rakes, 2009) was developed to address this need by integrating six aspects of teacher knowledge into a single, three-dimensional structure. The present study develops the validity of CFTK through a systematic review of literature by addressing the following questions:

1. Does CFTK address all aspects of teacher knowledge found in existing research?
2. Which CFTK aspects have been seen to interact in existing research?

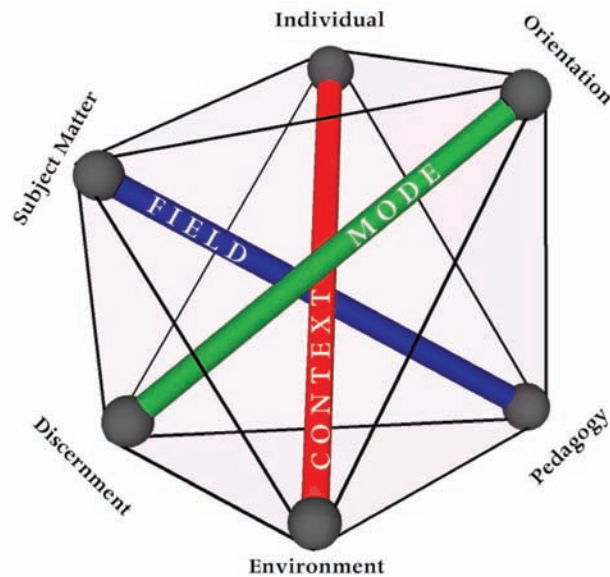
BACKGROUND

Several knowledge frameworks have been posited and accepted related to student thinking and learning such as Bloom's hierarchical taxonomy (Bloom, Englehart, Furst, Hill, & Krathwohl, 1956), Hiebert and Carpenter's (1992) procedural and conceptual knowledge, Skemp's instrumental and relational types of knowledge (1976/2006), Webb's Depth of Knowledge (Webb, 2002, Webb & Kane, 2004), and Porter's (2002) Cognitive Demand. These frameworks began the work of exploring knowledge and learning generally from the standpoint of what teachers need to know about student learning.

Another wave of studies developed Shulman's PCK further by examining the application of PCK to specific contexts such as Mathematics Knowledge for Teachers (MKT; Hill, Schilling, & Ball, 2004), and Technology Pedagogical Content Knowledge (TPACK; Mishra & Koehler, 2006; Niess, 2005). These and other frameworks significantly contribute to understanding the inner workings of some aspects of teacher knowledge including some aspect interactions, but none of these frameworks accounts for all of the components of teacher knowledge found in literature, and no framework has attempted to address all known interactions of teacher knowledge aspects. Such an absence in the literature may result in a lack of focus about fundamental problems in education such as which aspects are important for short term and long term student growth and learning, whether different aspects and interactions are more important across different subject matters and grade levels, and which aspects and interactions need further study and the nature of such needs. The complexity of teacher knowledge may account for much of this deficiency.

The nature of teaching demands a high degree of organization among multiple facets of teacher knowledge (Ball et al., 2008; Camp, 2001; Mishra & Koehler, 2006; Peressini, Borko, Romagnano, Knuth, & Willis, 2004). This demand is consis-

Figure 1. Comprehensive Framework for Teaching Mathematics (CFTK)



tently felt by teachers and researchers across a wide array of subject matters (e.g., Ariza & del Pozo, 2002; Carlsen, 1987; Craig, 2003; Gay, 2002; Lee & Hicks, 2006; Shavelson, Ruiz-Primo, Li, & Ayala, 2003). Existing frameworks address teacher knowledge by examining individual components in detail rather than attempting to tackle the holistic complexity of teacher knowledge.

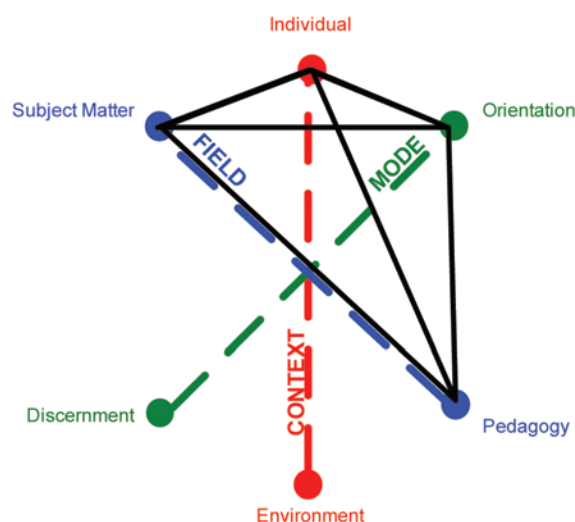
Based on earlier exploratory studies, we identified three primary components of teacher knowledge, each composed of two inter-related aspects, primarily within mathematics education literature (Ronau et al., 2010). We hypothesized that a three dimensional model (CFTK, Figure 1) might better account for much of the complexity observed in the way teachers use knowledge to improve instruction. We relabeled these primary components as *dimensions* and labeled them Field, composed of Subject Matter and Pedagogical Knowledge; Mode, composed of Orientation and Discernment Knowledge; and, Context, composed of Individual and Environment Knowledge.

The potential power of this framework for examining teacher knowledge dynamics can be

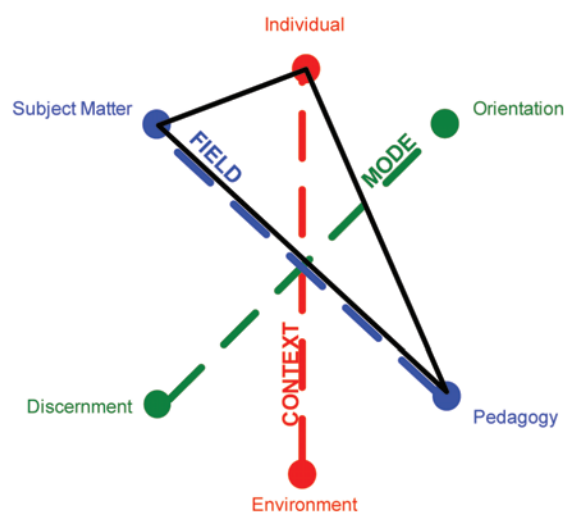
seen in its versatility with interactions of teacher knowledge aspects. For example, the model readily demonstrates how a three or four-way interaction might be illustrated without discarding the isolated aspects or ignoring the remaining intra-dimensional interactions (Figure 2).

In that exploratory study, we concluded that this versatility enabled CFTK to identify the principle aspects and interactions needed for teachers to address the National Council for Teachers of Mathematics *Principles and Standards for School Mathematics* (NCTM, 2000). These principles for effective teaching were organized under six headings: Equity, Curriculum, Teaching, Learning, Assessment, and Technology. The CFTK model informs the way teacher knowledge influences a teacher's growth in each of these areas through the interactions of all three dimensions. For example, Equity requires teachers to merge knowledge about subject matter and pedagogy with knowledge of affective issues (that is, orientation, e.g., beliefs, attitudes, and predispositions), knowledge that enables them to lead and conduct on-going reflection (discernment), and

Figure 2. Example CFTK Interaction Models



2A: An Example Four-Way Interaction between Subject Matter, Pedagogy, Orientation, and Individual



2B: An Example Three-Way Interaction between Subject Matter, Pedagogy, and Individual

knowledge of the role of individual and environmental contexts (e.g., gender, classroom culture; Bezuk, Whitehurst-Payne, & Avdelotte, 2005; Cobb, 1999; Confrey et al., 2008; Davis, 2007; Gutstein, 2005). In short, increasing knowledge about equity requires the interaction of all six aspects of teacher knowledge, implying that teacher-training programs should address all six areas of knowledge.

The knowledge for teaching required to successfully implement the NCTM Principles directly influences teacher quality. For example, Curriculum, Teaching, Learning, and Assessment interact; that is, teaching should produce learning, and assessment should inform both teaching and learning. The CFTK model clarifies the way teacher knowledge influences all four of these principles. Teacher knowledge of the Field influences curricular decisions, and the interaction of Field with Mode and Context affects pedagogical decisions and the ability to reflect on teaching episodes, both during and after the episode occurs. For these four principles, the CFTK model clarifies the role of

teacher knowledge in helping teachers meet these professional goals; furthermore, using the CFTK model to organize that teacher knowledge sheds light on how teacher preparation programs might address these principles for teacher trainees.

We also found that CFTK interactions helped explain the way teachers use technology in the classroom in a way that had previously remained unexplored. For example, teachers with low levels of interaction in CFTK may use technology solely for didactic purposes (Chickering & Ehrmann, 1996). On the other hand, using technology to enhance student interaction, engagement, relevance, and problem solving requires teachers to engage all three dimensions of their knowledge simultaneously (Brown et al., 2007; Chickering & Ehrmann, 1996; Ellington, 2006; Hiebert & Carpenter, 1992; Hiebert et al., 1997). This finding carries direct implications for the training of new teachers: Teacher-training programs that take into account all six aspects of teacher knowledge may increase the effectiveness of new teachers.

Finally, we found that the aspects of teacher knowledge have a wide scope, and no study can examine an entire aspect. Instead, each study can only examine a small part of an aspect, or measures of an aspect, or interactions of an aspect with other aspects. For example, although Subject Matter knowledge for teachers may seem fairly straight forward, a multitude of measures have been developed to try to represent this aspect, and none attempt to capture every facet of the aspect. (e.g., Praxis II assessments, Educational Testing Service, 2010; Diagnostic Teacher Assessment for Mathematics and Science, Saderholm, Ronau, Brown, & Collins, 2010).

The next phase of this study consisted of using CFTK as a lens for examining research on teacher knowledge about educational technology (Ronau et al., 2010). We found that the CFTK lens added an important component to our understanding of how research had been conducted on teacher knowledge about the use of technology; specifically, we found that it helped identify under-studied aspects of teacher knowledge. We also found that much of the research examining teacher knowledge about educational technology lacked robust research designs and methodology. So although aspects like Pedagogical Knowledge and Subject Matter Knowledge have been studied extensively, little consensus existed about how much knowledge of these aspects teachers need to be effective.

Overview of the Present Study

The present study examined the CFTK model through a systematic review of teacher knowledge research. Through this synthesis, we demonstrate how CFTK synthesizes a large body of research on disparate frameworks of knowledge for teaching and how such a framework adds to our understanding of teacher knowledge substantially. Similar to our procedures in the exploratory phase of this research, we examine how CFTK complements and expands existing frameworks of teacher knowledge to inform future research and

policies related to teacher knowledge. Unlike the exploratory phase, this research synthesis did not limit the content area to mathematics, and it was conducted systematically to enhance the validity of our findings.

METHODOLOGY

Research on teacher knowledge, though ongoing for several decades, can still be considered to be in its infancy. For example, Shulman proposed PCK in the mid-80's, but instruments designed to measure PCK as an interaction construct did not emerge until much later (e.g., Hill, Ball, & Schilling, 2008; Hill, Ball, Blunk, Goffney, & Rowan, 2007; Hill & Ball, 2009; Hill, Rowan, & Ball, 2005; Saderholm et al., 2010). The ability to validly and reliably measure individual aspects and interactions of teacher knowledge is not yet available to researchers. As a result, the sample articles consisted entirely of qualitative studies and theory development articles. Therefore, a meta-analysis was not possible (i.e., a quantitative synthesis of effects using statistics such as correlations and standardized mean differences) since statistical effects were not reported in these studies, and vote counting procedures were disregarded as an alternative because of the severe limitations of such a procedure with regard to validity, reliability, or statistical power (Hedges & Olkin, 1980). Instead, the present study methods were chosen to align with the nature of the sample by examining existing research qualitatively and reporting relevant descriptive statistics.

Content Validity

Representativeness and relevance are the two primary characteristics associated with content validity (Urbina, 2004). To maximize the representativeness of our sample, we searched eight electronic databases related to educational or psychological science research from three database

platforms. Within EBSCOhost, we searched Academic Search Premier (8327 journals; Academic Search Premier, 2010), ERIC (1111 journals, Education Resources Information Center, 2010), PsychInfo (2450 journals; PsychInfo, 2010), Psychology and Behavioral Sciences (559 journals; Psychology & Behavioral Sciences, 2010), and the Sociological Collection databases (500 journals; Sociological Collection, 2010). Within H.W. WilsonWeb, we searched Education Full Text (770 journals; Education Full Text, 2010) and the Social Sciences Index (625 journals; Social Sciences Index, 2010). We also ran searches in the ProQuest Research Library. We did not place any date restrictions on the sample; our search identified articles dating from 1966 to 2010. To minimize publication bias (the tilting of meta-analytic results toward a statistically significant effect size; Cooper, 1998; Lipsey & Wilson, 2001), we also included gray literature such as dissertations, conference papers, and technical reports.

To find relevant manuscripts in these databases, we applied the following search term phrase: (teacher knowledge OR knowledge of teaching OR knowledge for teaching) AND (framework OR model). Manuscripts were considered to be relevant if they met at least one of the following two conditions: The manuscript (a) discussed at least one aspect of knowledge teachers use to achieve educational outcomes or (b) described a framework of one or more aspects of knowledge teachers use to achieve educational outcomes. Using the definitions of each aspect developed in earlier phases of this study (Ronau et al., 2010; Ronau, Rakes, & Wagener, 2009; Ronau, Wagner, et al., 2009) as a guide, each study was coded as either addressing or not addressing each aspect. We also identified studies addressing components of teacher knowledge that (a) did not initially appear to easily fit into any of the aspects, (b) appeared to fit into the model in more than one place, but not clearly into any one aspect, or (c) stood out as unique for some reason from other teacher knowledge studies. We coded 140 articles

into this “other” category and examined each study together to determine how the study should be coded or if the model needed to be revised to accommodate a new component.

Inter-Rater Reliability

The set of 564 studies was randomly divided between the two researchers for coding. To check for inter-rater reliability, approximately 10% or 60 of this set of articles were randomly sampled to be blindly coded by each researcher (double coded), increasing the sample set of articles for each coder to 312. Every article contained seven opportunities for disagreement (six aspects and the *not relevant* category), providing 420 opportunities to disagree overall within the subset of 60 double-coded manuscripts. Of these 420 opportunities to disagree, we agreed 323 times for an overall inter-rater reliability of 77%.

We also examined the possibility of patterns (i.e., bias) within the disagreements for each aspect (Table 1). We first looked at the possibility of patterns of disagreement across aspects (e.g., whether the coding of Orientation included more or less disagreement than the other aspects). We also compared coding between authors within each aspect (i.e., whether one coder was more prone to including or excluding an aspect).

Subsequent discussions revealed that disagreements resulted primarily from the complex nature of the aspects and the lack of a comprehensive framework guiding teacher knowledge research. For example, some studies discussed pedagogy and teacher knowledge (e.g., Ball & Lardner, 1997), but the distinction of whether the pedagogy related to knowledge versus procedural skill was not clear. Often, the sample studies discussing pedagogy and teacher knowledge referred to both knowledge and skill simultaneously (e.g., Clark & Lesh, 2003). Other studies investigated the implementation of activities that addressed, for example, Subject Matter, Pedagogy, and Orientation, but did not directly study teacher knowl-

Table 1. Number of Times Each Coder Included an Aspect or Category when the Other Did Not

Coder	Subject Matter		Pedagogy		Orientation		Discernment		Individual		Environment		Not Relevant ^a		Total	
1	12	63%	11	48%	0	0%	11	61%	7	70%	3	50%	4	31%	48	49%
2	7	37%	12	52%	8	100%	7	39%	3	30%	3	50%	9	69%	49	51%
Total	19	20%	23	24%	8	8%	18	19%	10	10%	6	6%	13	13%	97	100%

Note: Percentages for the Total row represent the percent of total disagreements accounted for by each aspect or column category; Percentages in the Coder rows represent the percent of times a coder included an aspect when the other coder did not.
^a Studies were coded as “Not Relevant” if they did not examine teacher knowledge. For example, an abstract may have listed teacher knowledge as an important factor for student achievement but not actually discuss what was meant by *teacher knowledge* or which components of teacher knowledge were being considered.

edge of any of these aspects (e.g., Martray, Cangemi, & Craig, 1977; Metzler & Tjeerdsma, 2000; Schorr & Koellner-Clark, 2003; Zielinski & Bernardo, 1989). Overall, we found that no single aspect accounted for a high proportion of disagreements. Pedagogical Knowledge, Subject Matter, and Discernment each accounted for 19–24% of the total number of disagreements (Table 1). Furthermore, we found that each coder accounted for approximately 50% of the disagreements (i.e., included an aspect when the other did not). Therefore, we concluded that the 97 coding disagreements did not appear to contain any systematic bias that required additional coding or re-analysis of the coding criteria.

The complexity of the Orientation aspect added a layer of ambiguity to the coding: Several studies did not clearly distinguish between teachers’ knowledge of Orientation, knowledge of teachers’ Orientation, or the teachers’ orientation, whether toward students, teaching, or school administration. For example, Philipp, Thanheiser, and Clement (2002) conducted a study in which pre-service teachers participated in a professional development intervention to help them integrate mathematics content and student thinking to enhance teaching and learning. Philipp et al. noted that change in teacher beliefs about mathematics teaching and learning was an outcome of the study. One coder marked this study as primarily addressing pedagogical content knowledge, or the interaction of Subject Matter and Pedagogy.

The other coder marked an interaction of Subject Matter, Pedagogy, Orientation, and Discernment, noting the outcome of beliefs. As a result, Orientation appeared to have the greatest degree of coder bias in Table 1, but the disagreements accounted for only 8% of the overall disagreements. These issues were discussed in weekly meetings in which each coder brought studies whose coding was questionable. The issues were discussed to improve our understanding of the intricacies within the field of teacher knowledge research and to enhance the consistency of the coding. We coded these questionable studies together (140 studies, approximately 30% of the sample), so no meaningful reliability coefficient could be computed (i.e., coding for these questionable studies was established through the discussion and not finalized until both coders reached agreement).

RESULTS

Initial searches identified 646 manuscripts potentially relevant for the present synthesis. After eliminating 83 duplicate titles, the potentially relevant sample retained 564 titles. We identified 153 articles in our sample that did not address teacher knowledge or a framework of teacher knowledge, leaving a sample size of 411 articles.

The articles remaining in the sample came from a wide range of content areas. Studies examining teacher knowledge in mathematics accounted for

20% of the sample (84 out of 411); 14% from science (56 out of 411); 10% from reading/writing/literacy/language development (41 out of 411); and, 8% from other subject matter areas (see Table 2). Approximately half the sample addressed teacher knowledge without specifying a particular subject matter area.

Studies not specifying a subject matter addressed general characteristics of teacher knowledge. For example, 26% of the sample addressed the role of teacher knowledge in the development of in-service teachers, pre-service teachers, and with teacher quality (109 out of 411). Another 10% developed theories and frameworks about the nature of teacher knowledge (43 out of 411). Based on the wide array of subject areas included in the sample, we concluded that the sample was representative of general teacher knowledge research and not limited to concerns specific to any particular discipline.

The sample dates ranged from 1966 to 2010. Because it included several decades of research about teacher knowledge, we concluded that the sample was relevant for considering how conceptions of teacher knowledge had changed over time. Because the sample also included recent publications, we concluded that it was also relevant to current thinking about teacher knowledge.

These studies addressed both single aspects and interactions. Table 3 provides a distribution of the number of studies that addressed each aspect or interaction.

Sixteen types of interactions were not addressed in the sample. The most commonly studied interaction was the Subject-Matter/Pedagogy interaction under the label of Pedagogical Content Knowledge (75 studies, 18% of sample). Such imbalances may be due to the lack of a comprehensive framework to guide teacher knowledge research; that is, these omissions did not appear to be purposeful, but happenstance.

Several articles studied teacher knowledge under names not easily associated with CFTK due to the complexity; specifically, these knowledge

Table 2. Number of Studies Examining Teacher Knowledge from a Particular Subject Matter

Subject Matter	Number of Studies
Art	1
CTE	1
Foreign Language	1
Health and Human Services	2
Computer Science	8
Library Science	1
Mathematics ^{1,2,3}	84
Medicine	2
Music	3
Physical Education	5
Reading/Writing/Literacy/Language Development ^{2,3}	41
Religion	1
Science ^{1,2,3}	56
Social Studies ^{3,4}	9
Unspecified Subject Matter	208
Description of Studies not Specifying Subject Matter	
Early Learning	2
Education Reform	2
Elementary Education	7
English Learners	7
Gifted Education	3
Nature of Teacher Knowledge	43
Postsecondary Education	2
Special Education	12
Teacher Development	34
Teacher Leadership	7
Teacher Mentoring	3
Teacher Quality	42
Teacher Preparation	33
Technology Integration	11
¹ Seven studies examined teacher knowledge in both mathematics and science.	
² Two studies examined mathematics and reading/writing/literacy/language development.	
³ One study examined teacher knowledge in mathematics, reading/writing/literacy/language development, social studies, and science.	
⁴ Includes studies examining teacher knowledge in humanities.	

Table 3. Number of Studies Examining Each Aspect or Interaction of Teacher Knowledge

Aspects/ Interactions	Number of Studies	Aspects/ Interactions	Number of Studies	Aspects/ Interactions	Number of Studies
S	36	S-P-O	9	S-P-O-I	1
P	35	S-P-D	23	S-P-O-E	1
O	6	S-P-I	11	S-P-D-I	7
D	23	S-P-E	16	S-P-D-E	4
I	9	S-O-D	0	S-P-I-E	8
E	9	S-O-I	0	S-O-D-I	0
S-P	74	S-O-E	1	S-O-D-E	0
S-O	2	S-D-I	0	S-O-I-E	1
S-D	5	S-D-E	0	S-D-I-E	0
S-I	5	S-I-E	0	P-O-D-I	1
S-E	1	P-O-D	3	P-O-D-E	1
P-O	12	P-O-I	2	P-O-I-E	0
P-D	23	P-O-E	2	P-D-I-E	1
P-I	9	P-D-I	5	O-D-I-E	0
P-E	13	P-D-E	7	S-P-O-D-I	2
O-D	8	P-I-E	1	S-P-O-D-E	1
O-I	0	O-D-I	0	S-P-O-I-E	2
O-E	4	O-D-E	0	S-P-D-I-E	4
D-I	5	O-I-E	1	S-O-D-I-E	0
D-E	1	D-I-E	0	P-O-D-I-E	0
I-E	7	S-P-O-D	3	S-P-O-D-I-E	5
Note: S=Subject Matter, P=Pedagogy, O=Orientation, D=Discernment, I=Individual, E=Environment					

labels, such as “knowledge of student learning,” were not always used to mean the same type of knowledge. Such ambiguity also added to difficulties in obtaining reliable coding. As a result, we carefully considered the possibility that other knowledge constructs not identified by CFTK had been studied. We found no evidence that alterations were needed for CFTK to adequately model the types of teacher knowledge being studied. Instead, we found that the four labels most consistently used to mean different types of knowledge fit well within the CFTK model interactions: knowledge of student learning, knowledge of standards, knowledge of technology, and knowledge of the teaching profession.

Knowledge of Student Learning

Which aspects of CFTK are addressed by knowledge of student learning appeared to depend on whether the emphasis was placed on the students or on the learning process, both, or neither. For example, Tell, Bodone, and Addie (2000) considered the knowledge of student learning to be entirely dependent on Subject Matter and Pedagogical knowledge (i.e., S-P interaction). Higgins and Parsons (2009) also considered student learning knowledge to include Subject Matter and Pedagogy, but they also included knowledge of the Individual background and characteristics to be an important component (S-P-I interaction). Similarly, Allen (2008) focused primarily on

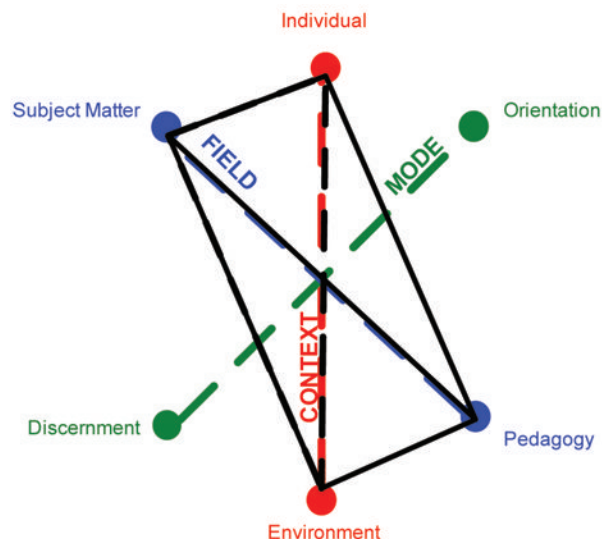
Pedagogy and Individual and excluded Subject Matter (P-I interaction). Esqueda (2009) and Kolis and Dunlap (2004), on the other hand, considered the understanding of student thinking (i.e., Discernment) to be more pertinent to student learning than background characteristics (S-P-D interaction). Using the standards of teacher quality put forward by the Interstate New Teacher Assessment and Support Consortium (INTASC), Ellison (2010) found that higher quality teaching requires knowledge of student learning, including all six CFTK aspects: Subject Matter, Pedagogy, Orientation, Discernment, Individual, and Environment. The variations across studies may indicate that knowledge of student learning is a complex structure that may include only a few or all components of the CFTK model. We found no evidence in any of these studies that other knowledge constructs outside the CFTK model were being addressed. As with knowledge of student learning, studies exploring *knowledge of standards* also appeared to refer to multiple constructs within the CFTK model.

Knowledge of Standards

The knowledge considered important for implementing standards-based instruction appears to have narrowed during the last decade. For example, Marrin, Grant, Adamson, Craig, and Squire (1999) considered standards-based practice to require knowledge of the student, the curriculum, teaching practice, and the learning environment (i.e., S-P-I-E interaction).

In contrast, Supon (2001) considered standards-based instruction to be a far simpler construct requiring an understanding of how curriculum, instruction, and assessment interact while standards are applied (S-P interaction). More recently, Rutledge, Smith, Watson, and Davis (2003) examined the knowledge needed for teacher educators (i.e., teachers of teachers) to develop the pedagogical skills and knowledge needed to meet NCATE standards (P only). Based on these results, standards based instruction may require the interaction of at least four CFTK aspects: Subject Matter, Pedagogy, Individual, and Environment. Like knowledge of student learning, standards-implementation knowledge did not

Figure 3. Knowledge Needed for Standards-Based Practice in CFTK



appear to include any components of knowledge outside of the CFTK model.

Knowledge of Technology

As with the knowledge of student learning and standards, knowledge of technology was often used to mean several different aspects of teacher knowledge. For example, Kent and McNergney (1999), Mouza (2006), and Stein, Ginns, and McDonald (2007) considered the inclusion of technology as requiring only additional pedagogical knowledge for quality implementation (P only). Leatham (2007) also considered the knowledge of teacher beliefs to be an important component of effective technology implementation (P-O interaction). Margerum-Leys and Marx (2002) considered technology integration to require pedagogical content knowledge, or an interaction of Subject Matter and Pedagogy (S-P interaction). Leach (2005) also considered the S-P interaction, including knowledge of reflection as an important component of technology usage (S-P-D interaction). Hatch, Bass, and Iiyoshi (2004) did not consider knowledge of Subject Matter to be as important to technology integration as knowledge of its effect on the learning environment (P-D-E interaction).

The Center for Development and Learning (2000) considered technology from a completely different perspective: Instead of focusing on knowledge needed to implement technology well, this report concentrated on the knowledge needed to reap the most benefits from technology: including knowledge of students, knowledge of the learning environment, and knowledge of how to reflect on technology-based lessons (i.e., D-I-E interaction). As with student learning, these studies indicated that knowledge of technology may include any of the aspects within CFTK and potentially a six-way interaction (S-P-O-D-I-E interaction). No knowledge constructs outside of the CFTK domain appeared to be proposed in these studies, leaving only one problematic

label for teacher knowledge to be considered, *Knowledge of the Teaching Profession*.

Knowledge of the Teaching Profession

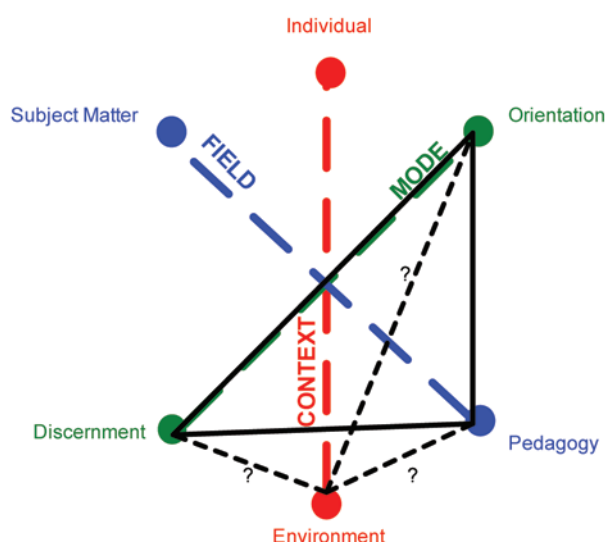
Professional knowledge was used to describe the knowledge teachers need to successfully implement the teaching profession, knowledge needed to navigate through an education system, or knowledge needed to increase the professionalization of the teaching field. As with the other three problematic labels examined above, this knowledge did not appear to include constructs outside the CFTK domain. In our sample, professional knowledge appeared to consist primarily of pedagogical knowledge, orientation knowledge, discernment knowledge, or interactions among the three aspects. Knowledge of the professional environment for teaching may be a particularly critical aspect of knowledge for negotiating any education system, so we expected to find Environment as a component of professional knowledge; however, only one study examined a Pedagogy-Orientation-Discernment-Environment interaction, but professional knowledge was not an outcome of that study (Levine, 1990). We found this omission from the sample studies surprising.

For example, Gustafson, MacDonald, and D'Entremont (2007) focused primarily on Pedagogy as professional knowledge (P only). Lemlech (1995), on the other hand, considered the knowledge about motivations, beliefs, and attitudes as well as the knowledge of reflection as important components of professional knowledge (O-D interaction). These studies may indicate that at least three aspects of teacher knowledge are needed to develop professional knowledge (Figure 4).

DISCUSSION

This review has provided evidence indicating that studies that include particular aspects of

Figure 4. Professional Knowledge within CFTK



teacher knowledge do not necessarily include interactions of those aspects. Far from a criticism of those studies, this is an acknowledgement of the complexity of the distinct aspects of teacher knowledge. The complexity within each aspect alone has proven to be a challenge for researchers. Studies that focus on teacher Subject Matter knowledge, for example, have often used proxy measures since direct measures of this aspect have not been available (e.g., Wilmot, 2008). Such proxies have included completion of teacher training and/or teacher certification (e.g., Arzi & White, 2008; Mullens, Murdane, & Willett, 1996; Neild, Farley-Ripple, & Byrnes, 2009), mathematics background (e.g., Arzi & White, 2008; Monk, 1994; Rowan, Chiang, & Miller, 1997), administrator observations (e.g., Borman & Kimbell, 2005), years experience (e.g., Neild, Farley-Ripple, & Byrnes, 2009), content tests (e.g., Rowan, Chiang, and Miller, 1997), and teacher interviews (e.g., Arzi & White, 2008). Not surprisingly, many of the proxy measures have produced mixed results; for example, teacher certification has not consistently been shown to positively impact student achievement (Neild, Farley-Ripple, & Byrnes, 2009). Similar difficulties can be seen

in the study of each of the other aspects as well (e.g., Abbate-Vaughn, 2006; Eng, 2008; Fluellen, 1989; Kreber, 2005; Runyan, Sparks, & Sagehorn, 2000). The difficulty of capturing single aspects of teacher knowledge pales in comparison to addressing the complexity involved when multiple teacher knowledge aspects and their interactions are examined in a single study. For example, Context as described in the CFTK model incorporates the knowledge aspects of individual and environment. The contributions that individuals bring to the learning situation are diverse, and understanding the effects of a learning environment such as a classroom or school may be a critical component of how a teacher conducts a learning episode (Hodge, 2006; McLeod, 1995). Lee and Bryk (1989) developed a contextual-effects model that demonstrated that school variables such as greater course work in mathematics, more homework, fewer staff problems, and disciplinary climate of schools all associated with higher levels of mathematics achievement across schools. The CFTK framework defines these factors in such a way that the aspects may be understood to stand alone or to interact.

The interaction of these two aspects (i.e., Individual and Environment) can capture the complex climate or set of relationships contained in a classroom and the knowledge that teachers require to understand the effect that an individual may have on a group and the effect that the group may have on the individual. For example, Cobb & Yackle (1996) pointed out that individuals have a role in the constructions of social norms of the group. Over students' careers, they take cues from teachers and peers that influence beliefs and collectively how classrooms function. Cobb, McClain, Lamberg, and Dean (2003) found that schools (i.e., environment) may incorporate teachers (i.e., individual) into groups (e.g., departments, teams) that may function independently or cooperatively. Davis and Simmt (2003) applied complexity science to discuss mathematics classrooms in terms of five conditions or properties that address possible dynamics within that context (2003). Davis later characterized classrooms as dynamic learning systems that are organic and have the potential of learning themselves (Davis, 2007). These two effects can interact which can be interpreted as a similarity effect.

Offering a different perspective on the interaction of Individual and Environment, Kenny and Garcia (2008) proposed that group effects influence individual factors as well as the reverse. First considering the dyadic effects of two individuals in a relationship (extending their Actor-Partner Interdependence Model), they also turned to study the relationship's effect on the individual in a group effects model (GAPIM). In its use as a dyadic model, one member of the dyad's response depends on his or her own characteristics, the actor effect, and also on the characteristics of the person's interaction partner, the partner effect. This model allows for new ways to measure knowledge aspects so that main effects can be separated from interactions. For groups, the individual who provides the data point is the actor and the remaining $n - 1$ members of the group is referred to as the others. Then an individual's outcome in a group

(Y_{jk}) may depend upon two main effects: (1) a particular characteristic(s) of the individual (X_{jk}) and (2) the degree to which that characteristic(s) is shared by the others in the group (X_{jk}'). In addition, there may be two interactions due to this characteristic: (a) the actor-by-others effect (I_{jk}) which measures how similar the individual is to the group with respect to this characteristic, and (b) the interaction of all possible pairs of the group on this characteristic (I_{jk}'). Therefore, the individual outcome Y_{jk} for a person j in group k is:

$$Y_{jk} = b_{0k} + b_1 X_{jk} + b_2 X_{jk}' + b_3 I_{jk} + b_4 I_{jk}' + e_{jk} \quad (1)$$

where

- b_{0k} (group effect term) represents the extent to which some groups share the outcome more than other groups,
- b_1 (actor effect term) is the effect of a person's own characteristic,
- b_2 (others effect term) is the effect of this average characteristic of the other members of the group,
- b_3 (actor similarity term) is the degree to which this characteristic is shared between the individual and the others,
- b_4 (others similarity term) is the degree to which this characteristic is shared between all possible pairs of the others in the group, and
- e_{jk} (error term) the extent to which person shares the outcome with this group more than other groups.

Models allowing such complexity create the potential to produce tightly honed measurements for examining the relationships between teacher knowledge and students outcomes (Kenny & Garcia, 2010).

These two examples, Subject Matter as a single aspect and Context as an interaction of Individual and Environment, serve to illustrate the complexity

Table 4. Number of Interactions Given the Number of Aspects in Model

Number of Aspects (n)	Number of Interactions possible ^a	Types of Interactions	Example Sets of Interactions ^b
1	0	None	None
2	1	2-way: 1	S-P
3	4	3-way: 1 2-way: 3	SPO SP, SO, PO
4	11	4-way: 1 3-way: 4 2-way: 6	SPOD SPO, SPD, SOD, POD SP, SO, SD, PO, PD, OD
5	26	5-way: 1 4-way: 5 3-way: 10 2-way: 10	SPODI SPOD, SPOI, SPDI, SODI, PODI SPO, SPD, SPI, SOD, SOI, SDI, POD, POI, PDI, ODI SP, SO, SD, SI, PO, PD, PI, OD, OI, DI
6	57	6-way: 1 5-way: 6 4-way: 15 3-way: 20 2-way: 15	SPODIE SPODI, SPODE, SPOIE SPDIE, SODIE, PODIE SPOD, SPOI, SPOE, SPDI, SPDE, SPIE, SODI, SODE, SOIE, SDIE, PODI, PODE, POIE, PDIE, ODIE SPO, SPD, SPI, SPE, SOD, SOI, SOE, SDI, SDE, SIE, POD, POI, POE, PDI, PDE, PIE, ODI, ODE, OIE, DIE SP, SO, SD, SI, SE, PO, PD, PI, PE, OD, OI, OE, DI, DE, IE
Note: S=Subject Matter, P=Pedagogy, O=Orientation, D=Discernment, I=Individual, E=Environment			
^a Number of interactions possible with one set of <i>n</i> interactions			
^b Main effects are not included.			

of knowledge for teaching. They also demonstrate that, as with any interaction model, the presence of two or more main effects is not sufficient to validate the presence of an interaction (Keppel & Wickens, 2004). Table 4 displays an example of how multiple aspects may lead to a great number of potential interactions.

A single study examining Subject Matter, Pedagogy, Orientation, and Discernment knowledge might study the four-way interaction, or it might focus on a couple of three- or two-way interactions (e.g., SPO and SPD; SP, PD, and PO). We do not claim that limiting the focus of a study reduces its validity; on the contrary, such limitations are appropriate and often needed.

The CFTK framework offers a way to structure such research efforts in teacher knowledge by providing a map for studies addressing specific aspects and interactions, more clearly depicting gaps in the current literature base, and encouraging research in under-studied aspects and the interac-

tions of those aspects to determine their potential impact on student outcomes.

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ENDNOTE

- ¹ References marked with an asterisk indicate studies included in the synthesis

Chapter 5

The TPACK of Dynamic Representations

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ABSTRACT

Effective teachers across K-12 content areas often use visual representations to promote conceptual understanding, but these static representations remain insufficient for conveying adequate information to novice learners about motion and dynamic processes. The advent of dynamic representations has created new possibilities for more fully supporting visualization. This chapter discusses the findings from a broad range of studies over the past decade examining the use of dynamic representations in the classroom, focusing especially on the content areas of science, mathematics, and social studies, with the purpose of facilitating the development of teacher technological pedagogical content knowledge. The chapter describes the research regarding the affordances for learning with dynamic representations, as well as the constraints—characteristics of both the technology and learners that can become barriers to learning—followed by a summary of literature-based recommendations for effective teaching with dynamic representations and implications for teaching and teacher education across subject areas.

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DYNAMIC REPRESENTATIONS AND TEACHER KNOWLEDGE

The K-12 school curriculum presents a significant amount of content to students that they are expected to understand without being able to see firsthand, especially in the middle school and secondary levels. This content may require abstract thinking (e.g., place value, solving equations, and linear programming in mathematics), or it may require them to internalize concepts and processes that are invisible or too fast or too slow or too far away to be observed from the classroom (e.g., molecular structure, Newtonian physics, distant geographic landforms, etc.). Visualization, spatial thinking, and the ability to understand and translate representations in multiple forms are highly valued skills for success in school, especially if students are not just to memorize but *understand* what they are supposed to be learning (Jiang & McClintock, 2000; Linn, 2003; National Council of Teacher of Mathematics, 2000; Newcombe, 2010). Yet, students have long struggled with curriculum requiring these skills, and many fail to develop conceptual understanding of the content (e.g., see Leinhardt, Zaslavsky, & Stein, 1990; White & Mitchelmore, 1996).

Visual representations, such as illustrations, photographs, graphs, maps, analogies, physical manipulatives, and three-dimensional models, are often used by effective teachers to promote conceptual understanding, but these static representations remain insufficient for conveying adequate information to novice learners about motion and dynamic processes (Rohr & Reiman, 1998). The advent of personal digital technologies has created new possibilities for more fully supporting visualization, however. Pictures and graphs may be animated, displaying changes in space over time; interactive simulations can set into motion models based on real data; three-dimensional maps and models can be rotated and zoomed in or out; two- and three-dimensional geometric figures can be resized, rotated, and reshaped; and

digital video, which is easier than ever to access and create, can capture actual events for repeated viewing and analysis. Multimedia environments can even combine multiple dynamic representations, linking them so that users can see the effects of changes made to one representation in all the others.

Some educators see all this capability for motion as intuitively beneficial, asserting that a dynamic representation of a dynamic phenomenon is more authentic and should be an obvious means for increasing student comprehension and conceptual understanding (e.g., McKagan et al., 2008; Ploetzner & Lowe, 2004). The literature includes numerous small-scale studies that support this conclusion (many of which will be cited in this chapter). In their meta-analysis of 26 studies, for example, Hoffler and Leutner (2007) found that representational animations produced significantly superior learning outcomes in students than did representational static pictures. The authors defined representational animations as explicitly presenting the topics to be learned and not there merely as motivational devices.

On the other hand, a number of researchers have presented students with animations and other dynamic representations and found their learning outcomes to be *inferior* to the learning of students viewing one or more static images of the same phenomenon (Lewalter, 2003; Lowe, 2003; Tversky, Morrison, & Betrancourt, 2002). As Ploetzner and Lowe (2004) concluded,

It is clear that under suitable circumstances [dynamic] representations do have considerable potential for facilitating the learning of dynamic subject matter. However, in many cases, merely making dynamic visualizations available to learners is probably insufficient for this potential to be fulfilled. (p. 293)

As researchers have sought to understand what conditions must be in place for students to learn from these powerful visualization technologies,

teacher knowledge rises to the forefront as key. Teachers who have a deep knowledge of their content and of the concepts students have most difficulty grasping can apply their understanding of digital technologies to select the best form of dynamic representation when appropriate. When they select a dynamic representation from among the many tools in their pedagogical toolkit, these teachers are aware of the advantages and disadvantages of different computer interfaces (Mayer, 2009; Kozma, 2003). They know how to mitigate the potential overload on students' cognitive capacities that may impede their learning (Lewalter, 2003; Mayer, 2009). They also know how to incorporate the representation into their instruction in ways that best support student learning (Lowe, 2003, 2004; Niess, 2005, 2008). This cumulative knowledge is, of course, referred to as technological pedagogical content knowledge (Koehler & Mishra, 2008; Mishra & Koehler, 2006) and in this volume is called technology, pedagogy, and content knowledge, or TPACK.

This chapter discusses the findings from a broad range of studies over the past decade examining the use of dynamic representations in the classroom. Studies included in this review include primarily research addressing the efficacy of and implications for dynamic representations in K-12 and college science teaching and learning published since 2000, although some older studies were included when no more-recent relevant study could be found. To select investigations for inclusion, we first carried out a database search of the ERIC and HW Wilson Education Fulltext databases to identify articles related to the effectiveness of and instructional issues related to dynamic visualizations in the broad content areas of science, mathematics, and social studies. We limited this chapter to these content areas both for the sake of space and because they seem to be core subjects in which dynamic representations are being most utilized in schools today. Search terms included *visualizations*, *dynamic visualizations*, *animations*, *simulations*, *geographic*

information systems (GIS) *digital video*, *graphing calculators*, *virtual manipulatives*, and *dynamic geometry software*. These terms were search both individually and in combination with *science*, *mathematics*, *social studies*, and *education*, when appropriate. We also reviewed and cross-checked the reference lists of all articles. In selecting studies for inclusion in this chapter, we gave priority to studies published in refereed journals, although in some cases studies with relevant information have been described only in conference papers or books. As a result, this chapter cites more than 150 studies published since 2000, as well as an additional 50 published prior to 2000, from across a broad range of journals publishing research in instructional technology, cognitive psychology, science education, mathematics education, and social studies education.

This chapter will briefly describe the research regarding the affordances for learning with dynamic representations, both across subject areas and specific to the selected subjects of science, mathematics, and social studies. Then we discuss constraints of dynamic representations—characteristics of both the technology and learners that can become barriers to learning. Following this section is a summary of literature-based recommendations for effective teaching with dynamic representations and implications for teaching and teacher education across subject areas. This section will include a list of guidelines for determining when use of dynamic representations may be most appropriate. Our goal is to synthesize the literature in a way that will facilitate the development of TPACK for teachers, specifically regarding dynamic representations.

Technology Knowledge

Dynamic representations are digital displays characterized by motion. They encompass a broad range of technologies, some of which are being used increasingly in K-12 classrooms—simulations, digital video, dynamic graphs and charts,

virtual manipulatives, and dynamic 2D and 3D maps and models. Digital video and animated images or graphs can illustrate motion inherent to the object(s) being illustrated. Dynamic maps and models, including dynamic geometry software, incorporate motion most often through dragging, rotating, zooming, and moving, although objects can also be animated to show a series of changes to the underlying parameters. Computer environments can combine multiple dynamic representations; for example, graphic representations of underlying data can be combined with an accompanying digital video or animation of the action (Velazquez-Marcano, Williamson, Ashkenazi, Tasker, & Williamson, 2004). Many of these representations may be either interactive or noninteractive, depending on the computer interface in which they are embedded or presented. Interactivity at its simplest can include the ability to pause, rewind, and view repeatedly (Ploetzner & Lowe, 2004) or the ability to rotate an image and change the viewing perspective. Video can be hyperlinked to additional information. More sophisticated interactivity includes the ability to change one or more variables underlying the model and view the results. Dynamic representations may also be incorporated in a computer environment that integrates any one or a combination of the following features: background stories to set context, informational content, problem-solving prompts, questions, hints, and feedback.

Technological Pedagogical Knowledge

Teachers possessing TPACK understand the pedagogical affordances and constraints of technological tools “as they relate to disciplinarily and developmentally appropriate pedagogical designs and strategies” (Koehler & Mishra, 2009). In other words, they possess technological pedagogical knowledge. Specifically regarding dynamic representations, the capability to represent movement comes with various affordances for supporting student learning (which teachers can take advan-

tage of), as well as constraints that may hinder learning (which teachers must be aware of and prepared to mitigate). This section discusses both general affordances and affordances specific to the content areas of science, mathematics, and social studies. We then describe the literature regarding some well-documented constraints of dynamic representations.

General Affordances

Affordances are the features of an object or environment that enable specific capabilities (e.g., see Norman, 2002). The characteristics primarily accounting for the affordances of dynamic representations for learning were categorized by Ainsworth and Van Labeke (2004): (a) realistic animation of a visible phenomenon, (b) visualizations of entities not visible but spatially distributed, and (c) displays of abstract information (in which space is used as a metaphor for some more abstract information). They noted that representations might also distort reality in the service of further explicating a representation. For example, they may slow down or speed up processes, show objects or phenomenon from different or changing viewpoints, have objects leave a trace or wake, make boundaries between events more obvious, or use cues to draw attention to the most-relevant information (see also Schwan, Garsoffky, & Hesse, 2000).

As a result of these features, dynamic representations can aid understanding of phenomena that are otherwise difficult to comprehend (e.g., see Chan & Black, 2005; Hobson, Trundle, & Sackes, 2010; Liang & Sedig, 2010; Özmen, 2008; Reimer & Moyer, 2005). Rohr and Reiman (1998) noted that text descriptions are strongly condensed and incomplete, which “gives students degrees of freedom to adjust, instead of reject, their naïve model” (p. 65). Static images may preclude some possible misinterpretations, they noted, but only the affordance of animated representations provides enough easily accessible information to

build a complete mental model of a phenomenon in motion.

Dynamic representations can display events taking place over time or data changing over time. Earth science students might learn about geologic processes with the aid of animations showing how landforms are created or follow the apparent path of the moon across the sky on a given day using virtual planetarium software. Social studies students can follow shifts in topical markets, such as real estate listings or currency exchanges. Calculus students might learn about rates of change with dynamic software by focusing on the salient geometric properties as time proceeds so they can relate the geometric (and numeric) changes to develop an algebraic representation of the event. Without this affordance of dynamic representations, students may not otherwise have visual access to time-dependent events and thus miss opportunities to build complete understandings of the effects of changing variables.

Dynamic representations can model abstract, invisible, unreachable, or unreplicable phenomena or events. Science students can view animations of molecular reactions (Kelly & Jones, 2007; Linn, Lee, Tinker, Husic, & Chiu, 2006). Social studies students can observe the relationship between a country's gross domestic product and carbon dioxide production over time with analytical tools such as GapMinder, which presents human development data in a rich, engaging dynamic form. Elementary students can investigate the meaning of place value by using interactive, virtual Base 10 blocks (Moyer, Niezgoda, & Stanley, 2005). Further, dynamic representations can depict slowed-down or sped-up dynamic processes. In social studies and other content areas, the concepts under instruction can span centuries or even millenia. As part of a lesson on immigration, for example, students can view animations showing the flow of migrants over centuries, noting points of departure, destination, motivations for moving, and ethnic or cultural identity. For this and many other topics, both the ability to compress time

and the ability to pause or slow the process are critical affordances.

In appropriate instructional contexts, interactive dynamic representations can enable learner-centered exploration and inquiry, allowing learners to change variables/parameters and view the results (e.g., Baki & Guven, 2009; Hsu & Thomas 2002; Rieber, Tzeng, & Tribble, 2004; Suh, Moyer, & Heo, 2005), with the added advantage of allowing learners to make personalized problem-solving decisions (Hargrave & Kenton, 2000; Rose & Meyer, 2002). Chemistry students might explore chemical reactions by changing the variables of temperature and pressure (Trey & Khan, 2007). Social studies students can experiment with setting a fixed exchange rate or a price floor or ceiling. In exploring probability, students can use virtual manipulatives such as spinners, coins, and number cubes to quickly generate a large number of outcomes that vary from student to student, which then can be compared and analyzed. Beck and Huse (2007) noted that by using virtual manipulatives to conduct probability experiments, students were able to spend more time making predictions, enacting a large number of experiments, analyzing results, and comparing their predictions to the experimental outcomes.

Dynamic virtual modeling software can not only allow users to view objects in two or three dimensions but to rotate objects and zoom in or out. In addition to allowing students to analyze and manipulate objects, these programs can allow students and teachers to create dynamic models, change parameters, and view results (Linn, 2003; Garofalo, Juersivich, Steckroth, & Fraser, 2008). Several computerized molecular modeling programs enable students to build virtual models of molecular structures, learning about molecular compounds in the process (Barak & Dori, 2004; Dori & Barak, 2001; Wu, Krajcik, & Soloway, 2001). In social studies students can diagram and analyze complex social behavior, such as political decision-making (Brandes, Kenis, Raab, Schneider, & Wagner, 1999), community

affiliation (Lipp & Krempel, 2001), or editing a Wikipedia entry (Viegas, Wattenberg, & Dave, 2004). Students can also create or interact with virtual environments, such as the Rome Reborn model from the University of Virginia, built using Google SketchUp (Wells, Frischer, Ross, & Keller, 2009). In mathematics education, a flash applet may allow students to explore the reasoning behind the Corner Point Theorem in linear programming (Garofalo & Cory, 2007). In this example, students input constraint functions and an objective function to be optimized and then graphed in two dimensions. Sliders allow users to update parameter values that are hyperlinked with the corresponding graphs. The applet also allows zooming in and out on the graphs to show the model in both two and three dimensions, helping students to see why the objective's extrema occur at the corner points (see also Labord, 2008; Leung & Lopez-Real, 2002).

A number of computer environments not only present multiple dynamic representations simultaneously but allow them to be linked so that changes to one representation are reflected in the others (Hsu & Thomas, 2002; Kozma, 2000; Linn et al., 2006; Wu et al., 2001). As Shulman (1986) noted in his discussion of the characteristics of pedagogical content knowledge, "Since there are no single most powerful forms of representation, the teacher must have at hand a veritable armamentarium of alternative forms of representation..." (p. 9). Obviously, different representations present different information and focus on different aspects of a domain. Specific information can best be conveyed in specific representations (Ainsworth, 2006; van Someron, Reimann, Boshuizen, & de Jong, 1998), and it follows that presenting multiple representations can result in learners forming more robust conceptions.

These general affordances of dynamic visualizations might be summarized as follows: With the appropriate pedagogical support, dynamic visualizations can enable learners to see representations of objects and phenomena more completely and in

a manner that they can manipulate and investigate more conveniently and thoroughly (and sometimes even more cost-effectively and safely) than may be possible with real objects and phenomena.

Affordances and TCK

The TPACK construct encompasses both technological pedagogical knowledge and technological content knowledge (TCK; Mishra & Koehler, 2006). As Koehler and Mishra (2009) noted,

TCK, then, is an understanding of the manner in which technology and content influence and constrain one another. Teachers need to master more than the subject matter they teach; they must also have a deep understanding of the manner in which the subject matter (or the kinds of representations that can be constructed) can be changed by the application of particular technologies. Teachers need to understand which specific technologies are best suited for addressing subject-matter learning in their domains and how the content dictates or perhaps even changes the technology—or vice versa. (p. 65)

Others have noted, as well, that all types of dynamic media are not likely to be equally effective for learning about all topics, and educators benefit by considering the affordances of different types of dynamic visualizations for different types of learning (Hegarty, 2004). This next section summarizes the literature exploring some affordances of dynamic representations specific to science, mathematics, and social studies learning.

TCK: Science Learning

The literature exploring uses of dynamic representations in science education is extensive, probably because so much of science learning is about understanding dynamic and abstract processes. Science demonstrations have long been a part of the science teacher's instructional toolkit, and science education reform documents such as the *National Science Education Standards* (National Research

Council, 1996) and *Project 2061 Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1993) promote hands-on participation in science and learning through inquiry. Not surprisingly, science educators have promoted dynamic representations as a potential way to engage learners more deeply in science content and scientific thinking. Simulations, for example, appear to promote content knowledge across a wide range of students and science topics (e.g., Dori & Barak, 2001; Ebenezer, 2001; Marbach-Ad, Rotbain, & Stavy, 2008). Huppert, Lomask, and Lazarowitz (2002) found that 10th-grade biology students who used a computer simulation on the growth curve of microorganisms attained greater achievement on content-based objectives than those in a control group. Trundle and Bell (2010) reported higher levels of achievement for students who collected data through the use of a computer simulation than those who collected data from nature. Casperson and Linn (2006) demonstrated that computer simulations can facilitate students' abilities to connect microscopic and macroscopic views of electrostatics phenomena and, thus, lead to more integrated and scientifically accurate understandings. Trey and Khan's (2008) investigation indicated that dynamic computer-based analogies may enhance college students' learning of unobservable phenomena in chemistry.

Dynamic representations can reduce the complexity of experienced phenomenon, as well, removing extraneous variables and constraining learners' focus on aspects experts believe are most important, thus improving the chances that students' efforts lead to productive learning (Bell & Trundle, 2008; Finkelstein et al. 2005; Wieman, Perkins, & Adams, 2008). Many science educators view dynamic representations as allowing more authentic instruction (Ramasundaram, Grunwald, Mangeot, Comerford, & Bliss, 2005), enabling learners to manipulate data and explore processes that cannot be manipulated in real life or that are too time-consuming, too dangerous, or otherwise

impossible to manipulate on their own (Akpan, 2002; Marbach-Ad et al., 2008).

Researchers have also reported the success of computer simulations in supporting scientific reasoning and process skills. For instance, Monaghan and Clement (1999) reported that a computer simulation facilitated students' abilities to test predictions and subsequently develop more accurate mental models of motion. Researchers have found interactive simulations to be successful in allowing students to quickly and easily change variables, test hypotheses, view results, and discover explanations for mechanisms and processes (Bodemer, Ploetzner, Bruchmuller, & Hacker, 2005; Hsu & Thomas, 2002). Dori and Barak (2001) concluded that a combination of virtual and physical models used with inquiry-style lessons supported learning and spatial understanding of molecular structure better than traditional lecture/demonstration methods (see also Chang, Chen, Lin, & Sung, 2008).

Perhaps all of these affordances can be summed up as promoting conceptual understanding and conceptual change (Vosniadou, 1991, 1999, 2003). This conclusion is especially well-supported in the science education literature, although it may be true for other content areas, as well. Because they allow a more complete visualization of spatial relationships and dynamic processes, dynamic representations have the potential to present scientific conceptions in ways that promote cognitive dissonance and provide experiences that lead to more scientifically accurate conceptions (Ardac & Akaygun, 2004; Bell & Trundle, 2008; Ebenezer, 2002; Kelly & Jones, 2007; Özmen, Demircioğlu, & Demircioğlu, 2009; Thorley, 1990). In fact, some have suggested that computer simulations have the potential to promote cognitive dissonance and conceptual change more effectively than direct experience (Winn et al., 2006), an assertion that has empirical support (Trundle & Bell, 2010). This notion is especially true for concepts that are counterintuitive, abstract, or difficult

to access through direct observation (Allessi & Trollip, 1991).

Researchers have also reported qualified success in promoting conceptual change with the use of multiple linked dynamic representations in learner-centered computer environments. When multiple static and dynamic representations are linked, they can be manipulated and viewed synchronously (Ainsworth & VanLabeke, 2004). Research has shown that scientists use multiple representations in their work both extensively and effectively (Kozma, Chin, Russell, & Marx, 2000). Learning science requires students to comprehend a variety of representations of scientific entities and processes and to coordinate these representations as they construct deeper understandings of natural phenomena. A number of researchers have explored linked multiple dynamic representations in science learning and have found positive effects (e.g., Hsu & Thomas, 2002; Kozma, 2000; Linn et al., 2006; Tsui & Treagust, 2007; Wieman et al., 2008; Wu et al., 2001).

In summary, dynamic representations literature in science education reports positive effects for learning science content, supporting inquiry learning, and promoting cognitive dissonance that leads to conceptual change.

TCK: Mathematics Learning

It is not surprising that technology and mathematics are perceived as being naturally related. In fact, mathematics and computer science rely on similar concepts, such as logical reasoning, pattern recognition, and abstraction. Despite a limited research base on technology and mathematics learning at the time, the National Council of Teachers of Mathematics (NCTM, 1980) took a bold step and recommended, "Mathematics programs must take full advantage of the power of calculators and computers at all levels." Moreover, the Council said that technology should be used to encourage students to engage in real mathematical activities and not simply to compute formulas. NCTM (2000) included technology as one of

the six principles of "high-quality mathematics education" in its *Principles and Standards*, but not until recently has mathematics teaching and learning with technology become a well-established research area. This is not to say that there has been no informative research done on the learning of mathematics with technology in the past, but rather that there has been no established method that is comprehensive and conventional in the framing, conducting, analyzing, and understanding of research in this area until the recent past (Ronau, Niess, Browning, Pugalee, Driskell, & Harrington, 2008; Zbiek, Heid, Blume, & Dick, 2007). Some researchers (Zbiek et al., 2007) have asserted that the growth of the research field may be slow because technological research requires more time and resources than other branches of mathematics education research, specifically with regard to development and assessment of software and hardware. The research that does exist shows positive effects on student learning. Dynamic representations generated by technology, such as graphing calculators, geometry tools, calculator-based laboratories (CBLs), and applets, can foster students' attainment and development of concepts, skills, and problem solving (Duke & Graham, 2006; Duke, Graham & Johnston-Wilder, 2007, 2008; Ellington, 2003; Heath 2002; Kimmins, 1995; Kimmins & Bouldin, 1996; Laborde, 2001; Shoaf-Grubbs 1992). Use of dynamic representations allows students to take a more active role in the classroom, promotes the use of the discovery approach to learning, and increases students' depth of mathematical knowledge.

When using dynamic representations in problem solving, students can explore physical models and multiple representations on their own, manipulate the representations, and immediately view the outcome of their decision (Seufert, 2003). Students can have many choices in directing their learning and freedom in their problem solving processes (Beyerbarch & Walsh, 2001). Dynamic representations also provide the opportunity for student discussion of individual findings and

allow easy communication through the use of a common displayed representation (Heid, 1997; Kimmins & Bouldin, 1996).

Incorporating dynamic representations in instruction provides a natural environment for the discovery approach. By using dynamic representations, students can view simple representations of abstract and complex ideas (Abramovich & Norton, 2000; Garofalo et al., 2008), generate multiple examples quickly, focus on certain elements in the examples (Seufert, 2003), and use these examples and inductive reasoning to determine the mathematical phenomenon represented. Then students can create their conjectures, test them through easy execution, and adjust if necessary (Antonette, Penas, & Bautista, 2008; Chazan & Houde, 1989; Demana & Waits, 1990; Klotz, 1991). Once they have decided that their conjecture is satisfactory, students can use it and deductive reasoning to prove their findings. For instance, by using dynamic geometry software, students can construct a triangle and its centers, manipulate the triangle, and discover that the orthocenter, circumcenter, centroid, and nine-point center are collinear in a non-equilateral triangle. By using their actions on the triangles, they can conceptualize and prove why the properties of triangles and their centers cause this collinearity to occur. Students are no longer memorizing theorems proven by previous mathematicians and dispensed by teachers but are acting as mathematicians who are rediscovering geometry (Baki, 2005; Bruckheimer & Arcavi, 2001; Leung & Lopez-Real, 2002).

Researchers have found that when software is used that enables students to represent mathematical situations in their own way, interpret their findings, and reflect on the outcomes of manipulation in conjunction with the immediate feedback, they work at a higher level and expand their understanding on both social and cognitive levels (Hong & Trepanier-Street, 2004). Furthermore, when students use dynamic representations as cognitive tools, their intellectual capabilities can be broadened, and teachers can expect new

and different types of student mathematical understanding (Bos, 2009). By using dynamic representations students can access content that is typically introduced later in students' mathematical careers because of the complexity of required procedures in which they either are inexperienced or are not yet fluent (Demana & Waits, 1990; Judson 1990; Palmiter 1991). For instance, related rate tasks and extrema tasks are usually situated in the application of derivatives section of a calculus book; yet, these topics can be explored in algebra by using dynamic representations, even though students are unfamiliar with computing derivatives.

Another affordance of technology is that multiple representations can be hot-linked (Kaput & Schorr, 2007) so that students can change one representation and immediately view the corresponding change in another representation. Students can investigate this link, compare and contrast the changes, and construct a more comprehensive image of the mathematical concept. Moreover, because representations can be dynamically linked, students can choose which representation they would like to explore. Thus, students are able to bypass a particularly difficult representation and perform actions on familiar representation to see how a change in the familiar representation impacts the difficult representation. This manipulation and observation helps them to focus on the meaningful features of the represented concept (Bos, 2009; Cheng, 1999).

For instance, consider the Box of Greatest Volume problem: A box is to be made from a square piece of cardboard, 24 cm on a side, by cutting equal squares, of side length x , from each corner. What are the dimensions and volume of the largest box that can be made in this way? This problem is usually first seen by calculus students, but when using dynamic representations on a graphing calculator that has dynamically linked variables across applications, algebra students can access this problem. Students can construct the box, manipulate the variable, and see the resulting effects on the diagram, graph, and numerical values by

using the automatic data capture while dragging the side of length x . By using these representations, students can visualize the underlying structure of the functional relationship of the volume and side length in the problem.

Some dynamic representations may also help improve spatial visualization skills (Baki, Kosa, & Guven, 2011). Spatial visualization, or “the ability to mentally manipulate, rotate, twist or invert a pictorially presented stimulus” (McGee, 1979), is important in fields such as engineering, computer graphics, art, geography, and architecture. The NCTM (2000) recommended that all students should learn 2D and 3D spatial visualization and reasoning, for it plays an important part in geometric modeling, problem solving, and learning other mathematical concepts. In fact, researchers have found a positive correlation between using visual imagery and problem solving performance (Van Garderen & Montague, 2003). While there has been some research showing how using dynamic representations in instruction can help students improve their spatial visualization skills (Miller, 1996; Ullman & Sorby, 1990), there is still debate about whether spatial visualization skills can be developed by instruction at all (Baki et al., 2009). Dynamic geometry software such as Geometer’s Sketchpad and Cabri has been primarily used to teach plane geometry, and there has been little research on how this software can influence spatial visualization skills, specifically with solid geometry. Some researchers (such as Christou et al., 2006) have shown that dynamic geometry software can enhance students’ spatial visualization skills in 3D, while other researchers (such as Wang, Chang, & Li, 2007) found no difference between 2D and 3D-based media on these skills. Although dynamic 3D geometry software can help clarify some student misconceptions about figures, they are not always effective and may further strengthen some misconceptions (Accascina & Rogora, 2006), especially for those students with insufficient domain knowledge.

TCK: Social Studies Learning

Historically, the only form of dynamic representation used in social studies education has been the motion picture. Some of Thomas Edison’s first demonstration films addressed topics directly aligned with the social studies curriculum, such as Sioux Indians’ Buffalo dances (1894, <http://www.youtube.com/watch?v=sPKtl2L1XAw>).

Within the following decades, interest in the educational potential of film exploded, with educators writing more than a dozen textbooks on “visual education” (Yeaman, 1985). Educators valued film as a medium for addressing topics that are geographically distant or far in the past. Through the dynamic medium of film, these topics became present, accessible, and interesting to students. One quasi-experiment addressed a set of films produced for middle school history education, addressing topics such as the British settlement at Jamestown and the Revolutionary War. The experimental groups showed relative but uneven gains in content knowledge and interest (Knowlton & Tilton, 1929). However, even at that early date, the researchers highlighted the significant role played by the classroom teacher—the teacher must direct students’ attention by preparing them before viewing the film, by asking questions and conducting follow-up discussions, and so forth (Saettler, 1990).

In the following decades, two patterns emerged in the use of film as dynamic representation in social studies education. For most teachers and teacher educators, film was (and is) a means of transmitting preselected information to the students. Film would be called upon to summon the distant past or remote places, but the key affordance was that “It is as it was” (Marcus, 2005, p. 61)—students could see and hear realistic representations of what was not otherwise accessible. In addition to transmitting information, film could arouse student interest and emotion in a topic. Students who might not be enthusiastic about reading accounts of Peter Stuyvesant, a major figure in the history of early New York City,

would be more motivated to watch a film about him and may even be more interested in reading other history topics (Knowlton & Tilton, 1929). In contrast to these transmission-oriented models of use, social studies educators have also used film as a primary source. In the 1960s, the New Social Studies used film clips of key phenomena (e.g., a baboon troop, an Inuit hunting party) as inquiry objects to explore larger questions such as “What is human about human beings?” (Dow, 1992, p. 166). More recently, innovative teachers such as James Percoco (1998) have used feature films as a primary source, such as studying *Sargeant York* to learn about World War II (when the film was produced) rather than World War I (when the film is set). Teacher educator Diana Hess has suggested framing documentaries as “perspective-laden narratives” (Hess, 2007, p. 194) to be analyzed in Socratic Seminars, writing assignments, and comparative reviews.

In the past decade, the development of geographic information systems (GIS) such as My World and the Arc family of products has provided an important new set of affordances for social studies instruction. GIS has existed since the 1960s and undergirds many mundane topics of daily life, such as generating weather reports, making route maps, or tracking delivery vehicles (Alibrandi & Palmer-Moloney, 2001). The significance of the tool is that it allows students to bridge the typical curricular activity of *map-browsing* with the more specific, disciplinary tasks of *analysis* (Edelson, Smith, & Brown, 2008). The early tools were expensive and complex, used only by specialists with access to high-powered computing environments. In 1994, the Environmental Systems Research Institute (ESRI) released a free, limited-function version of their commercial GIS engines. In 2005 the Geographic Data in Education (GEODE) Initiative at Northwestern University released My World, a tool built specifically for instructional settings. My World includes a large data library, a broad set of both geographic and

mathematical analytical tools, and built-in data editors (Edelson, 2004).

Despite the increases in the availability and power of educational GIS, the adoption and use of the tool has been slow. Educational GIS pioneer Joseph Kerski has conducted a series of surveys to monitor its growth in school settings. As of 2003, an estimated 5% of schools nationwide had access to GIS (Kerski, 2003), but Kerski noted, “Even among teachers who own GIS software, nearly half are not using it” (p. 129). The most frequently cited barriers to use were “complexity of software” and “lack of time to develop lessons incorporating GIS” (p. 131).

Although its use remains limited, a growing research base has explored its use across a wide range of educational settings, from elementary instruction (Keiper, 1999; Shin, 2006) to middle level (Doering & Veletsianos, 2007; Meyer, Butterick, Olkin, & Zack, 1999; Wigglesworth, 2003) and secondary education (Alibrandi & Sarnoff, 2006; Edelson et al., 2008; Kerski, 2003; West, 2003). At all levels, researchers report uses of GIS to support inquiry learning, such as using GIS coverages of the 1790 census to observe the limitations of historical data or adaptations of economic data from the Civil War period to explore the advantages held by the North (Alibrandi & Sarnoff, 2006). Younger students are typically presented with a problem or puzzle to solve, such as locating a missing bird (Keiper, 1999) or devising the most efficient delivery route (Wigglesworth, 2003). Studies frequently show increases in student interest and engagement of critical thinking skills (Keiper, 1999; West, 2003), the development of abstract concepts such as a “sense of place” (Doering & Veletsianos, 2007), and the more-typically assessed fundamental items such as geographic content knowledge and map skills (Shin, 2006; Kerski, 2003). Common stumbling blocks for students’ use of GIS resemble an inverse of teachers’ struggles: students are *not* frustrated by the technical challenges of GIS (e.g., Shin, 2006) but struggle with interpretation. What does this visual

display of data mean? How can this data be used to support or shape an argument? What does this map mean in human terms? (Radinsky, 2008.) Instructional strategies that support students' use of GIS include working across multiple representations of geographic areas (Hammond & Bodzin, 2009), making iterative passes at analysis to clearly state hypotheses, identify supporting evidence, and work through possible fallacies (Edelson et al., 2008; Radinsky, 2008).

Two emerging tools for social studies education bear further study. First, Google Earth is a rapidly changing environment for displaying scholarly work (e.g., Wells et al., 2009), assembling student work (Bodzin, Hammond, Carr, & Calario, 2009), or even engaging in advocacy (Parks, 2009). Although the current form of the tool supports map-browsing far more than analysis, the tool's open interface allows for increasingly intuitive importation and display of data. Future versions of the tool may empower new combinations of the satellite and archival data to more fully support dynamic analysis. Second, more purely quantitative tools such as Fathom (keypress.com/fathom) or GapMinder (gapminder.org) allow students and teachers to assemble data on the fly and create a variety of visualizations. No research currently exists exploring these tools in the context of social studies education, but they will no doubt diffuse into the classroom as rapidly (or more rapidly) than GIS.

General Constraints to Learning

Teachers possessing technological pedagogical knowledge should be aware of these general and content-specific affordances, but also be able to balance them against a host of constraints to the use of dynamic representations in teaching and learning. The literature indicates that by their very nature, because dynamic representations incorporate movement they can be extremely complex and confusing to learners, constraining their potential to promote conceptual understanding. A

number of studies have compared learning with noninteractive animations playing at a constant rate to learning with static representations (and sometimes text representations). In many cases these animations were found to have no advantage over static images (ChanLin, 2000; Hegarty, Kriz, & Cate, 2003; Koroghlanian & Klien, 2004; Lewalter, 2003; Narayan & Hegarty, 2002; Schnotz & Grzondziel, 1999; Tversky et al., 2002). In several cases, researchers determined that a static image or set of images that learners could reinspect may be more effective than a moving image, especially when a comparable amount of information is provided in both (Lewalter, 2003; Lowe, 2003; Tversky et al. 2002). Specifically, in the field of science education, using more interactive dynamic representations has been found in some cases to engender no significant improvement in learning over hands-on physics labs (Marshall & Young, 2006), fieldwork on physical properties of the ocean (Winn et al. 2006), or even a set of pencil-and-paper activities on air resistance (Steinberg, 2000).

Cognitive Load

Researchers have explored at length the possible reasons for these disappointing results. One theory is that a learner's perception and comprehension of an animation cannot keep up with the pace at which it is presented (Hegarty et al., 2003; Tversky et al., 2002). In some animations, like the animated complex machines used in the Hegarty et al. (2003) study, viewers need to attend to multiple simultaneous changes occurring in different regions of space. Specifically, researchers have noted that dynamic representations can transmit information too complex for some students to comprehend (Tversky et al., 2003), require "excessive demands on attention" (Kozma, 2003; Mayer, 2009), and cause cognitive overload. Cognitive load theory (Chandler & Sweller, 1992; Clark, Nguyen, & Sweller, 2006; Sweller, 2005) suggests that learners' cognitive capacity is limited, and they have a better chance

of building a coherent mental model of a concept when working memory is not overloaded. Working memory is where “all conscious processing of information takes place.” Its processing capacity is limited and is “by far, inadequate to meet the complexity of information that learners face in modern learning environments” (Wouters, Paas, & van Merriënboer, 2008, p. 648).

Mayer (2008; Mayer & Moreno, 2003) incorporated cognitive load theory into his cognitive theory of multimedia learning. Mayer (2009) identified the following three kinds of cognitive processing in which learners may engage that are relevant to learning with dynamic representations. Each of these kinds of cognitive processing draws on the learner’s available cognitive capacity:

- *Extraneous cognitive processing* draws attention from the instructional goal and is caused by confusing instructional design or activities required of the learner that are not related to learning (Chandler, 2004). No learning results.
- *Essential cognitive processing* (or *intrinsic cognitive load* [Sweller, 1999]) is required to represent the essential material in working memory and is caused by the complexity of the material or learner’s lack of prior knowledge (Chandler, 2004). The result is rote learning.
- *Generative cognitive processing* (or *germane cognitive load* [Sweller, 1999]) is “generated by mental activities that are directly relevant to the construction and automation of knowledge in long term memory” (Chandler, 2004, p. 354). Generative cognitive processing is required for deeper understanding and contributes to the construction of schemas (Sweller, Van Merriënboer, & Paas, 1998). It comes from the motivation of the learner and is more likely to result in good retention of information and knowledge transfer. (Mayer, 2009)

Mayer’s work indicates that extraneous cognitive processing should be reduced by eliminating unnecessary elements in representations, essential processing should be managed through reducing complexity of representations and providing clarity where appropriate, and generative processing should be fostered by ensuring that learning with representations seems relevant and engaging to students.

Event Segmentation

Another line of research has explored human conceptions of motion. In comprehending naturalistic action, perceivers overcome potential information overload in part by segmenting ongoing activity into meaningful “chunks,” divided by event boundaries (Zacks & Tversky, 2003). Event Segmentation Theory (EST; Zacks, Speer, Swallow, Braver, & Reynolds, 2007) describes the psychological and neurophysiological mechanisms that lead to event segmentation. EST predicts that event boundaries will tend to happen at changes in salient environmental features. Researchers have found event boundaries in reading, for example, to coincide with changes in time, spatial location, objects, characters, goals, and causes (Rinck & Bower, 2000; Speer & Zacks, 2005; Zacks, Speer, & Reynolds, 2009). Event boundaries in movies have been found to coincide with changes in motion (Hard, Tversky, & Lang 2006; Zacks, 2004), as well as changes in time, space, objects, characters, and goals (Speer, Reynolds, Swallow & Zacks, 2009).

Researchers have presented movies interrupted by commercials (Boltz, 1992) or brief pauses (Schwan et al., 2000) to viewers and measured subsequent memory for the content of the movies. Interruptions coinciding with appropriate event boundaries improved memory, but interruptions conflicting with appropriate event boundaries impaired memory. A computer interface that directly visualized the event structure of a procedure to be learned was found to improve later memory for the temporal order of the procedure (Zacks

& Tversky, 2003). An interface that visualized a potentially inappropriate event structure in that study, however, impaired learning. In light of this research, Tversky et al. (2002) suggested that depictions using multiple still images or diagrams may be better than uninterrupted animations (see also ChanLin, 2000).

Passivity

Some dynamic representations engage viewers in watching only passively (Schwan & Riempp, 2004; Steinberg, 2000). Static diagrams are more effective in some cases because, researchers speculate, they require students to mentally animate and are, therefore, more actively involved in their learning (Bodemer, Ploetzner, Feuerlein, & Spada, 2004; Hegarty et al., 2003). Foti and Ring (2008) examined students using a computer learning environment that included video and animated instructions and background information. They found that, although students engaged with the interactive simulations, they quickly lost interest in watching the passive media—until they found out that they could not perform the simulated experiments without the information it provided.

Learner Issues

Researchers have also considered learner issues that constrain learning with dynamic representations. Learners' understanding of representations, especially complex visualizations, may be limited by their level of prior knowledge (Bodemer et al., 2005; Rieber et al., 2004; Lowe, 2003). At a minimum they may fail to comprehend or may misinterpret the representations (Kimmings, 2004; Sanger, Brecheisen, & Hynek, 2001; sometimes due to poor design, as in Linn & Eylon, 2000), know their characteristics, or have vocabulary to name them (Mayer, 2009). Learners also may not know which features are salient to their understanding of the target concept (Bodemer et al., 2004; Lowe, 2003).

For a number of reasons, interactivity may add another layer of cognitive load for learners

(Schnotz & Grzondziel, 1999). The intense and demanding interactivity of many simulations may not provide adequate time for the user to carefully reflect on the principles being modeled by the simulation. Without sufficient guidance or time and opportunity for reflection, referential processing may not take place. Therefore, while the simulation may lead to successful implicit learning (i.e., success at completing the simulation activities), the simulation may actually hinder or interfere with explicit learning (Rieber et al., 2004). Left on their own with interactive dynamic representations, students must be motivated and must possess the metacognitive skills to take advantage of the interactivity. In one study examining use of a meteorology simulation, some college student participants had trouble exploring the relationship between variables, so they could not explain why changing one variable influenced the other the way it did. They could neither comprehend the graphic information nor select useful information for the problem they needed to solve (Hsu & Thomas, 2002).

Young learners often do not have the skills to determine a systematic plan for interrogating the interactive dynamic representation in a way that produces a credible conclusion (Lowe, 2004). Learners need to have specific prior knowledge of a domain in order to process a related dynamic visualization and to interact with it in a systematic and goal-oriented way (Bodemer et al., 2005; see also Chandler, 2004; Sierra-Fernandez & Perales-Palacios, 2003). Rieber et al. (2004) found that students with little prior knowledge in the physics domain represented in their simulation on Newton's laws of motion tended to ignore the conceptual messages built into the software—even though they knew they would be tested on their physics knowledge at the end of the session.

Working with multiple dynamic representations adds further complexity. Even with static representations, students have difficulty making connections between representations and the phenomena they stand for and in making connections

across multiple representations (Ainsworth, 2006). They may have difficulty spatially linking two representations, or they may pay attention to the wrong information and interpret surface features (color, motion, labels) inaccurately (Linn, 2003; Kozma, 2003). Learners may fail to integrate different external representations, resulting in fragmentary and disjointed knowledge structures (Ainsworth et al., 2002). Multiple dynamic representations can also split a learner's attention among multiple sources of information, leaving the learner uncertain about which part of the action to attend to (Mayer, 2009; Mayer & Moreno, 1998).

Despite a fairly long list of constraints that may inhibit learning with dynamic representations, the literature remains optimistic that those constraints may be overcome with thoughtful software design and effective pedagogy.

TPACK: Effective Teaching and Learning with Dynamic Representations

In any K-12 subject area being addressed, teachers possessing TPACK can incorporate dynamic representations throughout the instructional cycle. Dynamic representations can be used to introduce a topic (Hargrave & Kenton, 2009), to engage students in thinking about a question (Casperson & Linn, 2006), to deliver information to students, to promote students' conceptual understanding, to bring about cognitive dissonance leading to conceptual change, to provide practice for new skills or a context in which to apply new knowledge, to enable transfer of understanding to different contexts, or to assess students' understanding.

Regardless of where dynamic representations are integrated in the course of learning, a clear research consensus points toward the importance of teacher involvement, support, guidance, and facilitation. Teacher TPACK, therefore, must incorporate an understanding of design features of dynamic representations that may help or hinder student learning, as well as knowledge about

how to mitigate for the limitations of dynamic representations to support student learning in their content area. As Mishra and Koehler (2006) pointed out, teachers possessing TPACK “engage with the affordances and constraints of particular technologies” to meet specific pedagogical goals. Hsu and Thomas (2002) suggested that teachers must consider three interdependent factors when incorporating dynamic representations in instruction: software design, pedagogical support, and student learning skills. This section will discuss software design and pedagogical support that takes into account student learning skills and mitigates for their limitations.

Software Design

Because computer interfaces can add extraneous cognitive load, teachers must make thoughtful choices when selecting one or more appropriate dynamic representations to incorporate in their lesson planning and work to manage their complexity (Wouters et al., 2008). Even though they cannot change design features, they must be aware of features that promote rather than impede understanding. Design features should be generally consistent with Mayer's (2009) multimedia principles. For example, if text is included along with images in the representation, they should be near each other on screen and should be presented simultaneously. Essential text or graphics should be highlighted or cued in some way (see also Lowe, 2003, 2004). Buttons and sliders to manipulate motion and change variables should be clearly labeled and easy to use. In each of these cases, if the design is not ideal, the teacher should be prepared to mitigate for their limitations through instructional support.

Mayer (2009) and others have found that learners perform better on problem-solving transfer tests when an animation is accompanied by narration rather than onscreen text. Reading printed words can distract students' attention from a dynamic representation (Atkinson, 2002;

Hegarty et al., 2003; Mayer, 2009; Moreno & Mayer 2002; Moreno, Mayer, Spire, & Lester, 2001). (There may be cases when onscreen text is appropriate, however, such as with non-native speakers or hearing impaired learners). Narration can be either built into the dynamic representation or provided by the teacher (Sanger et al., 2001). When presenting multiple dynamic representations, teachers should note whether the software provides clear visual and conceptual connections between multiple representations (Ainsworth, 2006; Kozma, 2000; Mayer, 2009) and, if not, provide additional support to students for making these connections.

Instructional support (referred to as *mediation* by Mariotti, 2001) has been built into some interactive computer learning environments that incorporate dynamic representations, and sometimes dynamic representations can even be part of a broader technology-based curriculum, especially in the science subject areas. These environments or curricula may include multiple representations, narratives, tasks, puzzles, and representational assistance (e.g., Tsui & Tregust, 2007), as well as built-in prompts that engage students in exploration, reflection, and explanation (e.g., Davis, 2000; Huk & Ludwig, 2009; Linn, 2000; Linn & Hsi, 2000; Linn et al., 2006).

Pedagogical Support

Teachers possessing TPACK may use a number of pedagogical strategies to mitigate the constraints of dynamic representations, including segmenting dynamic representations, pretraining students, actively engaging students, and providing direct guidance.

Segmenting

The principle of segmenting, or “breaking a whole presentation into coherent parts that can be digested sequentially” (Mayer, 2009) converges with the proposals of Event Segmentation Theory for the design of dynamic representations. Segment-

ing dynamic representations at event boundaries with pauses, therefore, may improve learning and memory. During these pauses, the teacher can point out salient data, focusing on specific parts and actions, and check student understanding about relationships across representations, thereby increasing the likelihood that conceptual change will occur. Representations that “allow close-ups, zooming, alternative perspectives, and control of speed are even more likely to facilitate perception and comprehension” (Tversky et al., 2002, p. 256). Pauses may be built into the design of some dynamic representations. When they are not built into the software, teachers should be aware that putting the control of pacing in the hands of learners to slow down the action (e.g., through the use of a slider or pause button) can reduce the mental processing load (Mayer & Chandler, 2001). However, controlling pauses in the action can also add extraneous cognitive processing when novice learners lack the metacognitive skills to know when they need to stop and digest important information (as noted by Mayer, 2009). Mayer suggested that teacher-determined segmenting may be more effective.

Pretraining

Before viewing or interacting with a dynamic representation, providing learners with relevant names, locations, and characteristics of key components can preempt some potential cognitive overload (Mayer, Mathias, & Wetzell, 2002; Mayer, Mautone, & Prothero, 2002). Mayer (2009) referred to this strategy as the pretraining principle and noted that providing prior knowledge reduces the amount of cognitive processing needed to understand the dynamic representation. Perhaps another aspect of pretraining is the finding of studies by Bodemer and colleagues. They found that “learning with dynamic and interactive visualizations can be significantly improved by encouraging learners to actively integrate symbolic and static versions of pictorial representations in the external environment” (Bodemer et al., 2005, p. 82). These

researchers first presented and discussed static versions of the representations, giving learners “time to identify the presented visual structures and become familiar with them,” as well as to allow “learners to relate the possibly unfamiliar visual structures to representations already familiar to them” (Bodemer et al., 2004, p. 328).

Active Engagement

Although the easiest path for students may be to sit back and watch dynamic representations, a number of studies have indicated that students’ active engagement is required for conceptual understanding to occur. Even with digital videos, which are typically viewed passively, students can systematically observe and analyze content (Niess & Walker, 2010; Park, 2010). Digital video can also be designed with hyperlinks that take viewers to still images or text with additional information, although one study found few learners curious enough to take advantage of the hyperlinks (Zahn, Barquero, & Schwan, 2004). The learners who followed the hyperlinks in this study, however, demonstrated a higher understanding of the instructional material. In their study of high school students learning about molecular genetics, Marbach-Ad, Rotbain, and Stavey (2008) found a larger learning benefit with animations of dynamic processes, such as DNA replication, transcription, and translation, when compared to a control group learning with static illustrations. The effect occurred when the students conducted and repeated trials with the interactive animations. However, the students learned more about DNA *structure* when they worked with static illustrations that required them to draw and label parts. The treatment group in this case merely viewed an animated image of DNA structure. The researchers concluded that students’ active engagement made the difference regardless of the media format.

In addition to developing and testing hypotheses using simulations and models, student engagement may take a number of forms when using dynamic representations, including making

predictions before watching all or part of a dynamic representation (Hegarty et al., 2004; Trey & Khan, 2007), explaining and discussing results, and then reflecting on and reconstructing original conceptions (Bodemer et al., 2004; Edelson et al., 2008; Henderson, Eshet, & Klemas, 2000; Klahr, Triona, & Williams, 2007; Linn & Eylon, 2000; Pallant & Tinker, 2004; Trundle & Bell, 2010). Teachers can also increase student understanding by simply directing them to pause and capture their understandings by making a drawing (Zhang & Linn, 2008) or taking screenshots and adding their own annotations (Edelson et al., 2008).

Direct Guidance

Initial enthusiasm about educational technology has centered on minimal instructional approaches, with students having hands-on control of dynamic representations and teachers as more “guides on the sides” (e.g., see Foti & Ring, 2008). Although some open-ended exploration can be valuable, most of the research on dynamic representations indicates that more direct, well-structured guidance is necessary for helping students gain conceptual understanding of a targeted subject (e.g., Bodemer et al., 2004; Hsu & Thomas, 2002; McKagan et al., 2008; Pallant & Tinker, 2004). Rieber et al. (2004) recommended facilitated and guided discovery, recognizing that even though their simulations on Newton’s laws of physics offered multimedia feedback with explanations, “the explanations offered by a master teacher at just the right time for a student should offer much richer opportunities for reflection” (p. 320). An example of this guided discovery includes “encouraging the learners to formulate hypotheses on only one relevant aspect of the visualisation at a time and ... providing them examples of data that have the potential to highlight important relationships” (Bodemer et al., 2004, p. 328). Facilitated exploration helps place students’ activity within a larger instructional context (McKagan et al., 2008).

Explicit hints and instructions can help students know why knowledge or a skill can be applied

to a familiar situation so that they can recognize what to apply and how to apply it to a new situation. Students may also need explicit procedures for setting initial conditions in an interactive simulation or model (Hsu & Thomas, 2002). As mentioned previously, some of this guidance may be built into a computer interface (see also, Yaman, Nerdel, & Bayrhuber, 2008).

All of these findings are consistent with those of educational psychologists Kirschner, Sweller, and Clark (2006), who synthesized the body of literature on human cognitive architecture. They found that for novice to moderate-level learners in a domain, minimally guided instruction is both less effective and less efficient than strong, directly guided instruction. Rather than relying on dynamic representations as the sole learning experience, a number of science education researchers have found increased learning gains when dynamic representations were combined with traditional learning experiences, including lecture, hands-on labs, and static and three-dimensional representations (Bodemer et al., 2004; Pallant & Tinker, 2004; Smetana & Bell, 2007; Trundle & Bell, 2010).

Implications for Teaching and Teacher Education

In early approaches to determining the effectiveness of dynamic representations to enhance learning, much of the research on animations and multimedia learning, especially, left student participants mostly on their own to view (and sometimes to interact with) dynamic representations. Generally, researchers less connected to teacher preparation programs conducted these studies. The learning results were equivocal at best. On the other hand, studies that have examined dynamic representations in the context of the classroom environment (e.g., many of the studies cited in the content-specific sections of this chapter) have often found more positive results. Some would argue that variables are harder to control in these types of studies, and claims that a specific dynamic

representation significantly affects learning are harder to make. Others would argue that dynamic representations are merely one tool among many in an effective teacher's toolkit, and no tool is likely to single-handedly revolutionize learning anyway (e.g., Hsu & Thomas, 2002).

Student-Centered Hands-on Learning

The emphasis on student-centered learning has also driven much of the research on and design of dynamic representations. Proponents of student-centered learning have assumed that students must have individual or small-group, hands-on access to computers with dynamic representations and must be tasked with independent learning of the target content. Software designers have followed the implications of the research and have improved the clarity and convenience of computer interfaces, increased interactivity and engagement, and added instructional supports (primarily in the science content area)—sometimes creating comprehensive computer environments that also include multiple linked dynamic representations. Teachers using dynamic representations for independent student learning and exploration need first to evaluate the effectiveness of the dynamic representation and develop a plan for mitigating any limitations with supplemental support.

When students are working directly with dynamic representations individually or in small groups, they need support for using the technology, as well as explicit strategies for “interrogating” the interactive media (Hegarty, 2004; Lewalter, 2003), so that they reach desired conclusions. Kombartzky, Ploetzner, Schlag, and Metz (2010) noted that regarding animations approaches “empowering students to initiate, plan, organise, monitor, and regulate their own learning as well as to competently deal with challenging learning material” (p. 425) has been largely neglected. They found empirical evidence for a specific strategy for learning with animations, which involved a worksheet prescribing step-by-step instructions,

a method in direct contradiction with proponents of student-centered exploration. The researchers acknowledged that, of course, the ultimate goal is for students to “internalise the strategy step by step” and then “automatically apply it to new animations with success” (p. 431).

Student-Centered Whole-Class Learning

Weiman et al. (2008) viewed dynamic representations as powerful visual aids that can provide opportunities for interactive engagement in whole-class instruction. Rather than didactic, teacher-centered instruction, in this type of whole-class instruction, the teacher focuses student attention on a computer screen projected at the front of the classroom and orchestrates a demonstration with dynamic representations, questioning, asking for predictions, adding new information, and testing students’ ideas. A few studies have explored the whole class setting specifically for learning with dynamic representations. One study using simulations in a high school chemistry classroom found that whole-class instruction was more effective than students using computers on their own in small groups. The researchers found more highly collaborative talk and meaningful teacher-student interactions in the whole class instruction treatment. (Smetana, 2008). Dynamic geometry software fostered a similar kind of teacher-student interaction in studies on mathematics learning (Garofalo et al., 2008; Juersivich, Garofalo, & Fraser, 2009), especially due to the capability to dynamically manipulate diagrams. Preservice teachers in their study could produce multiple diagrams to help students see important relationships and make generalizations about the properties of objects. The teachers encouraged students to make predictions and explain results, and they were able to respond quickly to students’ questions and feedback about the diagrams. Whole-class instruction also allows teachers to scaffold and check student understanding of individual representations and

the relationships between multiple representations in ways not possible when students are working on their own.

The Invaluable Role of TPACK

Whether dynamic representations are incorporated in whole class instruction or one-to-one computing environments, the literature is clear that teachers having developed TPACK as explicated in this chapter are more likely to help students achieve instructional goals. Integrating knowledge from multiple sources, achieving deep conceptual understanding, and transferring this understanding beyond the exact conditions of initial learning may all be facilitated by technology, but only when teachers possess requisite levels of technology expertise, content knowledge, and pedagogical skills. “Merely knowing how to use technology is not the same as knowing how to teach with it” (Mishra & Koehler, 2006, p. 1033).

Therefore, teacher preparation should incorporate the findings of the research presented in this chapter, presenting opportunities for preservice teachers to experience a rich variety of model lessons using dynamic representations and opportunities to practice teaching with them (Garofalo et al., 2008; Juersivich et al., 2009; Niess et al., 2009). Teachers must also know the affordances and constraints of dynamic representations well enough to evaluate when they are worth the time and effort to incorporate in their instruction, as there are cases when static images not only suffice but are the superior choice (Hoffler & Leutner, 2007). The following guidelines summarized from the literature may be helpful in making decisions about when to use dynamic representations:

- When students are likely to have misconceptions about the topic, and the dynamic representation can promote cognitive dissonance and conceptual change.
- When the dynamic representation can provide a bridge between abstract and concrete

- concepts that students have difficulty understanding without visual representation.
- When the concepts are difficult or impossible to represent without complex and tedious calculations.
 - When the concepts involve motion that is too fast, too slow, too small, or too far away to view in person or impossible to replicate.
 - When the dynamic representations enable students to engage in exploration and inquiry not otherwise possible (e.g., because of location, cost, or safety).

FUTURE RESEARCH DIRECTIONS AND CONCLUSION

In each of the content areas covered by this chapter (science, mathematics, and social studies), additional rigorous research studies examining the conditions under which specific types of dynamic representations can best facilitate learning of specific curricular topics would inform the development of TPACK. Linking particular misconceptions to the technologies and instructional approaches that produce cognitive dissonance and lead to conceptual change appears to be an especially fruitful area for future work. Researchers should also consider the K-12 classroom context and further explore the instructional strategies most effective at helping young learners achieve instructional goals with dynamic representations. Use of some dynamic representations, especially in mathematics (Ronau et al., 2008) and social studies education (Hicks, Friedman, & Lee, 2008), is supported more by anecdotal evidence than by an adequate base of empirical research.

An in-depth examination of the most-effective strategies for developing dynamic representations TPACK in teachers was beyond the scope of this chapter, but this area is another in which more evidence would be useful to the field. Studies that thoroughly describe preparation methods

and then follow preservice and novice teachers into the classroom are most needed. The literature base documenting whether teachers use dynamic representations once they enter the classroom, how they use them, and how their use affects student learning outcomes would benefit from a greater robustness.

Although other types of dynamic technologies exist, including games and virtual or augmented reality, we chose not to include these in our definition of dynamic representations. The pedagogical methods surrounding learning with these tools (that is, their associated TPACK) seems to differ significantly from the methods used with the types of dynamic representations we covered here, thus making the scope too broad for a single chapter. However, the lines differentiating these types of tools are increasingly blurring, as features of each are hybridized (e.g., see Hauptman, 2010, for an example use of virtual reality for enhancing visual memory and 3D geometry skills).

One emerging use of dynamic representations that bears mention is networked simulations that allow students to collaborate in and engage in discourse online about their technology-facilitated discoveries (Ares, 2008; Hegedus & Kaput, 2004). Kozma's (2003) work on collaborative investigations using multiple linked dynamic representations indicated that extended discourse between pairs of students helped them to create shared meaning and scientific understandings. Thus, adding a social networking component to dynamic representations may be another fruitful area of exploration.

This chapter synthesized a broad spectrum of research from across the teacher education disciplines, as well as across the disciplines of instructional technology and cognitive psychology, all fields that too often work in isolation from each other. Teaching and learning can only benefit, however, from this cross-section of perspectives, frameworks, and methodologies. As new forms of dynamic representations continue to emerge, teachers need access to the full body of relevant

education research in order to develop robust TPACK around these technologies.

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Chapter 6

Overcoming the Tensions and Challenges of Technology Integration: How Can We Best Support our Teachers?

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ABSTRACT

This chapter informs teacher educators and individuals involved in teacher professional development about the tensions that frequently arise when K-12 teachers integrate technology into their classrooms. Suggestions for how individuals can help teachers confront and overcome these challenges are presented. In order to describe the various tensions that exist, findings are organized around concerns that are related to the innovator (e.g., the teacher), the technological innovation, and the contextual factors that arise from the environment in which teaching and learning occur. To describe ways to assist teachers as they confront the challenges of technology integration, recommendations are framed around the Cognitive Apprenticeship Model (CAM) and the four dimensions that constitute a successful learning environment: content, method, sequencing, and sociology.

BACKGROUND

As part of a movement throughout the United States to integrate 21st Century skills throughout

K-12 classrooms, various states are engaged in new initiatives to infuse the “four Cs” (critical thinking, problem solving, communication, collaboration, and creativity and innovation) throughout their curricula (Partnership for 21st Century Skills,

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2004). An emphasis on 21st Century skills brings with it an increased recognition of the role of technology in today's digital age society. Because of this emphasis, there has also been a heightened focus on the integration of technology in K-12 classrooms and increased recognition that teachers must be prepared to provide technology-supported learning opportunities for students. Despite this push for technology integration in K-12 classrooms, little technology is actually being used in classrooms in meaningful and transformative ways (Cuban, 2001; Hennessy, Ruthven, & Brindley, 2005). In fact, when technology is integrated into classroom instruction, few teachers radically alter their teaching practice in ways that motivate students, enrich learning or stimulate higher-level thinking and reasoning, in support of 21st century skills (Cuban, 2001; Goodson & Mangan, 1995). There are various reasons why teachers might not take advantage of the educational power of technology, some of which include limited access to technology, insufficient technological support, and teachers' own limited knowledge of the literacies that surround new technologies (Hennessy et al., 2005; Reinking, Labbo, & McKenna, 2000; Zhao et al., 2002). Yet even when these barriers do not exist, educators are still confronted with the fact that in order for the highest likelihood of integration to occur, teachers must value technology integration and see compatibility between its uses and their own existing values and beliefs (Zhao et al., 2002).

According to Straub (2009), successfully facilitating a technology adoption "needs to address cognitive, emotional, and contextual concerns" (p. 626). Ronau et al. (2010) describe a three-dimensional model for teacher knowledge that recognizes the complexities and interactions that surround the knowledge that is required for integrating technology into classrooms. In addition to acknowledging exposure to the pedagogy of technology integration, this framework also points to contextual and environmental factors that must be taken into consideration when exploring

the relationship between teacher knowledge and the integration of technology in classrooms. If educators are going to use technology in ways that are not simply seen as extensions to conventional print-based literacy while favoring skills such as critical thinking, problem solving, collaboration, and creativity, many of them will need to shift the educational philosophies that guide their instruction (Smolin & Lawless, 2004). In addition, they will need to take into consideration the ways that these various factors interact with one another.

To help educators confront the many challenges they might face when integrating technology into classrooms, this chapter investigates research on technology integration and teacher education. It explores what challenges can arise as teachers learn to use technology to support teaching and learning. It also investigates how others have confronted these challenges to explore how preservice and practicing teachers have been successfully supported in this learning process. The purpose of this chapter is to share these findings so that educators are better informed about the challenges that frequently arise when teachers are asked to integrate such technologies into classrooms. In addition, it offers suggestions for how teachers and teacher educators might confront these challenges.

Because of the wide array of technologies that exist and a need to provide a focused discussion within the confines of a single chapter, the following sections will speak specifically to issues related to the education of teachers, both preservice and practicing teachers, and the integration of computers into K-12 classrooms. Emphasis is also being placed on those classroom uses of digital technologies that promote the development of 21st century skills, which include critical thinking, problem solving, and collaboration (Partnership for 21st Century Skills, 2004). In order to describe the challenges that exist when teachers use computers for classroom instruction, findings are organized around concerns that are related to the innovator (e.g., the teacher), the technological innovation, and the contextual factors that arise from

the broader environment in which teaching and learning occur. Zhao et al. (2002), Straub (2009), and others have previously used this framework to organize and discuss the various factors that “significantly impact the degree of success of classroom technology innovations” (Zhao et al., 2002, p. 482). Some of these factors, as described throughout this chapter, include such things as teachers’ attitudes toward the role of technology in subject matter learning, teachers’ accessibility to technological support, and the ease in which a technological innovation can be used.

There is a large body of research that uses other frameworks to describe the diffusion of technology; however, many of these studies exist in fields such as business and industry rather than K-12 education (Straub, 2009). The framework described by Zhao et al. (2002) has been used specifically to describe issues of technology integration in K-12 education settings. Because these categories have been identified (although not always explicitly) in other frameworks, building a discussion around the innovator, innovation and context was deemed to be most appropriate for the purpose of this chapter. Of course, there are always limitations to viewing issues using just one or two frames of reference, and so these limitations are discussed in more detail in the conclusion section of the chapter.

When describing what supports or hinders the successful interaction of technology into K-12 classrooms, a large number of factors come into play. Many of these factors are beyond a teacher’s control, such as availability of computers, technology policies set by schools, and the structure of the school day (Aworua, Worrell & Smaldino, 2006). The purpose of this chapter is not to broadly describe all of the issues that surround the diffusion of technology. Instead, its purpose is to focus more specifically on those issues that are related to educating teachers about how to effectively use technology (i.e., computers and digital technologies) to support classroom teaching and learning. To better understand how

individuals might help support teachers in learning to integrate technology into their classrooms, this chapter additionally organizes findings using Collins’ (2006) Cognitive Apprenticeship Model (CAM) and the four dimensions that constitute a successful learning environment. This model can be used to help describe the learning process and the types of interactions that support teacher learning, thereby giving individuals direction as they support teachers through this learning process.

PERSPECTIVE AND METHODOLOGY

This chapter frames teacher education, which will also include teacher professional development, using a social constructionist perspective that acknowledges both the social and cognitive aspects of learning. With this view, learning is believed to occur through a non-linear movement between public, private, individual, and social dimensions (Gavelek & Raphael, 1996). Learning is “dialogic and interactive” in nature where participation with others is significant in the learning process (Kong & Pearson, 2002, p. 2). In order to educate others so that they better understand how to meaningfully support teachers as they integrate digital technologies into classrooms, this chapter also presents a cognitive apprenticeship perspective on learning. The Cognitive Apprenticeship Model (CAM) recognizes the need for teachers to learn in environments where the cognitive problem solving processes of more expert “others” are made explicit so that an individual’s internal thought processes (such as by an expert user of technology) are made “externally visible” to others (Collins, 2006, p. 48).

The CAM is grounded in the belief that when individuals are learning in an academic environment, they do not usually have access “to the cognitive problem solving processes of instructors as a basis for learning through observation and mimicry” (Collins, 2006, p. 48). It is designed to bring cognitive processes “into the open, where

students can observe, enact, and practice them” (Collins, 2006, p. 48). Framing suggestions around the four dimensions of the CAM that constitute any learning environment provides useful, categorized information for educating teachers on technology integration. These dimensions include content (i.e., domain knowledge and strategic knowledge), method (i.e., teacher modeling, coaching, etc.), sequencing (i.e., the increase in complexity and/or diversity in a task), and sociology (i.e., identity forming, participation in communities of practice, etc.).

To contribute to the discussion on how to assist educators in successfully integrating technology into K-12 environments, the chapter first introduces the various challenges and tensions that have been known to exist and then offers suggestions for how to potentially overcome these challenges. Findings are also organized using a framework that describes three categories of characteristics that influence the successful integration of technology into K-12 classrooms. These categories, which have been used by educational researchers, describe characteristics of the innovator (e.g., the teacher), concerns surrounding the innovation, and the contextual factors that influence the integration of technology (Straub; 2009; Zhao et al., 2002).

A review of the literature was conducted to obtain an overview of the challenges educators face when learning to integrate technology into K-12 classrooms. Literature was reviewed by searching online library databases such as Academic Search Premier and using a university library’s online “Searchlight” tool, which searches the following databases all at once: Academic Search Premier, Business Source Premier, Medline, PAIS, Periodicals Index Online, PsychINFO, Web of Science, and WilsonWeb Omnifile. The researchers also searched for articles using Google and Google Scholar and reviewed lists of references from current reviews of literature on educational technology and teacher education. Search terms included various combinations of words such as “teacher education + educational technology,”

“teachers + technology integration,” “educational technology,” and “technology integration.” Searches were conducted for empirical articles that provided information on the education of preservice and practicing teachers as they learn how to integrate technology into K-12 classrooms. A few theoretical articles that informed the topic and helped shed light on the review of the literature were also included.

Lawless and Pelligrino’s (2007) definition of “empirically based study” was used to review research studies. According to these researchers, an “empirically based” study means “any study that had a systematic data collection plan (qualitative or quantitative) that was created to answer specific research/evaluation questions that were established a priori” (p. 584). Articles that highlighted both the challenges that classroom teachers face and the ways that they learn to overcome these challenges were selected. There were instances, however, where more theoretically based manuscripts were added to the list of readings because they informed the overall goals of the chapter.

After searching through both online library databases and Google Scholar, the first review of the literature resulted in more than 78 articles. Upon a closer reading of abstracts, introductions, and methodologies, the authors then deleted articles that did not directly inform the topic of teacher education and the integration of technology into K-12 classrooms. Articles that were excluded included those that did not inform the current state of Internet-based technology use in K-12 classrooms or those that did not inform teacher education and technology integration. For example, articles that were position statements and editorials were excluded from the literature review. Narrative descriptions of teaching practice that were not grounded in research or theory were also eliminated. A couple articles focused on the use of technology to prepare teachers, but those articles that did not describe how preservice teachers themselves learned to integrate technology into practice were rejected.

A number of articles explicitly discussed how teacher educators and professional development programs have attempted to educate teachers on technology integration. Some of these articles were research based, while others described the topic from a theoretical perspective. Both research and theory pieces were included. At times when one or more authors had multiple articles describing a single research study or theoretical perspective, one or two key manuscripts were chosen to be included. Sometimes the decision on which article to include was based on the one that provided a more in depth discussion of the topic.

Lawless and Pelligrino (2007) stated that much of the literature prior to 1999 will likely “add little to the understanding of professional development on the integration of technology into instruction” because prior to 1999, school infrastructures “were significantly less rich, Internet speed was significantly lower, and federal funding initiatives for technology reform efforts were in their infancy” (p. 584). These authors argue that the resources and environments in which “teachers and students were expected to use technology prior to 1999 are no longer analogous to current standards” (p. 584). For the purpose of this chapter, however, older articles were considered if they could shed light on other areas of technology integration and teacher education. The authors also included research articles and theoretical pieces that discussed aspects of teacher learning, although they did not always explicitly explore aspects of technology integration. Articles that reported on teacher educator learning in higher education or the education of computer science teachers were deleted because their main focus was not on education in K-12 classrooms. In the end, forty articles that informed the goals for this chapter were selected. Out of these articles, twenty-four directly reported on research studies, two were literature reviews, and the remaining articles were theoretical, conceptual, or methodological pieces that did not directly report on research. (See the

Appendix for an overview of the research studies and literature reviews that were included.)

FINDINGS

By highlighting some of the tensions and challenges that exist when preservice and practicing teachers learn to use technology to support student learning, this chapter offers possible solutions for confronting these challenges. There are benefits to framing teacher knowledge using the Comprehensive Framework for Teacher Knowledge (CFTK) and the Technology, Pedagogy, and Content Knowledge (TPACK) framework, and these frameworks are referenced accordingly. To organize the challenges that teachers face, however, the sections below are organized around the following categories: innovator challenges, context challenges, and innovation challenges. Suggestions for dealing with these challenges are then given using the Cognitive Apprenticeship Model (CAM), with emphasis being placed on teacher learning and the four dimensions that, according to Collins (1986), constitute any learning environment.

Innovator Challenges

When describing factors that influence the “adoption and/or diffusion of an innovation” (Straub, 2009, p. 628), researchers have highlighted characteristics related to the individual, or the innovator, who is attempting to use the technology (Moos & Azevedo, 2009; Ropp, 1999; Straub, 2009; Zhao et al., 2002). Many of the innovator challenges that have been reported in the literature fall under the CFTK’s Mode dimension. The Orientation aspect of Mode describes the “knowledge of beliefs, dispositions, values, goals, and other personal qualities that embody and define an individual’s views and actions toward learning and teaching” (Ronau et al., 2010, p. 265). Characteristics of the individual, or the “innovator,” which can be

found in the Context dimension, also fall under this category. When describing innovator challenges, we can include knowledge of individual characteristics which relate to “socioeconomic status (SES), gender, age, background, learning styles, and other contextual factors that impact an individual’s approach to learning that teachers must understand and manage to be effective in a given learning situation” (Ronau et al., 2010, p. 266).

Individual characteristics such as not having a high capacity for uncertainty and change (Straub, 2009) can hinder the successful adoption of a new innovation such as technology. Educators’ dispositions toward themselves, the technology that they are using, and the subject matter that they are teaching can also enter the picture and create numerous challenges (Hennessy, Deane & Ruthven, 2003; Niess, 2005; Ropp, 1999). Moos and Azevedo (2009) have shown that an individual’s perception of his or her capabilities to “meet situational demands” is related to his or her “performance, persistence, and choice” (p. 578). Citing the work of Shapka and Ferrari (2003), Moos and Azevedo claimed that “higher computer self-efficacy is strongly associated with specific activities” during learning with computer based learning environments (p. 577). Using Wood and Bandura’s (1989) definition, they define self-efficacy as the “self-perception of one’s capabilities to meet situational demands based on current states of motivation, course of actions needed, and cognitive resources” (Moos & Azevedo, 2009, p. 578). They also explain how research has demonstrated “that students with higher self-efficacy tend to persist more in the face of difficulty (Torkzadeh & VanDyke, 2002), whereas those with lower self-efficacy tend to engage in fewer challenging activities (Bandura, 1977, 1982)” (Moos & Azevedo, 2009, p. 578).

Both CFTK and TPACK acknowledge teachers’ need for subject matter knowledge and pedagogical knowledge. TPACK highlights the interactions that occur between these various

types of knowledge (including knowledge of technology and technological pedagogical content knowledge) as teachers acquire the knowledge and skills that are needed to successfully integrate technology into their classrooms. It also describes a series of levels for technology integration. CFTK, however, further contributes to the discussion on teacher knowledge by providing insight into how various aspects of teacher knowledge interact with one another (Ronau et al., 2010).

Innovators obviously need to have a basic knowledge of technology in order to use such items as computers, LCD projectors, and various software programs (Holland, 2001; Zhao et al., 2002). There is a level of technological proficiency they must have in order to successfully use these technologies. Not only do teachers need to have knowledge of the technology they are using and value it as a key component to the teaching of their subject matter (Boling, 2008; Hennessy et al., 2005; Moos & Azevedo, 2009; Niess, 2005), they also need to have knowledge of pedagogical strategies for integrating it into their subject matter teaching (Davis, Preston, & Sahin, 2009; Hennessy et al., 2005; Mishra & Koehler, 2008). For example, educators can struggle to effectively use technology in their classrooms if they do not know how to problem solve computer glitches (Boling, 2008; Duran, Fossum, & Luera, 2007; Zhao et al., 2002), if they do not have the knowledge that is needed to effectively design instructional activities that will prompt authentic and meaningful online discussions (Mishra & Koehler, 2008), and if they do not see how technology is an integral component of teaching their subject matter (Boling, 2008; Hennessy et al., 2005; Niess, 2005; Ropp, 1999). CFTK further contributes to understanding teacher knowledge by acknowledging the ways that context, environment, values, dispositions, and beliefs can all interact upon both teachers’ subject matter and pedagogical knowledge (Ronau et al., 2010).

When describing the dimensions of an effective learning environment, the CAM also highlights

characteristics related to the innovator. Knowledge of these innovator traits and the challenges that innovators might face will assist individuals who are responsible for teaching or providing professional development to teachers. Challenges related to innovator traits can be related to each of the CAM's four dimensions, but they are particularly evident when considering the dimension called "content." For example, the CAM recognizes that content knowledge includes both domain knowledge and strategic knowledge, which is also recognized by the CFTK and TPACK frameworks. In addition, research conducted by Davis et al. (2009), Hennessy et al. (2005), and Mishra and Koehler (2008) highlights how teachers' subject matter knowledge can also not be ignored. For example, challenges can arise when teachers have limited subject matter knowledge or when they do not view technology as being a significant component to their content areas (Boling, 2008; Hennessy et al., 2005; Mishra & Koehler, 2008; Niess, 2005; Ropp, 1999). Using the CAM to inform the education of teachers also highlights how important it is for educators to obtain not only technological and subject matter knowledge but also technological pedagogical content knowledge (Mishra & Koehler, 2008).

Context Challenges

When describing 11 salient factors that "significantly impact the degree of success of classroom technology innovations," Zhao et al. (2002) described how contextual factors can have a strong mediating effect" (p. 482). CFTK also recognizes the role of context and describes how this third dimension of CFTK consists of two sources, Individual and Environment (Ronau et al., 2010). Since contextual factors surrounding the individual, or the innovator, were described in the previous section, this section speaks more to those environmental aspects of CFTK's Context which are also related to the contextual factors that Zhao et al. (2002) and others have described.

Zhao and his colleagues stated that the innovator and innovation are situated within the context of the school. They additionally described how the challenges related to the school and instructional context are complex and include factors such as the technological infrastructure, human infrastructure, and social support.

In regard to the instructional context and technological infrastructure, some teachers have access to more and varied forms of technology than others (Cuban, 2001; Doering & Hughes, 2003; Holland, 2001). For example, pre-service teachers who are ready to search for jobs do not know whether they will work in a school equipped with Smart Boards, laptop carts (or even one-to-one laptop initiatives), up-to-date computer labs, and so forth. The technology present in some schools provides much greater opportunities for innovation than in others (Cuban, 2001; Doering & Hughes, 2003). Teachers could have limited access to the Internet, computer labs, or to particular software programs or websites (Boling et al., 2008; Holland, 2001; Zhao et al., 2002). Having to reserve a computer lab and request that a member of the instructional technology department install software onto computers can slow down or even stop an innovation from being used (Zhao et al., 2002).

Human infrastructure refers to the level of support for teachers provided by technical staff and individuals who can help teachers learn about new technologies (Zhao et al., 2002). Human infrastructure also includes the policies and procedures that are put into place for accessing technologies, purchasing software, and providing professional development to teachers. Challenges in this area can relate to the type of professional development that teachers receive and the level of support that they do or do not receive from their school (Holland, 2001; Hughes & Ooms, 2004; Mulqueen, 2001). Teachers might attend one workshop given by an outside expert and struggle to integrate what they have learned in their particular school context. Teachers might find that their school administration places more emphasis on a statewide

curriculum and/or mandated assessment system that doesn't acknowledge technology integration and the type of instruction that might support more inquiry and research based curriculum (Holland, 2001). In addition, preservice teachers can also end up in classrooms during their teaching internships where their collaborating teachers are not modeling or reinforcing uses of technology in their classrooms (Rosaen et al., 2003). Teacher educators and classroom cooperating teachers can struggle to present their students and mentees with available, successful models of technology integration (Doering, Hughes, & Huffman, 2003).

Even the most basic and general contextual problems can inhibit the integration of technology in K-12 classrooms. Both technological and human infrastructure can create roadblocks (Zhao et al., 2002). For example, when Aworuwa et al. (2006) reviewed 32 technology integration projects that were funded by the federal government, they found examples of how the structure of an institution, a school's daily schedule, and teachers' limited time can be problematic and inhibit the successful integration of technology in classrooms.

The CAM also acknowledges the many contextual challenges that surround technology integration. A number of these can be identified under the dimensions labeled "method" and "sociology" (Collins, 2006). For example, the teaching and learning context offered by professional development programs can hinder teacher learning. According to the CAM, teachers need to interact in learning environments that allow them opportunities to collaborate with others, have opportunities to seek out their own personal goals, and are given time to reflect upon and articulate their ideas with others. If they are not provided such opportunities through teacher education and professional development contexts, then learning opportunities can be lost, (Davis et al., 2009; Duran et al., 2007; Dutt-Doner, Allen, & Corcoran, 2006). Based on the CAM and research studies, learning opportunities can also be squandered when teachers do not see technology as helping

resolve real world tasks and when they are not given opportunities to problem solve with others (Hughes & Ooms, 2004; Mulqueen, 2001).

Innovation Challenges

As described above, characteristics of the innovator and the context can have an impact on the likelihood of success for technology integration. In addition to factors that are related to the individual who is attempting to use technology, there are additional factors related to the actual innovation, or technology, itself that can increase or inhibit effective technology integration (Zhao et al., 2002). Through a review of the literature, however, it was discovered that that researchers spent much more time investigating personal and contextual factors that impact technology integration rather than studying the actual technologies that were being used. Zhao et al. (2002) presented an exception when they described a series of case studies that explored teachers' uses of technology in K-12 classrooms. They described how "the nature of the innovation itself" was the "prime determinant" of whether a technological innovation was successfully used (p. 496).

Some of the factors that influence successful technology integration, as described by Zhao et al. (2002), are related to how distant the technology innovation is from school practices and existing teaching practices and how compatible the technological innovation is to an individual's teaching beliefs or philosophy. For example, if a teacher does not customarily use collaborative group work in his/her classroom and then attempts to use wikis for collaborative work, he or she is less likely to successfully integrate technology than teachers who already engage their students in many collaborative activities. When technology integration practices are closely aligned with teachers' instructional philosophies and beliefs, teachers are in a better position to be successful during instruction.

In order to be successfully integrated into teaching practices, technology innovations must also be easily accessible, available, and visible to teachers (Straub, 2009). For example, educators who encounter technology so complex that it is confusing or difficult to use such that they need to rely on others to implement it are less likely to effectively use that technology with their students (Straub, 2009; Zhao et al., 2006).

Holland (2001) stated that teachers must first achieve mastery in their personal use of technology before they can attend fully to using technology in their classrooms. However, a study conducted by Parr (2009) revealed that even when personal use of technology is extensive and skill level grows, the use of computers in classrooms still remained low. Mills and Tincher (2003) reported that technology integration is a development process and claimed that this process begins with novice teachers using technology as a tool for professional productivity. Considering this, it seems logical that teachers might struggle to integrate technological tools into their classrooms if the tools themselves are difficult to use.

Teachers' perceptions of a technological innovation also impact its use. If teachers perceive a program as being useful and easy to use, they are more likely to actually use it (Straub, 2009). When evaluating the usefulness of new technologies and how they might be used to enhance teaching and learning, Moos and Azevedo (2009) argued that learning in computer-based learning environments "is dependent on students' active participation in the learning process, and the extent to which students actively participate in the learning process is related to motivational constructs (Moos & Azevedo, 2006, 2008)" (Moos & Azevedo, 2009, p. 577). Ross and Wissman (2001) also found that it could be difficult to staff a course with people who have both the content knowledge and technological knowledge that are needed for modeling the successful integration of technology to support subject matter learning.

The CFTK framework provides an ideal model for understanding the complex ways in which an individual's personal goals, values, dispositions, and beliefs are interrelated and can have an impact on content, technological, and pedagogical knowledge (Ronau et al., 2010).

The CAM's dimension labeled as "method" offers suggestions for how teachers might learn to use a specific type of technology, but it does not speak to the actual tools themselves (Collins, 2006). Offering professional development opportunities through modeling, coaching, careful scaffolding, and reflection could prove to be successful (Parr, 1999). The "sociology" dimension reveals that teachers need to see authentic purposes and uses for technology if they are going to most effectively learn how to use them. Because the CAM helps describe the learning process and the various dimensions that make up an effective learning environment, it is understandable that it does not speak directly and explicitly to the technological tools themselves. However, the framework does provide teacher educators with information on how these tools might be used and embedded within teacher education courses and professional development programs.

Sociological Approach to Support Teacher Learning

When considering the many challenges that are related to the innovator, the context, and the innovation, teacher educators might ask themselves what is the best way to support teachers as they learn to integrate technology into K-12 classrooms. Here "integration" does not mean using technology simply for the sake of using it or sending students to the computer once they have completed all of their other work. Sheingold (1990) stated that "integrating technology in schools and classrooms is not so much about helping people to operate machines as it is about helping teachers integrate technology as a tool for

learning” (Mills & Tincher, 2003, p. 382). The goal is to help teachers reach a level of mastery and innovation where they are able to “integrate the teaching of complex applications with subject area content, and of maximizing the potential for student learning through discovery” (Holland, 2001, p. 258). In order to assist teacher educators and others on this journey, it is helpful to turn to the CAM for guidance. Researchers have found the CAM lens to be useful and productive when exploring teacher learning and the integration of technology in K-12 classrooms (Brown, 2006; Collins, 2006; Dickey, 2008).

According to the CAM, individuals need to consider that the social characteristics of effective learning environments include such things as situated learning, a community of practice, intrinsic motivation, and cooperation (Collins, 2006). The CFTK framework also helps illustrate how social characteristics directly interact upon many other aspects of teacher knowledge (Ronau et al., 2010). If teacher educators and professional developers can help teachers see value in the technological tools that they are using and promote a positive attitude toward them, teachers will be more successful integrating the tools into their teaching (Moos & Azevedo, 2009). Research indicates that when teachers show curiosity and enjoyment using computer-based learning environments (Moos & Azevedo, 2009) and can acknowledge their advantages to the individual, they will be more successful using them (Straub, 2009). Teachers need to bridge technology use with their own ways of teaching to be able to incorporate technology effectively into their classrooms, that is they must see compatibility between the technology and their own ways of teaching (Zhao et al., 2002). Teacher educators can help individuals recognize the role of technology in subject matter learning through the courses that they teach and the professional development activities that they offer. Research indicates that if teachers do not see technology as playing a vital role in the teaching of their

subject matter, then it is less likely that they will emphasize its use while teaching in the content areas (Boling, 2008; Hennessey et al., 2005; Niess, 2005; Ropp, 1999).

Holland (2001) describes how models of professional development must take into account the

... level of knowledge and commitment that teachers bring to staff development and address the differing personal learning needs, satisfactions, frustrations, concerns, motivations, and perceptions that teachers have at different stages of their professional development. (p. 247)

Sharing concerns, hearing other’s opinions, and seeing real life examples of how technology can enhance teaching and learning can all play a role in helping individuals view technology as being relevant and important (Boling, 2008; Dickey, 2008; Doering et al., 2003; Ropp, 1999). Encouraging teachers to reflect on their own perspectives and fears, having them share these concerns, and asking them to revisit changing beliefs and perceptions over time can also support teacher learning (Boling, 2008; Collins, 2006). When doing this, it is essential that teacher educators create safe learning communities where teachers can take risks and feel comfortable admitting when they do not understand something (Aworuwa et al., 2006; Duran et al., 2007; Dutt-Doner et al., 2006; Hughes & Ooms, 2004).

Studies have highlighted the importance of having a supportive human infrastructure in place for teachers as they learn about new technologies and how to use them in ways that enhance teaching and learning. Rosaen, Hobson, and Khan (2003) described how infusing technology into literacy and mathematics methodology courses can support student teacher learning. Their study also illustrated how a role reversal occurred when these student teachers were placed into elementary classrooms, and collaborating teachers learned from their student teachers. Duran, Fossum, and

Leuera (2007) described how “effective interaction regarding teaching improvement calls for engagement among three entities: schools of education, school districts, and colleges of arts and sciences” (p. 34). Their study highlights preservice teachers’ student teaching experiences and how collaboration among many individuals supported novices in being able to develop technology-enhanced lessons. Their model included collaboration amongst student teachers, mentoring teachers, university-based field supervisors, content area faculty of the arts and sciences who specialize “in student teachers’ major fields of study,” and educational faculty “specializing in educational technology and methods” (p. 36).

Mulqueen (2001) studied the results of a professional development program on two different cohorts of teachers over a two-year period of time. The study revealed how enhanced professional development integrated three factors. First, it involved educators “taking responsibility for their own training and honoring their professionalism...” (p. 250). Second, it ensured “flexibility to adjust to individual learning styles, training schedules, and paces of professional development” (p. 250). Third, it made available opportunities “for collaborative learning and collegial support groups...” (p. 250). Results from the study revealed how professional development “became increasingly defined as a change management and team building rather than technology training” (p. 248). It’s evident from these studies and others that teacher education and professional development can make a difference. However, the more effective approaches to educating teachers appear to be based on social learning within a community of practice where collaboration and reflection are encouraged. Such findings support the CAM where situated learning, communities of practice, intrinsic motivation, and cooperation all represent the social characteristics of effective learning environments (Collins, 2006).

The Content and Methodology of Teacher Learning

While using the CAM as a lens to review the literature, the boundaries between its four dimensions of content, method, sequencing, and sociology were not always clear. Data frequently overlapped into more than one area. For example, one teacher education course had students keep reflective journals so that teachers could periodically reflect upon their knowledge and beliefs about the role of technology in education (Boling, 2008). This assignment was identified as being a “method” of instruction for encouraging more self-reflection on part of the students. It was also coded as “sociology” because it was a strategy used to encourage self-reflection, metacognitive awareness, and interaction between the students and their instructor. (The instructor of the courses read and responded to journal entries.) Because of the lack of clarity between these boundaries, the discussion of the various components of the CAM in this section will be more fluid and will at times touch upon each dimension of the CAM.

The TPACK model recognizes the various domains of knowledge that a teacher must acquire in order to effectively use technology to support student learning. It also provides a framework that describes a series of levels for technology integration (Mishra & Koehler, 2008). CFTK further contributes to the discussion by providing insight into the rich interactions that occur between and amongst the dimensions of Field, Mode, and Context (Ronau et al., 2010). Teacher educators and individuals offering professional development to K-12 teachers can use these two models and the CAM lens as they begin to consider the kind of learning environments they want to create for K-12 teachers. In addition, they can begin to consider the kinds of content that need to be covered. Educators need knowledge about the tools they are going to use, the programs they are going to integrate, and the pedagogical practices that are needed for integrating technology effectively

into classrooms (Collins, 2006; Hennessy, 2005; Hughes & Ooms, 2004; Zhao et al., 2002). The CAM recognizes that both domain knowledge and tacit knowledge, or “tricks-of-the-trade,” are needed for individuals to effectively integrate technology into instruction (Collins, 2006).

Recognizing successful methods of instruction, Hughes and Ooms (2004) described a teacher professional development model where teachers formed content-focused technology inquiry groups. In these groups, teachers who taught similar content and grades identified problems of practice and inquired into technology supported solutions. The study found that facilitation support was valuable in these groups and that “group identity, focus, and participation were extremely important parts of the process” (p. 407). The study identified three phases of group development that were important. These include “(a) defining the group, (b) identifying content-focused technology inquiries, and (c) initiating content focused technology inquiries” (p. 397). The authors identified one of the main advantages of this model was teachers’ use of technology “to solve content-related problems in their classrooms” (p. 397). Working with others to learn together and to brainstorm problems of practice can help provide the human infrastructure (a contextual challenge) that Zhao et al. (2002) described. In addition, working with others in this way can assist teachers in acquiring the knowledge of content matter and instructional strategies (an innovator challenge) that Mishra and Koehler (2008) have highlighted.

There are studies that show how teachers benefit from one-on-one mentoring from a more experienced individual, engaging in learning communities, and discussing problems of practice (Doring et al., 2003; Dutt-Doner et al., 2006; Hughes & Ooms, 2004; Ropp, 2009; Rosaen et al., 2003; Seels et al., 2003). Blair (2008) described a need for a “*knowledge broker*, or an intermediary,” to help teachers sift through “a wealth of information about programs, tools, and Web resources and to explain and demonstrate to them how to use it in

a way that supports and enhances student learning and personal productivity” (p. 71). After reviewing over 300 Preparing Tomorrow’s Teachers to Use Technology (PT3) projects, Aworuwa, Worrell, & Smaldino (2006) revealed how many successful teacher education programs were based on building community of learners for educators.

Availability of programs and tools and having an easily accessible support system or support groups are also important components for success (Duran et al., 2007; Dutt-Doner et al., 2006; Seels et al., 2003). Teachers can not simply be told about the technology; they must have ongoing experiences with the technological innovations that they are using or expected to use. Angeli and Valanides (2005) described a successful model where preservice teachers acquired such knowledge by using the very same modeling tools that they were expected to use with K-12 students. Having teacher educators and more experienced teachers model to their students the types of knowledge, skills, and dispositions that are needed is significant (Rosaen et al., 2003; Seels et al., 2003). Both preservice and practicing teachers can benefit from actual hands-on activities that allow them to acquire and practice the skills that are needed while also building their comfort level while using technology (Moos & Azevedo, 2009; Straub, 2009). To understand the value of its use, teachers must have access to examples and models of instruction that reflect the role of technology in their individual subject matter (Hennessey et al., 2005; Holland, 2001). While teacher educators are providing such models and examples, Ashton & Newman (2006) emphasized the importance of educators acting as “guides to the development of ideas rather than force-feed the wisdom of others” (p. 829).

Citing Putnam and Borko (2000), Hughes and Ooms (2004) described how teacher learning is affected “by the physical or social context within which learning is situated, the kinds of discourse communities supported, and the accessible tools/persons” (p. 398). They recommend that designers of teacher learning activities “need to be cogni-

zant of the social context in which the learning is situated to maximize optimal learning” (p. 398). An optimal learning environment would include learning both in and outside schools and providing opportunities for “collaboration, discussion, and reflection opportunities” (p. 398). Providing learning opportunities around the use of new technologies should also warrant considerations for the types of technologies that are being used. In order to help find compatibility between new technologies, computer programs, and schools and districts, teachers and administrators must evaluate technologies in relation to their educational needs, goals for teaching and learning, and philosophies toward education and technology (Smolin & Lawless, 2003; Straub, 2009; Zhao et al., 2002).

According to Collins (2006), teaching methods that emphasize apprenticeship “give students the opportunity to observe, engage in, and invent or discover expert strategies in context” (p. 51). Other methods associated also include modeling, coaching, scaffolding, reflection, and exploration. The studies described above help illustrate the types of learning opportunities that can assist teachers in acquiring the knowledge, skills, and dispositions that are needed to integrate technology into K-12 classrooms. Some of the methods that have been used include the use of content-focused inquiry groups (Hughes & Ooms, 2004), the use of knowledge brokers and mentors (Parr, 1999; Plair, 2008; Rosaen et al., 2003), and the incorporation of models and examples (Angeli & Valanides, 2005). Analyzing these methods and others using a CAM lens can be informative to teacher educators as they design effective learning environments.

Limitations Related to the Sequencing of Instruction

When discussing the CAM, Collins (2006) described the dimension of “sequencing” as the

“keys to ordering learning activities” (p. 50). This includes the ways that activities increase in both complexity and diversity. Sequencing also considers the ordering of events when they move from “global” to more “local” skills where focus is on “conceptualizing the whole task before executing its parts” (p. 50). In the review of the literature that was conducted for this chapter, very little information was found concerning the sequencing of activities for educators who are learning to integrate technology into classrooms. The review provided a wealth of information related to sociological aspects of learning, including information on teachers’ knowledge and beliefs (Angeli & Valanides, 2005; Boling, 2008). Researchers also explored different models of instruction that were used to educate preservice and practicing teachers (Davis et al., 2009; Duran et al., 2007; Hughes & Ooms, 2004), with some researchers emphasizing situated learning through mentoring, modeling, and/or coaching (Angeli & Valanides, 2005; Dickey, 2008; Parr, 1999). None of the studies that were reviewed, however, contained research questions that explicitly looked at the sequencing of learning activities. In professional development workshops and teacher education programs, it was easy to identify a sequence in learning events. However, no researchers explicitly looked at this sequencing and its relation to teacher learning. The lack of research in this area raises a number of questions, such as when and how should the sequencing of events grow more complex? How should face-to-face and online scaffolding, mentoring, and coaching be sequenced and structured? When is reflection and self-exploration most appropriate and most effective? At what point in time is it most effective for instructors to have their students reflect on learning? Additionally, how might self-exploration appear differently when students are learning face-to-face, online, or in hybrid courses? There is still much to be explored in this area.

CONCLUSION

As stated previously, the intent of this chapter was not to present a full literature review on the integration of technology in K-12 classrooms. Its purpose was to use current research and theory to inform teacher education and the professional development of teachers who are acquiring the knowledge, skills, and dispositions that are needed to successfully integrate technology into K-12 classrooms. The chapter highlights some of the challenges that these teachers might face and provides suggestions for confronting these challenges. Emphasis was placed on the use of computers and digital technologies in the classroom. Additionally, the authors sought ways to inform instructional practices that promote 21st century skills such as critical thinking, problem solving, inquiry-based learning, and collaboration.

There are, of course, limitations when research is reviewed from a particular lens. Findings were presented using the categories of innovator, innovation, and context. Although others have used these categories in the field of educational technology (Straub, 2009; Zhao et al., 2002), there is a large body of literature on the diffusion of technology that presents other frameworks. Many of these studies come from the business world and describe the integration of technology in contexts outside education. By extending consideration into these other fields of study, one will find that there are additional areas that still need to be explored. For example, Roger's Innovation Diffusion Theory (IDT), which describes the stages that an individual becomes aware of an innovation, includes a component labeled as "time." Time can be described as "what makes one individual adopt a particular innovation early versus late" and "what characteristics and influences are salient to an early adopter versus a late adopter?" (Straub, 2009, p. 631). Although IDT also describes components that inform categories such as the innovator and context, taking a

closer look at "time" could be very beneficial to researchers and teacher educators.

None of the studies that were reviewed for this chapter explicitly researched the sequencing of learning events. For example, no studies explored the order that particular methodologies should be carried out or how the sequencing of instructional strategies impact teacher learning. It would be beneficial to researchers if they explored such questions by considering theories and frameworks that might better inform where there are gaps in the literature. Diffusion theories can be used to describe the "abundance of different factors that influence whether an individual will choose to adopt a technology" (Straub, 2009, p. 641). Although this chapter used the CAM as a theory of learning to shed light on how teachers acquire the skills that are needed to integrate technology into K-12 classrooms, looking at the same issues through various diffusion theory lenses might provide additional information on the various gaps that exist in the literature.

Additionally, this chapter referred to "technology" as the use of computers in K-12 classrooms. More specifically, the authors emphasized the use computer-based technologies that promote the acquisition of 21st century skills. These skills include the use of student inquiry, collaboration, and problem based learning. Although this was the focus for the chapter, one must not forget that a multitude of technologies exist, and many of these technologies are not focused solely on the use of computers. In addition, there are other learning philosophies and perspectives that extend beyond social constructivist views, ones that do not place such emphasis on collaborative, learner centered, inquiry based teaching methods. Therefore, the field of education and educational technology needs additional studies that explore teaching and teacher learning from different perspectives. Only then will a more complete picture be obtained to best inform the field of teacher education.

When considering the sociological aspects of effective teaching and learning using a CAM lens,

it is important to recognize that teachers benefit from having positive views of themselves if they are going to persist in learning when contextual factors get in the way (Straub, 2009). School leaders can help reduce the number of challenges by creating an environment that supports risk-taking and encourages teachers to use technology in a variety of everyday professional purposes (Mills & Tincher, 2003). In addition, giving teachers time to form working groups and learn from one another is vital if other forms of teacher professional development are missing (Hughes & Ooms, 2004; Rosaen, Hobson, & Khan, 2003). Collins (2006) stated, "... learning through cooperative problem solving is both a powerful motivator and powerful mechanism for extending learning resources" (p. 53). Learning about new technologies and how to use them takes time; however, this is time that is often not given to classroom teachers (Aworuwa et al., 2006). School administrators, teacher educators, and individuals designing professional development opportunities might want to gradually introduce teachers to the complexities that surround technology integration and provide additional support systems for them during this process.

Successful technology integration and teacher education can require philosophical changes and shifts in beliefs regarding teaching, learning, and technology (Smolin & Lawless, 2003; Zhao et al., 2002). If new technologies and technological innovations counter current teaching philosophies and school practices, teachers will be much less likely (or even less able) to use these technologies in their classrooms (Zhao et al., 2002). In the end, one cannot ignore the fact that education must go beyond students' classrooms and teacher education courses. If teacher educators, administrators, and those in charge of teacher professional development programs want to see an increase in effective, learner-centered, technology integration practices, various types of educational opportunities must be extended to teachers. As these opportunities are being designed, developed and implemented, the

Cognitive Apprenticeship Model (CAM), Comprehensive Framework for Teacher Knowledge (CFTK), and Technological Pedagogical Content Knowledge (TPACK) can be used to help guide educators through this challenging endeavor.

TPACK can assist in determining where teachers are in regard to their level of technology integration, especially in relation to subject matter and pedagogical knowledge (Mishra & Koehler, 2008). CFTK can provide insight into the ways that various aspects of teacher knowledge interact with one another (Ronau et al., 2010). Finally, the CAM (Collins, 2006) can be used as a lens to inform the development and implementation of effective teacher educational opportunities. As seen in this chapter, the CAM provides guidelines for designing effective learning environments and insight into how to promote the development of teacher expertise (Collins, 2006). By taking into consideration the CFTK framework and the CAM, teacher educators can now make more informed choices about the content, design, and implementation of teacher education programs and professional development opportunities.

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APPENDIX

Literature Reviewed

Article Reference	Research Focus	Participants
Angeli, C., & Valanides, N. (2005). Preservice elementary teachers as information and communication technology designers: An instructional systems design model based on an expanded view of pedagogical content knowledge. <i>Journal of Computer Assisted Learning</i> , 21, 292-301.	Explored how to develop preservice elementary teachers' ICT-related PCK by using an Instruction Design Model (ISD)	More than 85 elementary education preservice teachers
Ashton, J., & Newman, L. (2006). An unfinished symphony: 21 st century teacher education using knowledge creating heutagogies. <i>British Journal of Educational Technology</i> , 37, 825-840.	Investigated competing priorities in preservice teachers' lives and their perceptions of flexible and blended approaches to learning as well as their knowledge and use of ICTs	Preservice teachers (n = 80 of a total 110 enrolled), staff in children's services (n = 16 settings; 30 staff), employers (n = 4) and university staff (n = 8)
Boling, E. C. (2008). Learning from teacher's conceptions of technology integration: What do blogs, instant messages, and 3D chat rooms have to do with it? <i>Research in the Teaching of English</i> , 43(1), 74-100.	Investigated preservice and practicing teachers' conceptions of the role of new technologies in literacy education; documented how these conceptions evolved over time and impacted the content and curriculum of a university course	19 preservice and practicing teachers
Aworwu, B., Worrell, P., & Smaldino, S. (2006). A reflection on partners and projects. <i>TechTrends: Linking Research & Practice to Improve Learning</i> , 50(3), 38-45.	Looked across 300 PT3 projects and if/how they developed school-university partnerships	PT3 awardees; 32 projects conducted in K-12 schools
Cuban, L. (2001) <i>Oversold and underused: Computers in the classroom</i> . Cambridge: Harvard University Press.	How do teachers and students use computers in classrooms for instruction? Have teaching and learning changed as a consequence of two decades of heavy promotion and investment in computers and other technologies? What explains the change and/or stability? Has the investment in computers and other technologies been worth the cost?	6 preschools, 5 kindergarten classrooms; 2 high schools; one university
Davis, N., Preston, C., & Sahin, I. (2009). Training teachers to use new technologies impacts multiple ecologies: Evidence from a national initiative. <i>British Journal of Educational Technology</i> , 40, 861-878.	Explored a range of approaches to ICT teacher training through a national initiative in England from 1999 to 2002; investigated most and least effective approaches to ICT teacher training	Various primary teachers, secondary teachers, and librarians
Dickey, M. (2008). Integrating cognitive apprenticeship methods in a Web-based educational technology course for P-12 teacher education. <i>Computers and Education</i> , 51, 506-518.	Investigated the integration of a cognitive apprenticeship model (CAM) in a Web-based course; explored how the CAM impacted preservice teachers' learning processes of technology skills and technology integration methods for teaching	3 graduate and 39 undergraduate students from 11 different licensure programs
Doering, A., Hughes, J., & Huffman, D. (2003). Preservice teachers: Are we thinking with technology? <i>Journal of Research on Technology in Education</i> , 35, 342-361.	Studied how preservice teachers envisioned use of technology before and after the implementation of an innovative component of a teacher education program; explored participants' ability to identify content-specific uses for technology	10 preservice science teachers
Duran, M., Fossum, P., & Luera, G. (2007). Technology and pedagogical renewal: Conceptualizing technology integration into teacher preparation. <i>Computers in the Schools</i> , 23, 31-54.	Described and analyzed one model of teacher preparation called the Michigan Teachers' Technology Education Network or "MIT-TEN"	Collaborating teachers, student teachers, university faculty, instructional technologists, and others involved in the MITTEN program

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Overcoming the Tensions and Challenges of Technology Integration

Literature Reviewed Continued

Article Reference	Research Focus	Participants
Dutt-Doner, K., Allen, S., & Corcoran, D. (2006). Transforming student learning by preparing the next generation of teachers for type II technology integration. <i>Computers in the Schools</i> , 22(3), 63-75.	Studied how educators can effect change in schools to foster the use of technology to actively engage learners	Preservice teachers enrolled in a one year Masters program
Goodson, I. F. & Mangan, J. M. (1995) Subject cultures and the introduction of classroom computers. <i>British Educational Research Journal</i> , 21, 613-628.	Examined the effects of computer usage on the context of classroom teaching and learning, and on the structure and presentation of curricular materials; assessed some of the reciprocal effects of classroom computing and the context and culture of schooling	20 teachers working in two London-area high schools
Hennessy, S., Deane, R., & Ruthven, K. (2003). Pedagogical strategies for using ICT to support subject teacher and learning: An analysis across 15 case studies. Research Report No. 03/1, University of Cambridge, England.	Investigated teachers' and pupils' changing roles and strategies in the context of using various forms of computer-based information and communication technology (ICT) to support subject teaching and learning at the secondary level	15 secondary level teacher-researchers
Hennessy, S., Ruthven, K., & Brindley, S. (2005). Teacher perspectives on integrating ICT into subject teaching: Commitment, constraints, caution and change. <i>Journal of Curriculum Studies</i> , 37, 155-192.	Examined how secondary teachers of the core subjects of English, Mathematics and Science have begun to integrate information and communication technology (ICT) into mainstream classroom practice in English schools	18 focus groups consisting of faculty in the Mathematics, Science, and English departments of 6 different schools
Holland, P. (2001). Professional development in technology: Catalyst for school reform. <i>Journal of Technology and Teacher Education</i> , 9, 245-267.	Explored how the efforts in staff development in technology were supporting teachers in learning and using technology; explored whether emphasis on technology was causing changes on a school wide level	61 middle school teachers
Hughes, J. E., & Ooms, A. (2004). Content-focused technology inquiry groups: Preparing urban teachers to integrate technology to transform student learning. <i>Journal of Research on Technology in Education</i> , 36, 397-411.	Examined the process of establishing and sustaining content-focused technology inquiry groups	3 middle school humanities teachers, 1 music teacher, 1 middle school curriculum coordinator, 1 educational technology professor, 1 university doctoral student, 1 Masters student, 1 undergraduate student
Lawless, K., & Pellegrino, J. (2007). Professional development in integrating technology into teaching and learning: Knowns, unknowns, and ways to pursue better questions and answers. <i>Review of Educational Research</i> , 77, 575-614.	A literature review that focused on what is known and unknown about professional development to support the integration of technology into teaching and learning	21 articles / conference papers were reviewed representing a variety of participants
Mills, S., & Tinker, R. (2003). Be the technology: A developmental model for evaluating technology integration. <i>Journal of Research on Technology in Education</i> , 35, 382-401.	Studied and appraised the value of a technology professional development initiative that was created to support teachers in modeling technology use in classrooms, applying technology to problem solving and decision making, and applying technology to facilitate collaboration and cooperation among learners	70 K-12 teachers completed a survey at the start of the year; 78 K-12 teachers completed a survey at the end of the year; 46 K-12 teachers completed surveys at both the start and the end of the year; teachers were all in the same school district
Moos, D. C., & Azevedo, R. (2009). Learning with computer-based learning environments: A literature review of computer self-efficacy. <i>Review of Educational Research</i> , 79, pp. 576-600.	A literature review that examined factors related to computer self-efficacy and the relationship between computer self-efficacy, learning outcomes, and learning processes with computer based learning environments	33 articles were reviewed representing a variety of educational contexts
Mulqueen, W. (2001). Technology in the classroom: Lessons learned through professional development. <i>Education</i> , 122, 248-256.	Investigated changes made in the professional development of the Year-Two cohort of TIPS teachers; determined how changes compared to the Year-One cohort of teachers	114 middle school and high school teachers (10 teachers in Year-One, 104 teachers in Year-Two)

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Literature Reviewed Continued

Article Reference	Research Focus	Participants
Niess, M. L. (2005). Preparing teachers to teach science and mathematics with technology: Developing a technology pedagogical content knowledge. <i>Teaching and Teacher Education</i> , 21, 509-523.	Explored how teacher preparation programs guide preservice teachers' development of TPACK; introduced 5 case studies that described the difficulties and successes of student teachers teaching with technology in molding their TPACK	22 student teachers in a 1 year graduate level science and mathematics teacher preparation program
Parr, J. (1999). Extending educational computing: A case of extensive teacher development and support. <i>Journal of Research on Computing in Education</i> , 31, 280-291.	Described various steps taken by one school over more than 5 years to ensure teacher development and support to extend the use of educational technology	48 secondary (grades 8-12) classroom teachers who worked at a large fee-paying school
Ropp, M. (1999). Exploring individual characteristics associated with learning to use computers in pre-service teacher preparation. <i>Journal of Research on Computing in Education</i> , 31, 402-424.	Looked at the relationship among individual teacher characteristics that might change through experience and instruction in pre-service teacher education	53 preservice teachers participating in a semester-long course
Rosaen, C., Hobson, S., & Khan, G. (2003). Making connections: Collaborative approaches to preparing today's and tomorrow's teachers to use technology. <i>Journal of Technology and Teacher Education</i> , 11, 281-306.	Explored teacher candidates' interpretations of technology-related assignments and experiences, their engagement in them, and their self-reports of growth in technology skills and uses; studied collaborating teachers' (CTs) experiences in learning to use technology for professional and pedagogical uses	24 teacher candidates and 15 collaborating teachers (grades k-5)
Ross, T. W., & Wissman, J. (2001). Redesigning undergraduate technology instruction: One college of education's experience. <i>Journal of Technology and Teacher Education</i> , 9, 231-244.	Explored the development of an introductory education technology course and the challenges that prompted its redesign	381 undergraduate students enrolled in an educational instructional media course (Year 1 = 155; Year 2 = 226)
Seels, B., Campbell, S., & Talsma, V. (2003). Supporting excellence in technology through communities of learners. <i>ETR&D</i> , 51(1), p. 91-104.	Described three research studies that documented the importance of technology support people who have excellent interpersonal skills, experience with instruction and the flexibility to adjust strategies to adopter needs, skills, and personalities	Collaborative members included student teachers, faculty members, mentor teachers, school administrators, expert partners (exact numbers not given)
Zhao, Y., Pugh, K., Sheldon, S., & Byers, J. (2002). Conditions for classroom technology innovations. <i>Teachers College Record</i> , 104, 482-515.	Studied why teachers do not innovate when they are given computers; explored the conditions under which technology innovation can take place in classrooms and what facilitated or hindered teachers' uses of technology in their classrooms	118 teacher teams who were recipients of a statewide technology innovation grant were surveyed; more detailed emphasis placed on 10 case studies

Section 3

**Examining the Role of
Educational Technology and
Teacher Knowledge Research in
Guiding Individual, Classroom,
and School Instructional
Practice**

Chapter 7

TPACK Vernaculars in Social Studies Research

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ABSTRACT

To address the myriad effects that emerge from using technology in social studies, we introduce in this chapter the concept of vernaculars to represent local conditions and tendencies, which arise from using technology in social studies. The chapter includes three examples of TPACK vernaculars in social studies. The first explores a theoretical TPACK vernacular where Web 2.0 technologies support social studies and democratic life. The second example is focused on a three-part heuristic for seeking information about digital historical resources from the Library of Congress. Example three presents personalized vernacular TPACK developed by teachers planning to use an online gaming website called Whyville. Research and theorizing on vernacular forms of TPACK in social studies can aid teachers as they reflect on their own experiences teaching with technology.

INTRODUCTION

The unique democratic purposes of social studies demand forms of research that are focused and long-range in view. This condition is particularly important in research on technology and social studies, where the connections between content and technology are complex. While technology

offers much in terms of access to information and new tools to learn using this information, technology can divide people based on socio-economic status and, in some educational settings, may distract from democratic and authentic learning.

In view of social studies' central purpose as a set of courses designed to prepare young people for participation in democratic life, the usefulness of technology is much debated (Berson, Lee, & Stuckart, 2001). Some proponents argue that

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technology can support democratic purposes by addressing social problems, facilitating the political processes, and enabling access to information (O'Brien, 2008). At the same time, technology can distract from some of the humanistic and interpersonal aims of social studies, such as face-to-face dialogue and equal access to information (Tally, 2007).

Technological pedagogical content knowledge (originally TPACK, now known as TPACK, or technology, pedagogy, and content knowledge) is a helpful context for exploring the various contradictions and complexities related to how teachers use technology in their planning and teaching. Within the TPACK framework is a mechanism for articulating the decision-making processes that teachers engage in when determining how to use technology. TPACK is a complex and situated process that occurs within very local and particular contexts. In their seminal work on the TPACK conceptual framework, Mishra and Koehler (2006) argued that the complexity of TPACK emerges out of multiple contexts including the rapid rate of change in technology, the inappropriate design of software, and the situated nature of learning. Consequently, Mishra and Koehler (2006) suggested that, "quality teaching requires developing a nuanced understanding of the complex relationships between technology, content, and pedagogy, and using this understanding to develop appropriate, context-specific strategies and representations" (p. 1029). In addition to being complex, TPACK is particularistic. Mishra and Koehler (2006) have gone so far as to argue that there is "no single technological solution that applies for every teacher, every course, or every view of teaching" (p. 1029). Perhaps what is most difficult about operationalizing TPACK is that it attempts to capture the internal dialogue of the teacher. TPACK is a fluid form of teacher knowledge that is continually growing and changing based on new experiences. What works in one classroom, may not work in another.

To address the myriad effects that emerge from using technology in social studies, we introduce in this chapter the concept of vernaculars to represent local conditions and tendencies, which arise from using technology in social studies. We further explore specific TPACK vernaculars as they take form in planning and teaching social studies. In the next sections, we discuss the unique purposes of social studies and ways that TPACK vernaculars may emerge using examples from three situated research contexts. The first of these contexts is a theoretical consideration for how Web 2.0 technologies might support social studies aimed at democratic life. Two case studies are also presented as additional research contexts that attempt to unpack local conditions that emerge when pre-service social studies teachers plan to use technology in social studies.

Conceptual Framework

The Purposes of the Social Studies

Social studies includes content and disciplines that are incomplete, contradictory and changing. Social studies has no standing as an academic discipline, and instead relies on disciplines such as economics, geography, history, and political science for content and structure. As Cherryholmes (2006) has noted "one important consequence for social studies educators is that there is no one or set of undisputed, authoritative stories or theories or concepts or facts for social studies educators to adhere to and teach" (p. 6). Consequentially, social studies content instruction is often unique and hard to standardize as seen in the many failed or under-realized efforts to establish national standards for the field. Thornton (2005) argued that social studies content is particularly unique because it seeks to meet John Dewey's standard of relevance for life. As such, social studies is characterized by complex, overlapping disciplinary frames and rapidly evolving definitions and approaches to the field. Unlike other school

subjects social studies unites multiple disciplines into a common purpose aimed at the preparation of democratic citizens; democratic life is likewise filled with complexities and ambiguities.

Determining the proper relationship between technology and social studies is contingent on whether the technology meets the purposes of the field. Berson, Lee, and Stuckart (2001) referred to this as “technological agency.” They wrote, “The extent to which technology facilitates social studies practices is a measure of technological agency” (p. 210). They further delineated the purposes of the field to include “economic production, human interaction, democracy, and critical thinking” (p. 213). With regard to these purposes, the usefulness of technology in education is much debated (McKnight & Robinson, 2006). Despite the debate, researchers have been slow to weigh in. A long-standing critique of the field is the relative lack of research studies that could provide a better understanding of the impact of technology on student outcomes (Friedman & Hicks, 2006). In their comprehensive review of the research on social studies and technology, Swan and Hofer (2008) reiterate this claim characterizing research on technology and social studies as continuing to be in what Berson and Balyta (2004) called an adolescent stage.

TPACK Framework

TPACK has gained the attention of social studies researchers because it provides a research framework for examining the outcomes of technology integration. The theory of TPACK emerged as a way to articulate the interplay of technology, pedagogy, and academic content in dynamic and productive contexts (Mishra & Koehler,

2008). Technological pedagogical content knowledge reflects Shulman’s (1986) notion that pedagogical content knowledge develops as teachers transform their knowledge of academic content for pedagogical purposes. TPACK extends

this idea by introducing technology as a dynamic component in this transformative process.

We have suggested elsewhere that social studies teachers might approach the TPACK process by engaging subject matter that is “inherently technological” and by “improving” subject matter given technological adaptations (Lee, 2008, p. 130). Continuing the idea of “technological agency,” TPACK can be observed as the enactment of teachers’ pedagogical aims (Hammond & Manfra, 2009). For instance when teachers are:

1. locating and adapting digital resources for use in the classroom,
2. facilitating their students’ work in non-linear environments by requiring students to make critical decisions about how to select their own resources and navigate through a wide variety of interfaces,
3. working to develop critical media literacy skills among their students,
4. providing students with opportunities to utilize the presentational capabilities of the Web,
5. using the Internet to extend collaboration and communication among students,
6. extending and promoting active and authentic forms of human interaction in technology enabled social networks,
7. making use of historical source materials available through online sources,
8. promoting understandings of spatial, human, and physical systems as aided by technology,
9. expanding social experiences using technology, and
10. encouraging economic literacy through the use of technology. (Lee, 2008, p. 130-131)

These pedagogical strategies provide examples of the possible combinations of technology, pedagogy, and content knowledge in the social studies classroom. Driving these strategies is a commitment to fulfilling the purposes of social studies.

These ten pedagogical stances might be thought of as TPACK vernaculars, which, much like architectural vernaculars, include locally available resources that reflect environmental contexts. Rather than treat TPACK as a fixed phenomena, we highlight TPACK as particularistic and context-dependent. It resides in the “lived” curriculum (Grumet, 1981) or the “enacted curriculum” of the classroom (Eisner, 2003). TPACK is a dynamic process that is influenced by student perceptions and student agency (Hammond & Manfra, 2009a). In a case study of a teacher’s use of moviemaking software in a social studies class, Hofer and Swan (2008-2009) reiterated these dynamic conditions arguing that:

We need to recognize the complexity and multi layered challenge of designing and implementing any type of technology project in the classroom that represents a departure from or extension of a teacher’s comfort level. It is important to note that TPACK is a moving target. Each teacher has her own knowledge base in terms of content, pedagogy, and technology. TPACK even varies with a given teacher in different situations. (p. 196)

Reflecting on TPACK vernaculars provides social studies educators and researchers with a new approach to understanding the complex nature of technology integration. Brush and Saye (2009) have likewise focused on the complexities of technology use in social studies when examining local and particular examples of TPACK. In particular, Brush and Saye (2009) argue for “best experiences that allow [teachers] to engage a multitude of variables within authentic learning contexts” (p. 47).

What follows are three examples of TPACK vernaculars in social studies. The first explores a theoretical TPACK vernacular where Web 2.0 technologies support social studies and democratic life. The other two examples describe the experiences of pre-service teachers as they constructed

personalized vernacular TPACK in using specific technologies to plan for social studies instruction.

TPACK Vernaculars

Social Studies, Web 2.0, and Democracy: An Emerging TPACK Vernacular

One of the unique characteristics of social studies is that it enables experiences that both reflect and represent democratic life. In much the same way, new Web 2.0 technologies may also enable experiences that reflect and represent democratic life. The similarity between the nature of social studies and the functions of these new technologies provides a rationale to make deliberate use of Web 2.0 in social studies. Examples of how Web 2.0 technologies support democratic life are vernacular or local in origin and reflect specific conditions in democratic culture and specific aims in social studies.

Social studies provides students an opportunity to investigate the history and structure of democracy as well as the rights and responsibilities of civic life in a democracy (Stern & Riley, 2001). John Dewey and Goodwin Watson (1937) described social studies as a field of study that helps break down the artificiality of academia by connecting schooling to life and social activity. For Dewey, such activity involved actions suited for the practical life of students as they mature into adulthood. With regard to social democratic life, Dewey (1927) argued that life is associative and constructive and that life involves continual change. Life in a democracy according to Dewey requires citizens to deliberate and reflect in a communal arena where barriers to participation are minimal and individuals act in practical and meaningful ways to improve their own life and contribute to the progress of humanity.

For social studies to help prepare students for democratic life, schools should reproduce, replicate, and even nurture democratic structures that

exist in society. However, public schools have struggled to create authentic and fair democratic classrooms and experiences for students (Kesson & Ross, 2004). One of the most important limitations of social studies and democracy in practice is the failure of teachers to situate social studies experiences in authentic contexts. This lack of authentic learning results in a “drudgery” of social studies - students listening to a teacher speak about content and reading unimaginative texts with little or no connection to an outside world (Doolittle & Hicks, 2003).

Emerging Web 2.0 technologies can lessen the drudgery of social studies and authentically represent democratic society in students’ school experiences. Using emerging web-based communicative and collaborative technologies, students can interact with others on a playing-field that does not prioritize cultural status or previous accomplishments (Gilbert & Driscoll, 2002). Such a level playing-field is democratic and enabling. Collaborative tools support interaction among people across space with little regard for the structures or inequalities that often separate people. Social studies educators can also use Web 2.0 technology tools to encourage critical and active learning. Social studies teachers have long struggled to reproduce such environments in schools as they exist in society. Web 2.0 technologies enable the development of experiences for students that can authentically represent American society in ways that are relevant to students’ lived experiences.

Students can use Web 2.0 applications to manipulate data, produce reports, and create knowledge in concert with others. By becoming producers of knowledge, rather than mere consumers, new technologies help shift the balance of authority with regard to who gets to verify knowledge as “truth.” Perhaps no better example exists than Wikipedia. As a collective effort to represent knowledge, Wikipedia embodies democratic tendencies that de-center old authorities and enable contributors at all levels.

The de-centering of old authorities is significant when considering teacher TPACK. Web 2.0 technologies lead to new roles for teachers in the classroom. Rather than delivering knowledge, teachers shift to knowledge facilitators. This change reduces teacher control and the likelihood that the planned curriculum will match the enacted curriculum. By distributing knowledge, students become students not just of the teacher but of each other. Teacher TPACK must take into account the particular nature of student learning in such a setting to select disciplinary content knowledge from life experiences and pedagogically repackage it to support democratic experiences for students.

This shift is a complex undertaking for social studies teachers given the traditional disciplinary structures that make up the field. Most social studies teachers understand the structures of the academic disciplines that make up the social studies such as economics, geography, history, and political science but it is more difficult for teachers to conceive of democracy in the social studies classroom. Furthermore, some teachers may find difficulty utilizing Web 2.0 technologies to encourage democratic experiences given the traditional academic status of social studies.

One way of connecting the democratic tendencies of social studies and Web 2.0 technologies is to expand the political meaning of democracy to encompass a democratic ideal or what John Dewey called a democratic way of life. Dewey (1927) argued that democratic life is associative and constructive and requires an attitude conducive to continual change. Dewey viewed life in a democracy as deliberate, reflective and as unfolding in communities with minimal barriers to participation. In these social settings, individuals act in practical and meaningful ways to improve their own life and contribute to the progress of the community. Conceived similarly, social studies can become an endeavor that helps students improve the human condition; building upon the democratic premise of the social studies, as

preparation for civic life in a democracy (National Council for the Social Studies, 1994).

Web 2.0 technologies can improve and enliven this process and promote the civic goals of education in a democratic society by facilitating authentic experiences that encourage critical and active student learning. Citizenship in a democracy implies critical thought, and critical thought requires information (Parker, 1991). In order to function effectively, democracies must cultivate and protect a variety of information sources. Without the protection and, in fact, a public visibility of plural ways of thinking, democracy is stifled. Web 2.0 technologies facilitate a wide range of voices to be heard and valued. TPACK emerges as teachers negotiate the use of Web 2.0 technologies in their teaching to facilitate these democratic and plural aims. In this context, TPACK is best understood as a vernacular or a local phenomenon that is responsive to the larger aims of the field of social studies, such as furthering democracy and pluralism.

In the next section, we provide the example from a study documenting the development of a vernacular TPACK among a group of pre-service teacher education students. This account of TPACK among pre-service teachers highlights the complexities of researching TPACK. The description of preliminary findings also highlights the transactional nature of TPACK by demonstrating how teacher participants exchanged considerations about technology, pedagogy, and content while struggling with a task related to enhancing their understanding of history content and pedagogy.

Information Seeking as a Vernacular TPACK

As the amount of information available online has in recent years exploded, finding useful information has become increasingly complicated. Google's effort to digitize printed books is a good example. By Google estimates there are over 130

million unique books in print today. As of August 2010, Google Books had digitized well over 10 million of these books. While that represents less than 10% of all books available in print, the fact that all 10 million books are available through a single web site requires new ways of thinking. The ability to access such large quantities of information requires new skills and dispositions that position students as critical users of online information (Coiro, Knobel, Lankshear, & Leu, 2007). The issue is most often not about availability but about accessibility. This dilemma of access informs the case presented here, which was an examination of how social studies pre-service teachers accessed and used historical resources from an online resource called American Memory.

The idea that information users need to be active and critical, emerged early in the research on information seeking. In fact, active engagement is central to current media literacy theory. The Center for Media Literacy's "MediaLit Kit" (CML) exemplifies this approach by focusing on John Culpin's original idea of "media literacy." The CML media literacy framework calls for students to access, analyze, evaluate and create media messages directed at empowering young people as global democratic citizens (CML, 2002). Within the framework of media literacy, various researchers have proposed theories and models to explain information-seeking activities. Ellis, (1989) proposed an early model for information seeking activities as including the following elements: starting, chaining, browsing, differentiating, monitoring, and extracting. Ellis' studies pre-date the Web, but provide a helpful heuristic for understanding how people locate information in digital and non-digital environments. Catledge and Pitkow (1995) conducted one of the earliest web-related studies and identified three prototypical web-based information users; the serendipitous browsers, the general purpose browser, and the searcher. More complex models such as Wilson's (1999) cycle of information activities, which involves intervening variables

that influence and activate information seeking behavior, have also been proposed to explain the way people seek and use information online. Despite these useful models, researchers have found that most information searches are initiated in common sense fashion and the problems that emerge are mostly procedural (Kuiper, Volman, & Terwel, 2005). For example, Nahl and Harada (2004) found that subject matter background knowledge informs information users' abilities to conduct productive searches for information. More recently, research from scholars in the new literacies has explored how students and teachers access and use information online (Leu, Coiro, Castek, Hartman, Henry, & Reinking, 2008). This online context contributes to a new learning ecology that repositions students and teachers and situates information as easily accessible through web-based technologies (Baron, 2004; Spires, Wiebe, Young, Hollebrands, & Lee, 2009).

In social studies, a limited body of research exists on the strategies used to find information. Delgadillo and Lynch (1999) studied information retrieval habits among college students in a history research seminar and found that students used specific strategies including tracing references, using bibliographies, using catalogs, and talking with experts. Fescemyer (2000) studied information seeking among college students in a geography class and found they used a wide variety of online and offline sources for class project work, which reflected a critical awareness while at the same time employing a strategy of least resistance to information retrieval. In a study of middle school students who were seeking information for a research project, Milson (2005) found that these younger students also followed a "path of least resistance" when searching for information. The student participants in Milson's (2005) study initially used search engines such as Ask Jeeves in an effort to quickly and easily locate information related to their research topic. After problems and frustrations related to the students' inability to find information, the teacher introduced a series

of metacognitive and metastrategic techniques to facilitate student participants' information seeking. Milson (2005) suggested that the teacher in his study was able to transfer her own knowledge and skills to students in an effort to help them develop new skills. Research on the strategies that teachers use to find information is limited, but suggests that they use expert knowledge to make decisions about what information to use in teaching (see Aideen, Stronge, Rogers, & Fisk, 2006).

In this study, we worked with pre-service teachers as they located materials in an online collection of historical resources called American Memory for the purpose of planning instruction. Data were collected on pre-service teachers' interactions with American Memory resources through 1) participants' written instructional plans, 2) observations of in-class discussions and email communication about participants' work, and 3) meta-cognitive writing about the processes participants undertook as they developed instructional plans. American Memory is a project of United States Library of Congress. American Memory has over 9 million individual documents in over 100 collections. Each collection includes four components, a framework, access aids, reproductions, and supplementary programs. One example of an American Memory project is a collection of ex-slave interviews and narratives from the Works Project Authority (WPA). This searchable collection includes 2,900 documents from over 300 WPA writers in 24 states. The documents were written in a variety of styles including narratives, interview transcripts, and case histories. Individual documents run between 2,000-15,000 words in length (including drafts and revisions) and include information on family income, occupation, political views, religion and mores, medical needs, diet and miscellaneous observations.

The participants (N=84) were pre-service social studies teacher education students in four separate graduate level social studies courses, taught over four consecutive years. The courses were the second of two methods courses in a

graduate teacher education program. Participants used digital historical resources from American Memory (AM) to conduct historical inquiries. Following this subject matter research, participants wrote instructional ideas which utilized the same AM resources. As a final exercise, participants constructed a reflective essay describing the way they used the AM resources. The courses in which the participants produced their work involved a significant emphasis on digital historical resources, including instruction in the historical methodology and the instructional use of historical resources. All of the participants had an undergraduate degree in history or a related social studies subject area. The distribution of male and female students was even (46% women, 54% men).

The data were analyzed in the framework of TPACK and findings emerged as vernacular strategies for locating American Memory resources, which teachers then used for planning instruction as opposed to general search strategies or the initial retrieval of information. The analysis of all data revealed a unique three-step process of engagement with AM resources that reflected the way participants located and used subject specific historical resources for constructing instructional ideas. These engagements were nested within each other with the first strategy focused on determining whether a specific resource would be subjected to the second and third strategies. What follows is an overview of these engagements given broadly stated themes from the data.

First Engagement: Establishing a Context

The first strategy participants used was to engage resources in order to develop a context for using a given resource. These contexts were built from curricular and secondary source-derived subject matter knowledge. Participants differed significantly with regard to their depth of knowledge and thus possessed varied abilities to contextualize resources. Contextualization, as described by Wineburg (1991), involves understanding historical events in temporal and spatial contexts. His-

torians understand historical events as “situate[d] events in concrete spaces” (Wineburg, 1991, p. 80). As participants engaged the American Memory collections they encountered historical resources that were for the most part de-contextualized. Effective use of these AM resources required that participants understood the value of a given resource from a historical or historiographical perspective. This situated knowledge informed the decision-making processes in which participants engaged with regard to whether they planned to use the resource in their instructional planning. If participants were able to successfully construct a context for engaging the resource, a second strategy emerged relating to how the resource might be used.

Second Engagement: Delimiting Resources

The second strategy employed by participants involved the personal delimitation of specific resources given its empirical characteristics. Delimitation involved a vetting, after a resource was located and contextualized, to determine the resource’s value given participant-sensitive characteristics such as length, reproductive quality, complexity, relevance, and consistent accessibility. When delimiting resources, participants were making decisions about whether they were able to use the resource in their own learning. The delimiting process resulted in the acceptance or rejection of specific resources. For example, if participants thought they did not have enough time to read a resource or if they thought the resource was poorly organized, they were very likely to stop any serious engagement with it. Participants used descriptive text and organizational information that framed the presentation of resources within American Memory collections as a source for making their delimitations. All of the American Memory collections include document lists and in most cases narratives about the collection and even summaries of individual resources. Participants, in part, used this information to make their decisions about whether to engage the resource. A

decision to use the resource meant that participants would engage the resource at an even deeper level resulting in a third strategy for finding and using the resources.

Third Engagement: Pedagogical Elaboration

The third strategy involved the pedagogical elaboration of the resource. In this process, pre-service teacher participants began to think about how the resource might be adapted and tailored for specific student use. This process drew on participants' preexisting and developing expectations about the learners for whom they were preparing the lesson. When elaborating the resources, participants were beginning to think about how a lesson would take form given their expectations for the amount of time they might spend on the lesson, the subject matter curriculum restraints on the topic, and their general ideas about student access to the resources. All of these considerations relate to what Shulman (1986) has described as a process of pedagogical reasoning. The elaboration process began when participants pedagogically engaged the resources. This engagement related directly to whether the participants planned to actually use the resources in their instructional plan.

The next section describes a case of teachers exploring the instructional value of an online gaming resource called Whyville.com. In this case, a third vernacular of TPACK emerges as teachers make transactions regarding the very specific affordances and limitations for using the Whyville online resource.

Whyville: A Case in Transactional Vernacular TPACK

Whyville is an online gaming environment that enables children and young teens to interact in virtual social settings and play toward a variety of educational goals. As a game environment, Whyville has considerable educational intent. By design, the online world exists to both encourage gameplay and learning in academic content areas.

Whyville is a free site that is sponsored by private and public organizations such as NASA, Disney, U.S. Center for Disease Control, and Toyota. The website is designed for learners at multiple levels and is focused around a range of interdisciplinary topics. The Whyville website describes these activities as follows;

Inside Whyville, citizens learn about art history, science, journalism, civics, economics, and really so, so much more. Whyville works directly with the Getty, NASA, the School Nutrition Association, and Woods Hole Oceanographic Institution (to name just a few) to bring incredible educational content to kids in an incredibly engaging manner.

Whyville was launched in 1999 by James Bower and fellow scientists at California Technical Institute in an effort to apply research on education and cooperative learning, particularly in science, using new web-based tools to support that learning. In 2006, the parent company of Whyville, Numedee Inc., secured private funding and began to more aggressively engage in commercial activities including advertising on the site. Even with this advertising, Whyville maintains a close focus on learning or what they term edutainment. Whyville claims one million users mostly between the ages of 8 and 15. The company has forged relationships with a wide range of organizations including science-based groups, schools and colleges, including colleges of education.

Much of the educational emphasis to date in Whyville has been focused on learning in science. Simons and Clark (2004) investigated Whyville along with four other environments in terms of how they sustain scientific inquiry. The authors argued that the Whyville website supports data-drive scientific work in "the way that scientist use computers: for (a) data collection, (b) scientific communication, (c) simulation and modeling, and (d) scientific communication" (Simons and Clark, 2004, p.29). However, Whyville also includes

content that reflects social and cultural norms and experiences. This content has relevance in the social studies.

Whyville as a Social Studies Learning Environment: Content and Pedagogy

In this study, pre-service teachers were asked to describe potential educational uses of Whyville in social studies middle grades settings. The study included 23 participants who were in the fourth year of an undergraduate teacher education program. Participants were asked to visit Whyville.com, create an identity, and explore at least one area that they identified as relevant for middle grades social studies. All 23 participants completed a focused reflection of the Whyville site and recorded their impressions of how children might have social studies experiences on the site. In addition, focused semi-structured interviews were conducted with three participants, directed at a deeper examination of how Whyville might be used in middle grades classrooms.

Ideas for using Whyville ranged across a diverse body of content and reflected an even more diverse range of instructional ideas. In general, participants' ideas were student-centered and focused on content as that content directly appeared on the Whyville site. Participants creatively applied their readings of this Whyville content given personal interests and background knowledge. One participant, Ann (pseudonym) exemplified this approach with her thinking about a Whyville resource called Alien Rescue. In this game, Whyville citizens try to help an alien find their lost friend. The game begins with player (a Whyville citizen) receiving a message regarding the lost alien. Ann recorded the following message as she received it when she played the Alien Rescue game.

The date today is May 27. Yesterday, the Sun rose at 5:53 am and set at 5:55 pm. I'm told that the day is close to 12 hours long here all year round. There is a scary creature looking at me from a

waterhole close by. I think it's called a crocodile. Come and get me quick!

As the game proceeds, Alien Rescue game players must select a time and place in the world based on the clue. After making a selection, players are given information about how close they are to the lost alien with regard to time and location. The game continues until the alien has been located. As Ann played the game she thought deliberately about how she could make use of it in her teaching. She chose to describe her experiences with the Alien game in the content context of seasons. Ann talked in general terms about how she might teach with this game.

I really liked...the alien game...I could teach about the seasons and the sun, and climate. The students could all meet at Whyville and play the alien game at a designated time. The difference is that after they played the alien game, they would write why they chose the city that they chose as the possible place to rescue the alien. Then the next day in class they would hand back their reasons for their choices to me.

Another participant, Sheryl (pseudonym), also focused on the Alien Rescue game and described her initial experiences with the game as full of educational potential.

My favorite activity that I stumbled upon in Whyville was the Alien Rescue game...I had to recall my knowledge about the longest day of the year to what day my alien was on in one mission, and had to figure out what language a word was in to figure out where the alien was in another. This would be an interesting game for students to play when they are studying earth's rotation around the sun and have a competition within teams to see who could figure out clues the fastest.

Both of Ann and Sheryl engaged their content knowledge (e. g. seasons; longest day of the year)

when they initially considered pedagogy (e.g. students could meet at Whyville and play the alien game; they would write down why they chose the city; a competition within teams to see who could figure out clues the fastest). Ann's broad understanding of seasons coupled with a pedagogical focus on individual written work might have reflected a belief that the content idea of seasons is best represented in written form. In contrast, Sheryl talked about the status of her own knowledge and framed her pedagogy as a competition. These two approaches – recognition of personal understandings of content and comparisons with other people's knowledge - represented forms of a vernacular TPACK.

A second area of content that caught the attention of participants related to health and nutrition. Several participants specifically talked about content and pedagogy related to health and nutrition. One participant, Emma (pseudonym), describe a health and nutrition related game called "Whyeat."

I seemed to have a really hard time with this challenge! My diet had either too much fat or too much fiber!...I believe [Whyeat] has curricular relevance because it would be great to integrate healthy living when studying nutrition in science, reading about mal-nutrition of people in of people in countries being studied in social studies, and calculating calories, grams, etc. in math.

Emma situated her talk about the Whyeat game in her understanding of content given what she anticipated with regard to curriculum. Another participant named Sydney (pseudonym) talked about how the positive attributes of other nutrition-related activities in Whyville. She described one activity focused on diet as "cool" and "a great way to look at nutrition." She was particularly interested in the activities with regard to fiber as a dietary supplement. Sydney extended her thoughts about the game to focus on learners saying "many students don't know what things are starches and fibers." Like Emma, Sydney

had some initial thoughts about how to use this resource with her students.

[Using the game] could lead to a discussion of needs vs. wants. The students could look at indigenous populations and make menus for that population. If the students wanted to, this could lead to a food drive, in which the students ask for those food items that would be needed by those populations.

All of these ideas about content and pedagogy emerged from participants thinking about the Whyville site without close attention to the technology supporting Whyville. The next section of findings describes how participants planned through the complexities of the Whyville technology given their specific understandings of content and their emerging pedagogical understandings.

Transactional TPACK and Whyville

Given the way participants understood Whyville content, how did participants' TPACK take shape? The answer to this question takes form as another vernacular TPACK. The data suggested that participants made personalized and deliberate transactional exchanges as they negotiated the technology and concurrently thought about content and pedagogy.

Returning to the example of the Alien Rescue game, we can see how participants thought about the technology as a factor in their content and pedagogical thinking. Ann, who had planned to have students write about their experiences playing the Alien Rescue game had trouble herself actually completing the game. She explained these difficulties.

It took me around 10 guesses before I finally figured out where that alien was. The only thing was that I could not figure out how to win the game. The site said I had found the alien and that I could pick him up after sunset. I waited a while, thinking that the sun would set and I could pick

him up, but it never did. Since I never did pick my first alien from out of Africa, I could not move on to my other aliens and rescue them. I just started another game, because the alien game was getting too complicated for me.

Given her difficulties with completing the game, Ann did not want to have students focused on playing the game toward completion. Instead, she deemphasized the competitive aspects of the game and suggested that students play at home. She wanted students to keep a record of their play and “write why they would chose the city they chose as the possible place to rescue the alien.” She then wanted their experiences to serve as background and context for a class discussion on “the seasons, sun and climate.”

In contrast to Ann, another participant, Robert (pseudonym), envisioned a deeper engagement by students with the Alien Rescue game. He viewed the technology as less limiting and in fact helpful. As he put it, “one of the games that I found most useful, academically, was the Alien Rescue game.” He argued that the game was easy to play and included a supportive, although limited structure for learners. He pointed out “the game does indicate to the participant when one of the two is correct, and let’s that person keep guessing until both the location and time have been answered correctly.” With regard to limitations, Robert only noted that “the Alien game only has twelve levels, or twelve different questions, so a teacher can’t refer to it while focusing on any one part of the world.” Robert valued the game with regard to how it might provide a direct experience for students to learn about absolute location, time and seasons. Robert did not have any technical problems completing the game, so the transactions he made in determining the worth of the game were more positive than Ann, who had significant technical problems. As a result of the transactions she made regarding the technical procedures needed to play the game, Ann envisioned a more limited role for the technology in her pedagogical thinking.

Another participant named Maya (pseudonym) had similar limited expectations for the technology, expressing more serious reservations about the extent to which Whyville could be used in middle school. Maya couched her consideration of Whyville technology in previous experiences using technology. “I am a not a stranger to gaming environments like this one. I have had a Neopet account since 2000 and have managed to follow it through all their changes, but did not care for how Whyville works.” Maya was concerned with what she viewed as distracting graphics and disorienting navigation. As she put it “I found myself having to backtrack to directions a lot.” Maya also expressed concern that the technology would actually distract from her pedagogical goals.” I know how easily a kid can get ‘sucked into’ a virtual world, and I worry that whatever lesson I chose would quickly take a back seat to earning clams to buy facial features.” Maya’s approach to teaching using the technology and content was vastly different from Ann and Robert. One idea she had was to use the site as a context for other work. “I think if I was going to use this site to teach social studies I might look at it from the perspective of creating my own ‘ville’.” In terms of using specific content from Whyville, Maya was very guarded in her talk. “If I had to use a specific location in the site as an inspiration for a social studies lesson, I would probably connect the lesson to the Trading Post/War Wagon as that incorporates geography and archeology.” Maya’s lack of interest in the Whyville environment resulted in a sort of transactional thinking about the Whyville technology that limited applications of content in her pedagogy. She offered no specifics for how the technology would support any specific content related learning objectives.

The participants who talked about health and nutrition likewise engaged in a range of transactional thinking regarding the Whyville technology. Emma talked extensively about the applications of Whyeat in middle grades. For her, the technology integrated in a seamless manner. Emma

made several specific mentions of the Whyville technology, and always with regard to how the technology supports student learning. “Aesthetically, Whyville is quite pleasing to the eye, using bright colors, and well organized, allowing users to find material and destinations successfully and efficiently.” She specifically mentioned Whyville user controls with regard to material on health and nutrition.

The Cafeteria destinations allow avatars to go to the Whyeat market, Grill, and even make reservations for a meal. An arrow directs avatars to the nutrition center which then opens in a web page that allows the individual to ‘mingle’ and chat with others in the nutrition [center], but also to be able to talk with a dietitian.

Emma planned for several different uses of these health and nutrition materials. Her comfort with the technology seemed to enable Emma to think broadly with regard to pedagogy. This open transactional mindset resulted in Emma focusing on very specific uses of the technology. Emma talked about having students journal about their experiences in Whyville, monitor their eating habits through the website, learn about current events related to health, and do comparative studies relating to global health.

In contrast to Emma, another participant named Tabitha (pseudonym) expressed deep reservations about the value of Whyville. More than any other participant, Tabitha rejected the technology of Whyville and consequentially, in her transactional thinking, limited the role of technology as she reflected on content and pedagogy. As she put it, “After creating an account at Whyville.com, I am yet to find anything remotely educational.” She was particularly frustrated by the technology. While deliberately looking for educational activities on the site she said, “I think there is something I am missing or not seeing. I have clicked every single page from the home page and all I get is

chat rooms and places I can change my face...I am very tech-savvy and this is frustrating me to no ends.”

Pedagogical ideas suggested by participants related to civic life also reflected personalized transactional thinking by participants about technology, content and pedagogy. One participant named Wanda (pseudonym) who provided very little depth with regard to content and pedagogical ideas in her talk about Whyville described the difficulty she was having with the Whyville technology. “I found the site not very user friendly...my technology challenge is definitely getting in my way of playing at this site.” Wanda did mention that she visited City Hall and read “some of the petitions and ideas for change within the community,” but she did not provide any ideas about how students might use the site to promote civic knowledge. Although she expressed interest in the Whyville City Hall because “participants could see [what] it might be like to try to make change within a government and even pretend government,” Wanda did not think she could use the site for instructional purposes. As she put it “I do not know that I would instruct my students using [Whyville] because I had so much trouble with the site.” Another participant, Barbara (pseudonym) had similar concerns and a similarly shallow level of transactional thinking with regard to civics content. Barbara expressed a concern with the technology saying, I did experience difficulties in Whyville. I am not sure if it was my computer or the operator (myself) that could not get around Whyville successfully.” She also thought the site might not appeal to middle school students because she thought Whyville appeared “childish.” Barbara did offer some interests in civic related pedagogy saying, “I do think Whyville has some curricular relevance, particularly visiting City Hall,” but she did not offer any pedagogical thinking about what those visits might entail or what content students might engage.

DISCUSSION

In each of the three accounts, related to Web 2.0, information seeking and online gaming, specific or vernacular instances of TPACK emerged. In our theorized example of how collaborative Web 2.0 technologies can be used to support teaching and learning aimed at democratic life, unique forms of TPACK emerge that have characteristics situated tightly within the contexts of lived democratic experiences. Such a TPACK vernacular reflects immediate and local needs and technological resources. For example, a teacher may wish to situate an activity on the Bill of Rights in the context of a local example of free speech or expression. Ten years ago, media technologies such as television and print media would have been the best source for teachers; today social media technologies such as Twitter or Facebook may be more useful. The details of each activity arise out of local concerns and dictate how the activity is developed and implemented by the teacher. Ultimately, teachers must be familiar with the technologies that support and facilitate democratic life if they are to prepare their students for active participation in democratic society.

In much the same way, information seeking is idiosyncratic and teachers apply their own unique ways of working with technology. The three information processes that emerged in our second account of a vernacular TPACK were nested within one another and were mostly sequentially dependent. If teachers did not have the prior content knowledge or were otherwise unable to develop a contextualized understanding of a particular resource that they encountered, they typically would stop any serious engagement with the resource. If the participants' were able to continue their engagement, they began a two-step process of determining the personal costs associated with using the resource (delimiting) and determining the pedagogical worth of the resource (elaborating). The delimiting process emerged as participants considered limitations associated with their own

prior knowledge and the general quality of the resource. If the resource was considered generally unusable due to length, text, quality of the reproduction, or any other technical limitation, participants were likely to disregard it. These delimiting actions were linked to the participants' abilities or inabilities to engage the resources. If the participants' felt comfortable enough with the resource to continue, they began to consider its pedagogical characteristics, subjecting the resource to various learner-centered elaborations.

In our third example, teachers engaged various forms of transactional thinking to make decisions about the relative pedagogical worth of Whyville.com resources. The resulting vernacular TPACK among teachers was also idiosyncratic and highly personalized. Many participants talked about incorporating Whyville technology in a seamless manner as they thought about content and pedagogy. These participants generally did not view Whyville technology as burdensome or difficult to use. The ideas these participants had about using Whyville emerged as a result of a transactional exchange between participants' views about the technology and their content and pedagogical knowledge. Other participants were less likely to engage content and pedagogy. They judged Whyville as technologically inadequate and thus not worthy of their pedagogical attention. A third group of participants seemed to accept the technology without any transactional considerations. These participants talked about using Whyville without consideration for the relevant content or pedagogical outcomes.

Technological pedagogical content knowledge developed as a theoretical framework for articulating teachers' pedagogical thinking to the integration of technology in teaching. As TPACK theory has further developed and been applied, unique characteristic have emerged. Cox and Graham (2009) described some of these conditions in their conceptual analysis of TPACK. Specifically, they described TPACK as involving "a teacher's knowledge of how to coordinate the use of subject-

specific activities (AS) or topic-specific activities (AT) with topic-specific representations (RT) using emerging technologies to facilitate student learning” (p. 64). We would suggest that these categories be expanded to a collection of vernaculars that can represent the local considerations of the technological resources and applications that are being used. Research and theorizing on vernacular forms of TPACK in social studies can aid teachers as they reflect on their own experiences teaching with technology. Such scholarship can also help teacher educators deepen their knowledge about how TPACK emerges in an effort to guide the development of pre-service teacher-knowledge.

The ideas presented in this chapter challenge the artificial divisions sometimes established between subject matter and pedagogy as well as between technology and subject matter. In the three accounts of vernacular TPACK presented here, subject matter and pedagogy were found to be interdependent as were subject matter and the technological affordances of the specific resources. These accounts present TPACK as an active and dynamic body of knowledge that emerges in authentic and meaningful contexts. Additional, nuanced descriptions of TPACK in practice will aid in the continued development of our knowledge about how technology can promote meaningful democratic social studies.

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Chapter 8

Principles of Effective Pedagogy within the Context of Connected Classroom Technology: Implications for Teacher Knowledge

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ABSTRACT

Classroom Connectivity Technology (CCT) can serve as a tool for creating contexts in which students engage in mathematical thinking leading to understanding. We theorize four principles of effective mathematics instruction incorporating CCT based on examination of teachers' use of CCT within their Algebra I classrooms across four years. Effective implementation of CCT is dependent upon (1) the creation and implementation of mathematical tasks that support examination of patterns leading to generalizations and conceptual development; (2) classroom interactions that focus mathematical thinking within students and the collective class; (3) formative assessment leading to teachers' and students' increased knowledge of students' present understandings; and (4) sustained engagement in mathematical thinking. Each of these principles is discussed in term of its implications for teacher knowledge.

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BACKGROUND

Mathematics classrooms are complex systems co-constructed by teachers and students as they negotiate norms for participation (Bowers, Cobb, & McClain, 1999; Cobb, Boufi, McClain, & Whitenack, 1997). The norms and resulting interactions are the basis for students' construction of what it means to learn mathematics, to act competently, and to engage in mathematical thinking in general and, more specifically, within the mathematics classroom in which they are presently learning (Gresalfi, Martin, Hand, & Greeno, 2009; Hiebert et al., 2005; Turner et al., 1998). Further, the quality and locus of thinking established within the mathematics classroom ultimately determines students' understandings. From a situated/sociocultural perspective, learning is the "relationship between an individual with a body and mind and an environment in which the individual thinks, feels, acts, and interacts" (Gee, 2008, p. 81). Gee theorized about opportunity to learn in terms of the learner's capacity (or, in Gee's terms, effectivities) to interact with the affordances of a classroom environment.

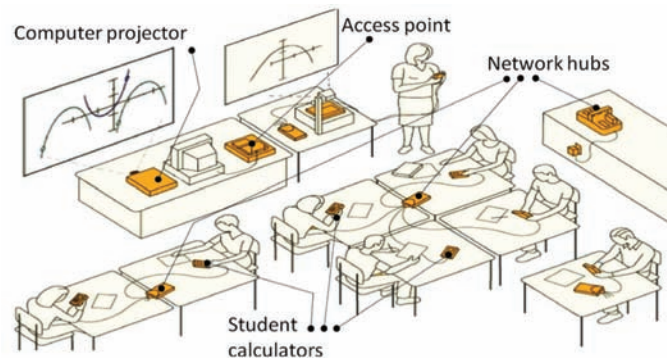
While the classroom context is co-constructed jointly by the teacher and students, the teacher's role is particularly important and influential. Teachers shape students' mathematical thinking through the tasks they provide, norms they set, classroom discourse they lead, feedback they provide, and levels of engagement they establish. Broad considerations in terms of such contexts include the nature of and sequencing of tasks (Hiebert & Wearne, 1993), establishment of an inquiry microculture (i.e., enculturation into ways of knowing in mathematics; Cobb et al., 1997), the nature of classroom interactions (Cobb et al., 1997; Patrick, Anderman, Ryan, Edelin, & Midgley, 2001), formative assessment and provision of feedback (Bell & Cowie, 2001; Shute, 2008), and creation of "contexts for involvement" (Turner et al., 1998).

Learning with understanding is an important goal of school mathematics and is predicated on deep examination of mathematical concepts and processes. While memorization of mathematical facts is critical for the development of expertise (Chi, Feltovich, & Glaser, 1981), understanding depends upon raising prior conceptions to a level of consciousness and deeply analyzing new knowledge in terms of these prior understandings (Bransford, Brown, & Cocking, 1999). Whether an individual learner can engage with the environment to gain new knowledge is contingent upon the relationship between the learner and the environment. Opportunities for deep examination of mathematics concepts and active learning may be possible through a metacognitive approach to learning, which includes students examining their present understandings, explaining their reasoning for mathematical operations, and investigating alternative processes for solving problems (Bransford et al., 1999).

In this chapter, we argue that classroom connectivity technology (CCT) can be used as an important tool for creating contexts in which students engage in deep mathematical thinking. Our analysis across four years of a randomized field trial, *Classroom Connectivity in Promoting Mathematics and Science Achievement* (CCMS), documented teachers' use of CCT within their Algebra I classrooms. Based on analyses of varied data (e.g., teacher interviews, classroom observations, student achievement data, and student focus group interviews), we propose four interrelated and complementary principles of effective mathematics instruction incorporating CCT.

- **Principle 1:** Effective CCT implementation is dependent upon mathematical tasks that support examination of patterns leading to generalizations and conceptual development.
- **Principle 2:** Effective CCT implementation is dependent upon classroom inter-

Figure 1. Depiction of the TI Navigator™ within a classroom



- actions that focus mathematical thinking within students and the collective class.
- **Principle 3:** Effective CCT implementation is dependent upon formative assessment instructional practices that lead to teachers' and students' increased knowledge of students' present understandings.
 - **Principle 4:** Effective CCT implementation is dependent upon sustained engagement in mathematical thinking.

In addition, each of these principles is discussed in term of its implications for teacher knowledge.

Classroom Connectivity Technology (CCT)

CCTs encompass a broad range of devices that network a teacher's computer with students' handheld devices employed to increase communication among and between students and teachers. Connected classrooms in this study were equipped with the TI-Navigator™, and students typically used a handheld calculator such as the TI-83 Plus or TI-84 Plus (see Figure 1). The TI-Navigator™ has five components. The teacher can pose a single question using *Quick Poll*, and with *Learn Check*, several questions can be sent to the students' calculators. These questions may include multiple-choice, true/false, or open-ended formats. *Class Analysis* summarizes students' responses,

which may be displayed as bar graphs. Using the fourth feature, *Screen Capture*, the teacher can take a "snapshot" of individual student's calculator screens for display. The fifth feature, *Activity Center*, allows the teacher to display a coordinate system. Students may be asked to contribute coordinate pairs or equations to be displayed graphically. Finally, the teacher can aggregate data collected from student handhelds and send data lists to students for analysis. Thus, two benefits of CCT for students and teachers are (1) immediate information that may lead to instructional adjustment and (2) public display of anonymously contributed responses and mathematical objects, which may lead to discussion of mathematical processes and thinking.

Early research with similar technology more broadly known as Audience Response Systems produced enthusiastic student response but limited conceptual gains when coupled with traditional lecture (Judson & Sawada, 2002). When innovative instructional practices were used in college contexts, several outcomes were found: increased class attendance and participation (Burnstein & Lederman, 2001), collaborative learning and student engagement (Dufresne, Gerace, Leonard, Mestre, & Wenk, 1996), and conceptual gains (Judson & Sawada, 2002; Mazur, 1997). An emergent research base indicates that CCT facilitates mathematics teaching, enhances student outcomes by promoting active participa-

tion, provides opportunities for inquiry lessons, and facilitates formative assessment (Roschelle, Penuel, & Abrahamson, 2004).

Teacher Knowledge

CCT may serve as a tool for the development of powerful contexts for learning mathematics, but it makes the teaching and learning process more complex than in typical classrooms. This increased complexity results from both the potential to increase student engagement in learning by supporting understanding through investigation of mathematics concepts and increasing the amount of formative feedback the teacher receives regarding students' present level of understanding (Cowie & Bell, 1999). As a result there are important implications for teacher knowledge. Researchers have identified both mathematical content knowledge (MCK) and mathematical content knowledge for teaching (MCKT) as important for effective practice (Ball, 1991a, 1991b; Ball, Thames, & Phelps, 2008; Hill, Rowan, & Ball, 2005). MCK includes both *knowing how to perform* mathematical operations and procedures as well as having *deep conceptual understanding* of mathematical processes. MCKT focuses on knowledge of *how to teach* mathematics rather than *how to do* mathematics and is considered to be similar to pedagogical content knowledge (PCK) for mathematics teachers. Unlike general pedagogical knowledge (e.g., classroom management and organizational aspects of classroom functioning), PCK focuses on "the most useful representation of ... ideas, the most powerful analogies, illustrations, and demonstrations—in a word the ways of representing and formulating the subject that make it comprehensible to others" (Shulman, 1986, p. 9). Knowing algebra is one set of skills; knowing how to teach algebra effectively requires different kinds of knowledge.

A broader conception of teacher knowledge, *Comprehensive Framework for Teacher Knowledge* (CFTK; Ronau et al., 2010; Ronau, Rakes,

Wagener, & Dougherty, 2009; Ronau, Wagener, & Rakes, 2009), includes three interrelated and interconnected dimensions: *Field*, which includes Subject Matter Knowledge and Pedagogical Knowledge; *Mode*, which includes Discernment and Orientation; and *Context*, which includes Individual and Environment. While the components of field may be described in terms of MCK and MCKT, the mode and context dimensions broaden our conception of teacher knowledge. Mode is related to MCKT in that it has been defined as

knowledge about what to teach, how to teach, the ways students learn, and ways for a classroom to meet the needs of every student.... Orientation describes the knowledge of beliefs, dispositions, values, goals, and other personal qualities that embody and define an individual's views and actions toward learning and teaching. (Ronau et al., 2009, p. 10)

Discernment relates to the lenses teachers bring to the instructional decision-making process as they reflect on and in action. This dimension includes knowledge of the cognitive domain, which includes reflection, inquiry, cognition, and decision making. The Context dimension "explains the knowledge teachers need of external factors that influence a learning situation" (Ronau et al., 2010, this volume). The Individual aspect includes teachers' knowledge of individual learners and the impact of their individual characteristics on learning, and Environment focuses on teachers' knowledge of factors external to the individual (e.g., the classroom culture, school policies) and their impact on the learning process.

Each of these aspects of this broad conception of teacher knowledge impacts the ways that teachers may effectively use CCT. For example, teachers draw on sophisticated interactions between subject matter knowledge, pedagogical knowledge, and discernment as they work to develop and sequence tasks to support complex mathematical knowledge. Further, they draw on

their orientation toward mathematics, and mathematics teaching and learning as they construct classroom norms and interactional patterns that make students' knowledge objects of discourse. Finally, formative assessment practices require, for example, well developed subject matter and pedagogical knowledge as teachers construct questions to use in interactive formative assessment practices.

Twenty-first century classrooms demand teachers who are also proficient in technological pedagogical content knowledge, or TPACK (Angeli, 2005; Hughes, 2004; Koehler & Mishra, 2009; Mishra & Koehler, 2006; Niess, 2005; Niess et al., 2009). TPACK refers to "the integration of the development of knowledge of subject matter with the development of technology and of knowledge of teaching and learning" (Niess, 2005, p. 510). The Association of Mathematics Teacher Educators' (2009) position statement details important aspects of TPACK including the design and development of technology facilitated mathematical tasks and experiences for students, integration of modern electronic technologies to maximize student learning, use of appropriate technology to assess and evaluate student learning, and professional development (PD) to promote equitable and ethical applications of technology in the classroom. In other words, in addition to having technology skills, teachers need to know how to use technology effectively when they teach. The complex nature of information about student learning and understanding available to teachers within a CCT classroom has important implications for teacher knowledge. Specifically, the detailed nature of teachers' understandings of students' present knowledge creates contexts in which sophisticated pedagogical decisions that necessitate deep knowledge of both content as well as technology are possible.

THE CCMS RESEARCH AND PROFESSIONAL DEVELOPMENT PROJECT

The CCMS project was a four-year field trial designed to investigate the impact of an intervention incorporating CCT and PD within Algebra I classes on student achievement and beliefs as well as classroom interactions. One hundred twenty-seven teachers were chosen to participate from a pool of volunteers in 28 U.S. states and 2 Canadian provinces and randomly assigned to treatment or control groups. The Year 1 control group received the intervention in Year 2 of the study. Thus, the research design of the overall study was a randomized control trial with cross-over design. Data collection and analyses used varied quantitative and qualitative techniques and measures in a mixed methods design.

The CCMS project incorporated the principles of TPACK in the design and implementation of the PD that served as an integral part of the intervention. The PD included a weeklong summer institute patterned after the Teachers Teaching with Technology (T³) model, with workshop instructors selected from a pool of secondary school teachers who were successfully implementing the technology in their own classrooms. To directly attend to issues of TPACK, participants were provided instruction on using the TI-Navigator™ functionalities, ideas for classroom activities, models of effective pedagogy that the principal investigators explicitly reinforced through brief lectures, and opportunities to design or enhance lesson plans to incorporate CCT.

Follow-up PD at the annual T³ International Conference was provided to further develop and refine teachers' practice throughout their participation. Prior to the T³ conference, participants met for a one-day session facilitated by the project PIs. The foci of these meetings were sharing successes and frustrations and presenting participant-created lessons, which were then distributed to all participants. The PIs engaged participants in discussions

related to effective pedagogy and disseminated study results as they became available. During the remainder of the conference, teachers attended and/or presented sessions on K-16 classroom uses.

Informal PD included telephone interviews, a listserv, and online training and technical support provided by Texas Instruments. Central to all of the PD were opportunities to engage in authentic practice by designing, implementing, and disseminating rich mathematical tasks using CCT. Finally, the nature of the study afforded teachers both extended time and practice, potentially increasing the likelihood of full implementation.

Framing the CCT Principles

The CCMS project relied on varied quantitative and qualitative data sources and mixed method data analytic approaches to broadly capture CCT implementation, its effects, as well as students' and teachers' perceptions of the connectivity technology. Teachers completed several measures, participated in telephone interviews twice per year, and a subset of teachers and their classes participated in two-day classroom observations. Students completed an Algebra I pretest and Algebra I posttest. If their teacher was selected for a classroom observation, students completed a survey related to their impressions of the technology and selected students participated in a focus group interview.

The four principles proposed in this chapter are hypothesized from findings across several separate analyses from four years of the project. Hierarchical linear modeling (HLM) was used to examine associations between student achievement and treatment group as well as several implementation variables coded from teacher interviews (i.e., frequency of technology use, teacher perceptions of improved understanding of student knowledge, and teacher perceptions of instructional changes resulting from CCT use) as independent variables (Irving et al., 2010; Owens et al., 2008; Pape, Irving, et al., 2010). Classroom

observations were transcribed and coded to analyze verbal interactions and potential differences in these interactions within treatment and control classrooms during Year 1 (Pape, Bell, Owens, S. K., et al., 2010). In addition, several teacher case studies were examined in depth for instructional strategies used to support student knowledge of quadratic equations (Pape, Bell, Owens, D. T., & Sert, 2010), and science and mathematics classes were analyzed and compared for features of successful classroom practice that were congruent with CCT implementation (Irving, Sanalan, & Shirley, 2009; Shirley, Irving, Sanalan, Pape, & Owens, in press). Finally, student focus group interviews were coded to examine students' perceptions of the impact of CCT (Lee, Irving, Owens, & Pape, 2010). Thus, we have theorized across these various analyses to frame the four principles. While these data sources and analyses are described briefly below, a full description is beyond the scope of the present chapter (for further information, see Irving et al., 2009; Irving et al., 2010; Lee et al., 2010; Owens et al., 2008; Pape, Bell, Owens, D. T., et al., 2010; Pape, Bell, Owens, S. K., et al., 2010; Pape, Irving et al., 2010; Shirley et al., in press).

Data Collection and Analysis

Teacher-Level Data Sources

Teachers participated in telephone interviews in the fall and spring of each year. The *Telephone Interview Protocol*, consisting of 17 questions, elicited the date of initial technology use, frequency of use across the school year, comfort using CCT, effect on the teacher's knowledge of student understanding, purposes for using each component, student reaction to the technology, and effect of the technology on planning and implementing instruction. The interviews were transcribed and coded using grounded analysis resulting in a coding scheme that was modified through discussion. Each interview was reviewed by at least three

raters for eight resulting constructs: (1) technology availability, (2) frequency of technology use, (3) comfort level, (4) CCT component use, (5) teachers' knowledge of student understanding, (6) change in planning and teaching strategies, (7) technology implementation, and (8) participants' report of student liking of the system. Except for technology availability and frequency, which were direct measures of time, inter-rater reliability was computed in percent agreement (0.69 to 1.00) and intra-class correlation (0.80 to 1.00). Exploratory factor analysis suggested that frequency of use, comfort level, and component use represent the frequency and level of TI-Navigator™ use, and the ratings of improved understanding of student knowledge and degree of change in planning and implementing instruction are separate constructs (Pape, Irving, et al., 2010).

Between 30 and 40 of the 127 teachers in the larger study participated in classroom observations each year. The observations were conducted in 18 states (i.e., AR, AZ, FL, IL, MA, MD, MT, NC, NE, NM, NY, OH, OK, OR, SC, TX, VA, and WA), which were representative of at least four regions of the United States: South, Midwest, Mid-Atlantic, and North East. With few exceptions, classroom observations consisted of two consecutive class periods, a student focus group, and a teacher post-observation interview. Each two-day classroom observation was transcribed verbatim from the videotape of the lesson and coded line-by-line in NVivo 8 using a priori categories (see Pape, Bell, Owens, S. K., et al., 2010). The codes were established through an iterative process beginning with a review of extant literature. The first coder coded the transcript while viewing the videotape. The second coder reviewed the coded transcript and videotape, as necessary, and indicated any discrepancies, which were resolved through regular discussions.

Student-Level Data Sources

The *CRESST Algebra I Pretest* (National Center for Research on Evaluation, Standards, and Student Testing, 2004) and *CCMS Algebra I Posttest* (Abrahamson et al., 2006) consisted of 32 items ($\alpha=0.81$) and 30 items ($\alpha=0.85$), respectively. The pretest focused on early algebra concepts, served as a covariate in HLM analyses (Irving et al., 2010; Owens et al., 2008; Pape, Irving, et al., 2010), and consisted of multiple choice, short-answer, and extended-response questions drawn from released National Assessment of Educational Progress, Trends in Mathematics and Science Survey, and California Standards Test items. The posttest was developed following a review of the algebra content standards from 13 states representing a majority of participants. The posttest items consisted of item response formats similar to the pretest and were drawn from the Algebra Pretest (11 items), Virginia and California state tests, and the Second International Mathematics Study. IRT analyses were conducted to ensure the technical quality of each of these measures (Herman, Silver, Htut, & Stewart, 2010).

The *Student Survey* completed during classroom observations asked students to indicate their impressions of how the technology supported their understanding and served only as a springboard for questions during the focus group interviews in which selected students participated. The *Student Focus Group* (SFG) asked students to comment on the degree to which the technology use was typical during the observed class, their perception of the purpose of the technology, and student responses to the Student Survey. Using Miles and Huberman (1994) as a guide, analysis of SFG data provided initial codes of students' learning, students' meta-cognitive awareness, teachers' awareness, classroom interaction, and student engagement. Consensus of coding category distinctions, definitions, and examples was reached through negotiation and refinement. The Kappa statistic was calculated to measure inter-rater

reliability between two coders who coded all of the transcripts ($K > .80$; Wood, 2007). Finally, the SFG interview data were analyzed both individually and together to generate empirical assertions (Patton, 2002).

Four Mechanisms of Effective Implementation of CCT

These data captured significant portions of the ways in which participants used the technology to support student learning within their Algebra I classes. While we argue that CCT is a tool for supporting engagement, this was not the case in every classroom. Findings from our four-year study support the following statements: (1) students in classrooms incorporating CCT outperformed their peers in control classrooms during Year 1 implementation ($ES = 0.32$; Pape, Irving, et al., 2010), and on average CCT classrooms outperformed Year 1 controls across four years of the project (Irving et al., 2010); (2) CCT disrupted traditional interactional patterns on average, but not for all teachers (Pape, Bell, Owens, S. K., et al., 2010); (3) teachers reported learning about their students' understanding, which was related to student achievement ($p = .013$; Irving et al., 2009; Pape, Irving, et al., 2010); and (4) students reported greater engagement in connected classrooms (Lee et al., 2010). Frequency of technology use alone, however, was negatively associated with achievement (Pape, Bell, Owens, S. K., et al., 2010). Therefore, qualitative data analyses were conducted to deeply describe and theorize mechanisms of effective CCT use.

In the next section, we describe the four principles beginning with a brief review of extant literature, illustrations from classroom use or teacher and student perspectives, and connections to teacher knowledge necessary to implement CCT effectively. An overarching premise of these principles is that mathematical understanding is enhanced by the inclusion of technology when it increases the degree to which students actively

engage in mathematical thinking. While these four principles are stated separately, we describe their interrelated nature and their complementary power to create contexts for mathematical thinking in the conclusions. We use the convention of (Participant number/source of data/date) to identify teacher and student direct quotations used to support our assertions. Four sources are included: classroom observation data (CO), student focus group (SFG), telephone interview (TI), and teachers' statements from the T³ International Conference (T³).

***Principle 1:** Effective implementation of CCT is dependent upon the creation and implementation of mathematical tasks that support examination of patterns leading to generalizations and conceptual development.*

Mathematics learning is deeply connected to the representations individuals employ (Kaput, 1987; National Council of Teachers of Mathematics [NCTM], 2000). Facility with transforming and translating one representation into another and learning to solve problems using multiple representations such as equations, tables, graphs, and diagrams are both aids in developing mathematical proficiency and hallmarks of mathematical proficiency (Kilpatrick, Swafford, & Findell, 2001). "Mathematically proficient students can explain correspondences between equations, verbal descriptions, tables, and graphs or draw diagrams of important features and relationships, graph data, and search for regularity or trends" (Council of Chief State School Officers, 2010, p. 6). Gaining facility with multiple representations enhances students' conceptual understanding because of their redundancy. That is, knowing how to reach a solution or represent a problem in more than one way supports connections between these mathematical ideas (Kaput & Educational Technology Center, 1989). Learning to employ representations to effectively and efficiently solve problems requires practice within a multi-representational learning environment (Bostic

& Pape, 2010; Brenner et al., 1997; Even, 1998; Greeno & Hall, 1997; Herman, 2007). Thus, to develop mathematical understanding and proficiency, students should be engaged in tasks that foster examination of patterns and relationships within and across multiple representations resulting in generalizations and leading to concept formation. By generalized knowledge we mean a conceptual framework through which students come to understand related but oftentimes discrete concepts (Bransford et al., 1999).

Multi-representational learning environments have recently become easier to create because technology has provided means for efficiently translating between representations (Heid, 1997, 2005; Greeno & Hall, 1997). CCT in conjunction with handheld graphing calculators enables students to manage mundane procedures while focusing their energy on complex tasks (Heid, 1997, 2005; Interactive Educational Studies Design, 2003) and links students as well as their work products with their teacher and peers (Heid, 2005). By bundling handheld graphing calculators with CCT, students and their teacher are able to co-examine problem solutions and representations of their strategic thinking and discuss them in a way that facilitates mathematics learning (Heid, 2005). CCT provides affordances for public display and investigation into multiple representations of mathematical concepts including similarities and differences in graphs and individual solution strategies that support knowledge construction.

We examined the ways in which our participants supported students' understanding of quadratic equations (Pape, Bell, Owens, D. T., et al., 2010). Through examining the relationships between equations, their graphs, and associated tables of values, students can generalize the effects of changing the coefficients of an equation (i.e., $f(x) = ax^2 + bx + c$) on the shape, size, orientation, and position of its graph. During one of our classroom observations, we witnessed a participant using the CCT in this way (66/CO/03.14.2007). At the beginning of the lesson, the teacher asked

his students to enter a quadratic equation of the form $y = ax^2 + c$ into their graphing calculator and to graph the function. The teacher projected the parabolas and their equations for public display and examination, which provided a vehicle for making patterns an explicit object of discourse for all of the students. By examining the patterns, they noticed the relationships between the coefficient of the quadratic term and the size, shape, and orientation of its parabola and offered generalizations about the effect of changing this coefficient on the graph. Subsequently, the class engaged in an investigation of the position of the parabolas while examining the different c -values. This multi-representational activity coupled with careful teacher-directed investigation of patterns afforded these students the opportunity to abstract general principles related to the effects of these coefficients.

To manipulate representations effectively, students must manage their internal, external, and relational representations (Ainsworth, 1999; Goldin, 2002, 2003). Within classroom contexts where students are asked to solve unique problems and explain their mathematical reasoning, the learner must create a mental model of the problem (i.e., internal representation), recognize an efficient way to answer the problem by perhaps drawing a graph (i.e., external representation), and then use verbal language to explain their thinking, thus drawing on a third representation (i.e., relational representation). This process of making internal representations available to others requires sophisticated moves by both the teacher and the student (Kaput & Educational Technology Center, 1989) and may be facilitated through the use of CCT.

In another classroom, the teacher projected the image of a basketball player shooting a foul shot, and a student was asked to read the directions:

Work together, [to] come up with an equation that you think will match the parabola on the screen and get the [basketball] in the hoop. Use a

second calculator to try out your equation before submitting it, creating a table of values from the calculator to plot points and form the parabola. (35/CO/05.02.2007)

The students were allowed to move to the projection screen and analyze the parabola to determine coordinates of points such as the vertex and intercepts. As the students worked in groups, they discussed different possible solution methods and tried several as they externalized their internal representations in the form of equations and graphs. Each group's graphed equation was projected over the picture of the basketball player. The whole class examined the different parabolas and their equations, and students were encouraged to make suggestions for other groups' equations to show the path of the foul shot. Students then had the opportunity to make changes to their equations and experience the effect of these changes immediately. Thus, students were required to externalize their thinking, explain their reasoning, and think about relationships between the equations, graphs, and their knowledge of quadratic equations as they suggested adjustments. These investigations provided students with powerful opportunities to learn important general principles related to equations and their graphs.

These examples illustrating our first principle highlight the need for complex teacher knowledge. The open-ended lessons tasked the teacher with interpreting the students' representations and orchestrating related conversations. The teachers' efforts to elicit general principles through exploration of the patterns that the students noticed, rather than telling them what they should notice, was an important lesson characteristic. Thus, the teachers drew heavily on their subject matter knowledge (MCK, CFTK) to direct the discussions and highlight the relationships intended for students to understand. The teachers' sequencing of the activity and discussion required sophisticated MCKT and an interaction between knowledge of subject matter, pedagogy, and discernment

(CFTK). Finally, in their planning, these teachers drew on important knowledge of the benefits of CCT (i.e., pedagogical knowledge of technology) for engaging students in active learning that supported students' understanding.

Principle 2: *Effective implementation of CCT is dependent upon classroom interactions that focus mathematical thinking within students and the collective class.*

We have argued that mathematical proficiency and understanding is facilitated through tasks that require examination of patterns leading to generalized mathematical knowledge. We further assert that a critical component of facilitating mathematical understanding and effective use of CCT are classroom interactions and norms that make mathematical thinking an object for public examination. While teachers and students co-construct norms for classroom interactions, the teacher plays an important role in fostering mathematical thinking. Teachers can use CCT to increase the level and amount of classroom communication and students' mathematical thinking by, for example, taking up students' responses as they are entered in Learn Check or pressing students for an explanation regarding their contribution in Activity Center.

Classroom interactions have been characterized largely as Initiate-Respond-Evaluate (IRE) patterns in which the teacher asks a question, students respond, and the teacher evaluates their responses (Durkin, 1978-1979; Hoetker & Ahlbrand, 1969). This pervasive interactional pattern potentially contributes to the consistently low achievement of U.S. secondary students in international comparisons (Hiebert et al., 2005), is a significant difference between U.S. and Japanese mathematics classrooms (Inagaki, Morita, & Hatano, 1999), and is based on both students' and teachers' expectations for classroom talk (Fisher & Larkin, 2008). Through this pattern of interaction, teachers tend to retain authority

for mathematical accuracy thus limiting student engagement in mathematical thinking.

We examined the classroom interactions within CCMS participants' classes with a focus on teachers' questions and the ways they took up student responses for discussion. From a situative/sociocultural perspective, students' ability to learn within a classroom context is affected by their capacity to engage with its components (Gee, 2008), and language is an important medium for negotiating their interactions with learning processes. Because students are sensitive to the intentions and demands of teachers and perceive the meaning of competence through the discourse in the class (Gresalfi et al., 2009), classrooms that are dominated by lower-order, recitation questions (i.e., questions that elicit known-answer responses; Nystrand, Wu, Gamoran, Zeisler, & Long, 2003) and restricted student utterances limit the complexity of students' mathematical thinking and ultimately their mathematical understanding.

Data from the CCMS project indicate that IRE patterns of interaction are prevalent within the teaching of Algebra I (Pape, Bell, Owens, S. K., et al., 2010). Across the treatment and control classrooms, teachers asked on average 90 mathematics-related questions in 60 minutes, 85 of which required students to recall known information. This abundance of teacher questions within a class period limited student mathematical statements to approximately four words per utterance. Further, more than half of these interactions (approximately 50 out of 90) ended with the teacher evaluating the students' response, which were taken up for investigation on average a little more than three times per 60 minute period. Thus, mathematics communications were dominated by teacher-to-student questions that elicited limited mathematical thinking by students. Further, we noticed patterns of interaction whereby the teacher performed the mathematical thinking and the students performed the arithmetic operations. In the context of finding the length of two chords in a circle, for example, the teacher in the following

excerpt tells the students what they need to know and asks them to do the arithmetic operation:

- T: What are these doohickies?
S: They're lines ... chords.
T: They are chords. And when chords intersect within a circle their products are the same. Isn't that the same as last time? 2×3 is...
SS: six. (22/CO/04.21.2006)

Thus, the teacher performed the mathematical thinking and told the students about the relationship to prior knowledge, and the students computed two times three.

An impact of the CCT intervention on the interactional patterns within the treatment classrooms, however, was identified. Treatment teachers reduced their questions on average by approximately 22%, and while these questions were still predominantly known-answer questions, some reduction in these questions occurred (i.e., 92% to 88% of the total). Thus, the IRE question event episodes that are typical of mathematics classrooms may be disrupted within the context of CCT (Pape, Bell, Owens, S. K., et al., 2010).

While the quantitative data from the classroom observations only minimally support teachers' impressions, the teacher participants reported changes in their classroom discussions as a direct outcome of implementing CCT. Specifically, in their telephone interviews, the participants noted more and different classroom discussions when the teacher and students could see students' responses. As one participant described, "they comment so much more when we use the Navigator™... it's consistently a much richer conversation, a lot more questions" (07/TI/2009). Furthermore, some teachers noticed that their mathematical conversations extended beyond correct or incorrect responses and focused more on explanations for mathematical phenomena and justifications for their reasoning. One participant explained that "because we're putting answers up in front of the whole classroom and everybody gets to see

the different graphs, there's spontaneous discussion about 'where did that one come from' and all of that" (50/TI/2009). CCT makes students' responses objects of discourse, which can be stimulated by the teacher taking up students' responses and pressing for explanations. In the following episode we see several conversational turns during which the teacher both takes up students' statements for examination and presses the students for explanations:

- T: What's the one point two five for? Let me read it ... [teacher reads the problem]
S: The guest.
T: The guest. So the X stands for the number of guests? Ok, go ahead.
S: Point seventy five times two hundred.
T: And why did you multiply that [by] two hundred?
S: Because two hundred sophomores plan to attend.
T: Right. Less than or equal to?
S: Less than.
T: Why less than? (36/CO/02.02.2006)

The increased discussion extended to student self-assessment and peer assessment. Although teachers generally obscured students' identities when displaying their contributions through the Navigator™ system, students rapidly became comfortable with sharing their responses and acknowledging their own contributions, even when their response was incorrect. Teachers often attributed student ownership of responses to the increased comfort level in their classrooms. One participant described, "the kids are just more comfortable... they're able to see that they're not the only ones that don't understand a concept" (33/TI/2009). Another participant presented her perspective regarding why students were willing to use CCT to share their responses:

They use it to assess their knowledge and to help them see that other students maybe don't understand the same concepts, and they don't have

to feel like they're the only person that doesn't understand and be self-conscious. They're just more open to discussing things when they can see that other students don't understand it either. (33/TI/2009)

The use of CCT promotes the sense of community that encourages students to risk sharing their responses.

CCT provides varied and important information that requires teachers to examine and analyze student thinking. To successfully conduct these conversations with students, Principle 2 depends upon the social and sociomathematical norms for participation (Yackel & Cobb, 1996). Setting these norms draws heavily on teachers' orientation toward teaching and learning mathematics and the knowledge of how their orientation influences a learning situation. To shift the authority for mathematical learning to the students, teachers also must shift their beliefs about the construction of knowledge. As this authority shifts and classroom discourse is opened to greater student input, teachers are challenged to make sense of these contributions, which requires significant subject-matter knowledge. Further, as student input is increased, the teacher must interpret varying solutions and strategies while making complex decisions during the enactment of the lesson, necessitating deep subject matter, pedagogical, and discernment knowledge. Finally, effective use of CCT requires that teachers identify critical junctures in student's learning, thus drawing on their knowledge of the students as individuals and difficulties students encounter with particular mathematics concepts. This may result from and depend upon important interactions between knowledge of individual students, subject-matter knowledge, PCK, orientation knowledge, and discernment knowledge as the teacher makes decisions regarding the flow of the lesson as a result of his or her knowledge of individuals within the class.

Principle 3: Effective implementation of CCT is dependent upon formative assessment instruc-

tional practices leading to teachers' and students' increased knowledge of students' present understandings.

The third principle, which incorporates the first two, is formative assessment, which served as a critical theoretical underpinning for the CCMS project and highlights the important role of MCKT and TPACK. Formative assessment is an instructional strategy that positively impacts student achievement in a variety of classroom settings (Black & Wiliam, 1998; Stroup, Carmona, & Davis, 2005; Yourstone, Kraye, & Albaum, 2008). During formative assessment cycles, teachers present students with rich instructional tasks (Principle 1) and gather evidence of student learning typically through classroom interactions (Principle 2). Teachers then act on that evidence in adapting subsequent instruction to meet identified learning needs (Black & Wiliam, 1998; Bell & Cowie, 2001; Wiliam, 2006; Torrance & Pryor, 1998). In this section we argue that CCT is an important tool to facilitate teachers' formative assessment strategies; CCT helps teachers know what students know and make adjustment to subsequent instruction based on the information they obtain about students' understanding.

Black and Wiliam (1998) indicated that one of the hallmarks of effective formative assessment is that students learn more as a result. This finding was supported within the CCMS study. Telephone interviews with our participants were rated for teachers' perceptions of their understanding of their students' knowledge as a result of using CCT, and HLM analysis showed these ratings to be positively associated with student achievement on the Algebra I posttest (Pape, Irving, et al., 2010). Our qualitative analysis of teacher interviews further supports the role of CCT in promoting formative assessment.

An important component of formative assessment is the elicitation of student responses to questions posed by the teacher. In order to accurately uncover levels of student understanding,

teachers must provide students with appropriate assessment tasks presented in a timely fashion that generate data regarding what students do and do not understand (Bell & Cowie, 2001; Cowie & Bell, 1999; Torrance & Pryor, 2001; Erickson, 2007). Implementing instruction with CCT provides teachers and students with additional reliable evidence. According to one participant:

Before, without the TI-Navigator™, I would always say, yes, I distinctly understand [what students understand] because I'm looking at their test score. That's all we had to look at. But with the TI-Navigator™, I have so many more things to look at that give me feedback, through all the Quick Polls, Activity Center, the discussion groups that go on, what they see another student did. (44/TI/2009)

The increased evidence comes not only from having a greater number of sources of data, but also from increased participation from the entire class. Participants remarked about the advantages of having responses from a majority of the students, "you can get a response from everybody in the class; you can see who knows what they're doing" (61/TI/2009). CCT provides responses from more students (often every student logged in will respond), giving the teacher a more accurate profile of student understanding (Irving et al., 2009).

One participant described the importance of this ongoing formative assessment by saying, "you can get a better understanding of where they are in terms of understanding the new concepts... when you take a test it's [a] little too late to know how your class is doing" (23/TI/2009). More importantly, the students' statements during the student focus groups indicated their awareness of the teachers' increased knowledge and facility to support their understanding. One student commented, "She knows like who is wrong and who is right and what they need to work on" (13/SFG/02.08.2006).

Many participants found that the CCT complemented the use of a variety of planned classroom assessments they typically implemented. For example, teachers employed CCT to administer weekly reviews to prepare for high-stakes tests, daily warm-up questions, and planned question prompts, as well as to efficiently collect and examine students' responses to questions. One participant explained:

Before [using the Navigator™] I would do a 5-minute check at the beginning of class, but I didn't always get them looked at until that night or sometimes even a day or two later, so the immediate feedback has been wonderful. (58/TI/2009)

Moreover, another teacher commented that brief warm-up quizzes at the beginning of class "let me know right away whether they remember[ed] what I taught them the day before" (46/TI/2009). Assessments such as these that were aimed at identifying whether students held a predetermined core set of knowledge, have also been termed *convergent assessment* (Torrance & Pryor, 2001). Participants found that CCT allowed them to administer a variety of convergent assessments, such as forced-choice quizzes or single question prompts as well as open-response questions with one desired answer.

While some assessment tasks generated evidence of student learning in the form of students' direct responses to teachers' questions, the flexibility and variety of instructional choices with CCT provides additional types of data. For instance, in the example described earlier where students were tasked with determining the equation of a parabola to make a foul shot (35/CO/05.02.2007), the teacher was able to engage students in a conversation about aspects of the equations that did not satisfy the goal of putting the arc of the parabola through the basketball hoop. The teacher received immediate evidence of students' progress with this task and therefore had the opportunity to elicit suggestions for coefficients for the

quadratic equations, which supported students' understanding as they changed coefficients and were immediately able to see the effects. This example demonstrates *divergent assessment*, which by contrast to convergent assessment focuses on uncovering what the students understand or think about a given concept (Torrance & Pryor, 2001).

In another example, a participant described asking students to use the equation submission feature of Activity Center to "send [her] a quadratic and then a linear and then an exponential [equation] just to see if they got the difference between them." She continued by explaining how the visual display of student understanding allowed her to "see it right there when you're looking at it" (03/TI/2009). Here, the teacher's evidence of student learning comes from her ability to quickly identify whether students can generate an equation that fits the type of graphical representation requested. Rather than looking for specific right or wrong answers to convergent questions, teachers were able to use CCT to elicit a range of possible responses, such as graphs of equations generated by students. As students submitted their responses, teachers were able to identify aspects of those responses that illuminated the level of student understanding.

The Class Analysis component of the TI-Navigator™ supports aggregating students' responses to Quick Poll or Learn Check. The ability to interpret these data is an essential component of formative assessment, which requires heightened PCK (Cowie & Bell, 1999). Once teachers have identified and made sense of the assessment data, they must then take action by changing the intended course of the lesson in some way (Erickson, 2007; Cowie & Bell, 1999; Bell & Cowie, 2001), which requires not only knowledge of pedagogy but also discernment. Teachers cannot ignore the additional evidence, as this participant explained:

When they're in front of you, you can't go on, you can't ignore it. If you never see it, you can pretend like it doesn't exist, but when it's up there on the

whiteboard for everyone to see, you just have to deal with it. (69/TI/2009)

The ways that teachers adapt instruction to address students' identified learning needs is a critical component of formative assessment. The results of assessing with CCT prompted many teachers to alter the pacing of their lessons, in some cases by working through additional sample problems as a class or by accelerating the pace of the lesson. As one participant explained, "I might have to give extra examples, or I can move on faster if I see that the whole class is getting it" (23/TI/2009).

Teachers are not the only individuals engaged in the formative assessment process; rather, students are integral to formatively assessing their own and others' learning (Bell & Cowie, 2001). This affordance of CCT was stated several times by students during our focus group interviews. One student commented: "you can tell when you are doing it wrong or like how you are doing it wrong so you can see. And then why" (02/SFG/04.25.2006). Enhanced formative assessment opportunities afforded by the use of CCT, together with an increased sense of community in the classroom, hold potential for supporting rich discussion of mathematical concepts.

Principle 3 entails interactions between several components of the TPACK and CFTK frameworks. Teachers need sufficient knowledge of technology and confidence to learn to use the many options available for assessing students. They draw on their subject matter knowledge and pedagogical knowledge as they construct questions for planned formative assessments. Further, teachers' decision-making processes rely on the interaction between their subject matter knowledge, discernment, knowledge of the individual, and their orientation toward the domain. This enriched and interrelated knowledge influences instructional planning as the teacher uses his/her pedagogical knowledge to frame ongoing instructional strategies based on learning difficulties revealed through formative assessment.

These decisions about students' misconceptions and instructional adaptations also depend to a large extent on sophisticated content knowledge as it interacts with PCK necessary to identify appropriate instructional strategies to address these misconceptions. As teachers develop expertise in CCT classrooms, their knowledge of how their specific curriculum and curricular materials fits with the technology, of students' understanding, thinking and learning with technology and their pedagogical knowledge of instructional strategies and representations for teaching and learning in CCT environments grows (Niess et al. 2009). That is, teacher enhanced TPACK develops through successive cycles of formative assessment as they develop strategies to learn more about student learning and then change their instructional plans in recognition of students' conceptions and misconceptions.

Principle 4: *Effective implementation of CCT is dependent upon sustained engagement in mathematical thinking.*

We have presented evidence that within typical patterns of classroom interaction, students are less likely the locus of mathematical thinking (Pape, Bell, Owens, S. K., et al., 2010). Specifically, we have argued that typical interactional patterns limit responses to few students, and these responses are often focused on computation rather than mathematical thinking. In traditional mathematics classrooms, this interactional pattern results in teachers maintaining careful control of mathematical knowledge, often demonstrating how to follow algorithmic procedures, and then assigning practice of those procedures. Discussion in many of the classrooms we observed was dominated by IRE patterns (Pape, Bell, Owens, S. K., et al., 2010), and because students in traditional classrooms are asked to respond one at a time, many students are able to avoid participation.

In contrast, calls for reform in mathematics education envision classrooms where all students

are actively engaged in learning (NCTM, 2000; Kilpatrick et al., 2001). From a sociocultural perspective, engagement might be seen as actions taken during the social construction of knowledge that are much like processes found in more mature mathematical communities—problem solving, questioning, reasoning, justifying, and representing mathematical ideas in a variety of forms (Brown & Hirst, 2007). Students and teachers create mathematical discourse communities as they develop shared understandings through engagement in mathematical processes and discussion of both processes and products (cultural artifacts) of their individual and group work (Cole, 1996; Cobb, Yackel & Wood, 1992; Lampert, 1990).

Engagement in mathematical thinking refers to the level of cognitive and metacognitive strategies employed, motivational goals, dispositions toward learning, and classroom interactions (Turner et al., 1998). Consistent with Gee's (2008) definition of effective learning, Turner and colleagues (1998) defined "involvement as the perception that the challenges afforded by the instruction and students' skills were both high and fairly balanced" (p. 742). These authors confirm that support for understanding through whole-class discussions is critical to involvement. Further, engagement or involvement is heightened when teachers are aware of their students' interests and make the mathematics relevant and meaningful (English, 1998). In the context of CCT where formative assessment is used to learn about students' understandings, the public display of students' contributions may result in changes in instruction that create contexts for engagement and scaffolds for understanding. In addition, uptake of students' responses makes students' contributions the focus of whole-class discussion, which potentially increases engagement in the learning process.

Students' perceptions of what it means to do mathematics and their expectations for participa-

tion in a mathematics class are important to this discussion of engagement. Conceptions of appropriate mathematical behavior, such as ways of speaking and thinking, are learned through norms for engagement (Brown & Hirst, 2007). Teachers may promote student engagement through discourse practices that encourage questioning, reasoning, arguing and justifying, rather than asking known-answer questions.

The characteristics of classroom talk that productively engage students in the practices of mathematics are those that assist students in making sense of the mathematics being presented to them and that assist students in linking their ideas to the conventions of mathematics rather than to teacher and/or textbook evaluations of students' answers. (Brown & Hirst, 2007, p. 27)

Students' statements have helped us to understand the ways that CCT contributed to the perception of greater engagement. Screen Capture provides a mechanism for teachers to know what students are doing while working on their calculators. This information may serve a variety of purposes, such as gauging the time needed for a task or monitoring student activity, or helping students remain on task as one student noted: "We kind of have to be engaged. She can ... tell if we are paying attention or not; and besides that, if we want to learn more we have to pay attention" (57/SFG/03.30.2006). Screen Capture can also be used to display and examine the various approaches that students take to solve problems or represent mathematical ideas.

Overall there is more press to respond to teachers' questions when CCT is used and all students are expected to submit a response. The public display of students' responses also increases the expectation for participation. "I think everyone tried harder to get the right answer because, like, you have to put [your answer] into [the] calculator and enter it, like, it shows up on the screen"

(13/SFG/02.08.2006). And another student commented, "because when you have to answer the quick poll and stuff the teacher can actually see who did not answer it ... and you feel like you should be answering it and you should be following along" (27/SFG/03.06.2006). Students also noted that the public display of responses increased the competitive nature of the classroom because students did not want to contribute an inaccurate response or mathematical object: "It is a competition that makes you want to get it right. If somebody else gets it right, you want to get it right" (29/SFG/02.16.2006). Beyond the public display of students' contributions, the students reported greater enjoyment and feelings of knowing, which contributed to their involvement and engagement. The students' statements highlight a sense of interest in working with CCT as opposed to taking notes in mathematics class: "It really helps you focus because things keep changing and moving differently and you are just not copying down words [from] the board" (02/SFG/04.25.2006).

A final important theme within the students' comments related to increased engagement due to feeling supported within a community of learners who provide feedback and help each other make corrections. One student commented, "Yes, we are more involved, too, so that we are to the point [where] we are arguing about [the mathematics]" (44/SFG/04.21.2006). Yet another students' comment provides evidence of the community that is possible within connected classrooms:

I think when you use the TI-Navigator™ we work more to solve the problems. So if you are having like trouble with one part of solving the problem, other people can help you learn how to do it and you can help them. (13/SFG/02.08.2006)

Similarly, students reported greater engagement because they perceived that their teacher had greater knowledge of their understanding

and therefore could provide assistance when needed. "It gets better because [the teacher] can send those Learn Checks and she helps us with our mistakes and we can go back and correct them" (26/SFG/04.27.2007). Communication was not only between students and teachers but between students and their peers, as one student noted, "I try to figure out by myself but with the Navigator™ you can see what everyone else did and then you can see what you did wrong and then ask questions about it" (13/SFG/02.08.2006).

We contend that effective implementation of CCT is dependent upon sustained engagement in mathematical thinking, and that CCT, when used strategically, helps to create the context for sustained engagement in mathematical thinking. In many typical mathematics classrooms only one student who raises his or her hand will have the opportunity to respond to a teacher's question. Bell and Cowie (2001) identified the practice of teacher selective notice of some but not all students in a classroom. Because displays of student responses are public within a connected classroom, the teacher may engage students in conversations about the meanings of each other's contributions, thus potentially deepening student mathematical understanding as well as informing the teacher about the progress of many students rather than just the few who typically respond during class without CCT. Fostering these conversations requires interactions between teachers' MCK and MCKT as well as knowledge of individual students including their approaches to learning and how these individual characteristics interact within their classrooms. Further, teachers must possess PCK as they manage a wide range of pedagogical practices such as asking questions that require thoughtful responses with the expectation that students will share their mathematical thinking. The increased information about student learning garnered through the use of CCT has additional implications in terms of teacher knowledge. Specifically, teachers must draw on complex interactions between MCK and their ability to reflect on

and in action (i.e., discernment) as they engage students in mathematical conversations.

CONCLUSION

Within this chapter we have examined the effective use of CCT by analyzing beneficial characteristics of the connected classroom for teachers and students. From an examination of varied data across four years of our CCMS project, we have argued for four interrelated and complementary principles of effective CCT. For CCT to be used effectively teachers must (1) design rich mathematical tasks that create contexts in which students may examine patterns and form generalizations, (2) co-construct classroom norms for interaction that raise students' contributions to a level of object of discourse through which mathematical reasoning may be revealed, (3) enact formative assessment instructional practices that provide teachers and students access to increased knowledge of students' understandings, and (4) sustain students' engagement in mathematical thinking.

Our investigation was conducted from a situated/sociocultural perspective that defines opportunity to learn in terms of students' capacity to engage within the ecology of the classroom (Gee, 2008). The interaction between the individual and the learning context creates varied opportunities for learning for individual students. This perspective elevates both teachers' and students' roles to that of active participants in the learning process. That is, the teacher must create an interactive learning environment that is predicated on the tasks, interactional patterns, and formative assessment, and students must take advantage of these affordances in order to sustain engagement and ultimately achieve mathematical understanding. Each of the principles provides mechanisms for making learning accessible to students. While the tasks must provide ample opportunity to examine patterns with the goal of determining general principles, the classroom interactions

provide entry to these patterns. Further, formative assessment practices are essential to just-in-time modifications of instructional practices in ways that are sensitive to students' capacity to interact with the tasks and increase the likelihood that students are able to interact effectively with the learning goals. Finally, the advantages of CCT in combination with the tasks, discourse, and formative assessment provide the potential for sustained engagement in mathematical thinking leading to understanding. Thus, the four principles are interrelated and complementary; each of them providing the context for the others.

The notion of technology as a tool rather than a transformative mechanism was evident within several participants' statements at a PD event early in the first year of implementation as one participant stated:

I'm hearing all these things about [how CCT] does this ... it does that. But I feel like it ... doesn't create all this. Maybe it helps you get to the point where you interact in a different way.... I think we need to consciously be developing the kind of discourse that we want with and without the [CCT]. (34/T³/Feb 2006)

Technology itself is never a panacea for creating powerful contexts for learning. Teachers must learn to implement the technology well. Simply equipping algebra classrooms with CCT will do little to improve students' mathematical competence. Twenty-first century classrooms demand teacher knowledge of content, pedagogy and effective integration of twenty-first century technologies.

In the connected classroom, teachers must merge their multiple knowledge bases (content, pedagogy and technology) as they progress through predictable developmental stages (recognizing, accepting, adapting, exploring and advancing) to actively engage students in mathematics learning with appropriate technologies (Niess, et al. 2009). To effectively use CCT in the

mathematics classroom, teachers must draw on extensive MCK and MCKT (i.e., subject-matter knowledge, pedagogical knowledge, and PCK) as they develop tasks, sequence these tasks, and create questions for planned or interactive formative assessment. Further, because CCT potentially increases the amount of information about student understandings and reveals student misconceptions, the teacher's ability to interpret and respond to increased student contributions heavily depends on deep subject-matter knowledge as well as PCK and knowledge of individual learners. To use CCT effectively, teachers must select and support rich mathematical tasks that require student to engage thoughtfully, set norms for discourse that allow students to safely reveal their understandings, and attend to students' thoughts and ideas as the lesson unfolds. Each of these tasks requires orientations to teaching and learning that focus on student knowledge rather than a prescribed curriculum as a guide, and interactions between orientation, subject matter knowledge, pedagogy, and discernment. Finally, the teachers must develop and draw upon knowledge of technology implementation to conduct lessons that are aligned with the principles set forth in this chapter.

Future research should continue to examine both effective ways of incorporating CCT within mathematics classrooms and the teacher knowledge constructs that impact its effective use. Specifically, more research is needed to examine teachers' trajectory through the stages of technology implementation and components of effective PD that might impact teachers' implementation of CCT and passage through these stages (Niess et al., 2009). Finally, the mathematics education community needs to explore powerful ways in which CCT can serve as an effective tool in the complex ecology of the mathematics classroom.

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Chapter 9

A Model for Examining the Criteria Used by Pre-Service Elementary Teachers in Their Evaluation of Technology for Mathematics Teaching

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ABSTRACT

Multiple existing frameworks address aspects of teachers' knowledge for teaching mathematics with technology. This study proposes the integration of several frameworks, including TPACK (Mishra & Koehler, 2006), MKT (Ball, Thames, & Phelps, 2008), and technology evaluation criteria (Battey, Kafai, & Franke, 2005) into a new comprehensive model for interpreting teachers' knowledge of the use of technology for teaching mathematics: the T-MATH (Teachers' Mathematics and Technology Holistic) Framework. The study employed quantitative and qualitative methods to examine 144 pre-service elementary teachers' evaluations of technology for future mathematics teaching. The proposed model and its application to this group of pre-service teachers suggest that there are multiple dimensions to understanding teachers' knowledge of uses of technology for mathematics teaching, and that teachers' self-identified evaluation criteria reveal the dimension in which their knowledge resides. Understanding teachers' progressions through these dimensions may provide insights into the types of experiences that support teacher development of the knowledge necessary to teach mathematics using appropriate technologies.

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INTRODUCTION

Pre-service elementary teachers come to mathematics methods coursework with a variety of backgrounds and experiences in using technology. Some identify themselves as extreme technology users, using multiple technologies regularly as an integral part of their daily lives. Other pre-service teachers are limited technology users. They may use email and basic software packages, but other technologies are not essential to their daily activities. Because technology knowledge varies among pre-service teachers, there are multiple factors that influence pre-service teachers' selection and use of technology for mathematics teaching and learning. Typically experiences in mathematics methods courses introduce pre-service teachers to various types of technology tools for mathematics teaching. Pre-service teachers often create lesson plans which integrate technology, or they may evaluate technology tools for mathematics learning during their pre-service experiences.

This chapter proposes an integrated model of teachers' use of technology for teaching mathematics and uses that model to examine pre-service teachers' evaluations of technology for use in mathematics teaching. The chapter integrates relevant literature on technology for teaching mathematics including: TPACK (Technological Pedagogical Content Knowledge) as it applies to the teaching and learning of mathematics (Mishra & Koehler, 2006; Niess, Suharwoto, Lee, & Sadri, 2006); the TPACK framework proposed by Mishra and Koehler (2007); the Domains of Mathematical Knowledge for Teaching (MKT) framework proposed by Ball, Thames, and Phelps (2008); and, the mathematics and technology evaluation criteria proposed by Battey, Kafai, and Franke (2005). We suggest that integrating these frameworks and evaluation criteria may help researchers better understand how pre-service teachers develop in their evaluation of technological tools for mathematics teaching. We then apply this model to the examination of a group of 144 pre-service

teachers as they evaluated technology tools for their future teaching of elementary mathematics. From this analysis, we provide recommendations that teacher educators approach teacher training in the teaching of mathematics with technology as a more integrated and multi-dimensional task, which is more closely aligned with the characteristics of TPACK and MKT.

Current Frameworks and Theories on Technology, Pedagogy, and Content Knowledge

Kersaint, Horton, Stohl, and Garofalo (2003) note that pre-service elementary and middle-school teachers don't necessarily receive specific instructions or engage in activities designed to assist them in technology integration in their own future mathematics lesson plans. Teacher knowledge of mathematics teaching supported by technology is critical when evaluating tools for use in lesson plans. If pre-service teachers are confident in their knowledge of mathematics, then they will create classroom environments that allow students to use technology freely (Doerr and Zangor, 2000). Conversely, if teachers' knowledge of mathematics is weak, or if they do not understand the output of the technology, they might be hesitant to use the technology with students (Monaghan, 2004). Kurz, Middleton, and Yanik (2004) studied pre-service teachers who were engaged in activities in which they were introduced to technology tools for mathematical learning and subsequently classified the tools according to five different categories. As a result of the required coursework, the elementary pre-service teachers not only identified the features of the tool, but were able to explain how these features could benefit student learning.

There are currently several theoretical and graphical frameworks used to explain relationships among technology knowledge, pedagogical knowledge, and mathematical content knowledge as these variables are used in teaching mathematics. One such framework is TPACK. TPACK

(previously known as TPACK in the literature) for mathematics is defined as “the intersection of the knowledge of mathematics with the knowledge of technology and with the knowledge of teaching and learning” (Niess et al., 2006, p. 3750). Mishra and Koehler (2007) represent this intersection of knowledge as a Venn diagram, where each of three circles contains pedagogical knowledge, technological knowledge, and content knowledge, with each circle intersecting the others. While the three components (technology, pedagogy, and content knowledge) represent distinct entities, Mishra and Koehler remind researchers that “TPCK is different from knowledge of all three concepts individually” (2007, p. 8). The representation of concepts using the technology, based on pedagogical strategies for teaching the content, and an understanding of how to use the technology to develop those concepts in children demonstrates the complexity of the integrated nature of TPACK.

Although the original expression of TPACK refers to “content” in general, Niess (2008) takes this model one step further by identifying how TPACK is expressed within mathematics education. In particular, she identifies the importance of teachers’ knowledge of students, curriculum, and instructional strategies for teaching and learning mathematics with technology. As Niess explains, this is an integration of “what the teacher knows and believes about the nature of mathematics, what is important for students to learn, and how technology supports learning mathematics” (p. 2-3). To investigate this phenomenon, Niess (2005) designed a course in which pre-service teachers identified technology resources for mathematical learning, and then identified the corresponding mathematics and technology standards which could be supported by the technology tools. As a result, the pre-service teachers purposefully engaged in reflection over appropriate technology use for mathematical learning.

A similarly complex and integrated model for understanding teachers’ mathematical knowledge for teaching is the Domains of Mathematical

Knowledge for Teaching (MKT) graphical framework described by Ball et al. (2008). In describing this framework they note that, based on their empirical results, “content knowledge for teaching is multidimensional” (p. 403). Described in detail elsewhere, three of the six domains that are pertinent to this discussion include Common Content Knowledge (CCK; “the mathematical knowledge and skill used in settings other than teaching,” p. 399), Specialized Content Knowledge (SCK; “the mathematical knowledge and skill unique to teaching,” p. 400), and Knowledge of Content and Teaching (KCT; “combines knowing about teaching and knowing about mathematics,” p. 401). These researchers propose models that include an emphasis on the integration of various types of knowledge to describe knowledge that is more complex than the individual parts themselves.

Capitalizing on the criteria proposed by Battey et al. (2005) in their study of pre-service elementary teachers, a third framework evolves for understanding teaching and learning mathematics with technology. They identified four main criteria for evaluating mathematics software for use with students: software features, mathematics features, learning features, and motivation features (see Table 1 for definitions of each feature). Johnston’s (2009, 2008) research with pre-service elementary teachers, using Battey et al.’s four criteria, found similar results. In all three studies, pre-service teachers emphasized Software Features most often over all other criteria. This finding suggests the important consideration that pre-service teachers need to view technology use in mathematics teaching situations as a mathematical instrument, rather than as a stand-alone tool. It also highlights the challenge that this type of integrative thinking poses for pre-service elementary teachers.

One final theoretical construct that considers relationships among technology, pedagogy, and mathematics is an understanding of the fidelity of the technology tools selected for instruction. Of particular importance in the development of our model are mathematical fidelity and cognitive

Table 1. Coding Schema for RQ 3a: Theoretical Categories, Substantive Codes, and Operational Definitions

Codes	Operational Definitions
Software Features	
Clarity	Clarity of directions to the user
Visual	Clear visual presentation
Technology	Ease of technology use
Purpose	Purpose of tool needs to be clear
Feedback	Feedback provided by tool for the user
Security/Safety	Pop-ups not included, doesn't link to inappropriate sites
Time	Time needed for set up or to understand usage
Mathematics	
Content	Comments about mathematics content (e.g. specific math concepts which can be explored via the tool)
Visual	Offers visual representations and/or reinforces concepts visually
Learning	
Student Use	Comments about how students use the tool (e.g. independent learning, centers)
Student Learning	Comments about student learning (e.g. allows for differentiation within a specific concept)
Motivation	
Affective	Comments about the tool being fun or students liking the tool
Student Interest	Comments about tools maintaining student interest
Engagement	Maintains student engagement

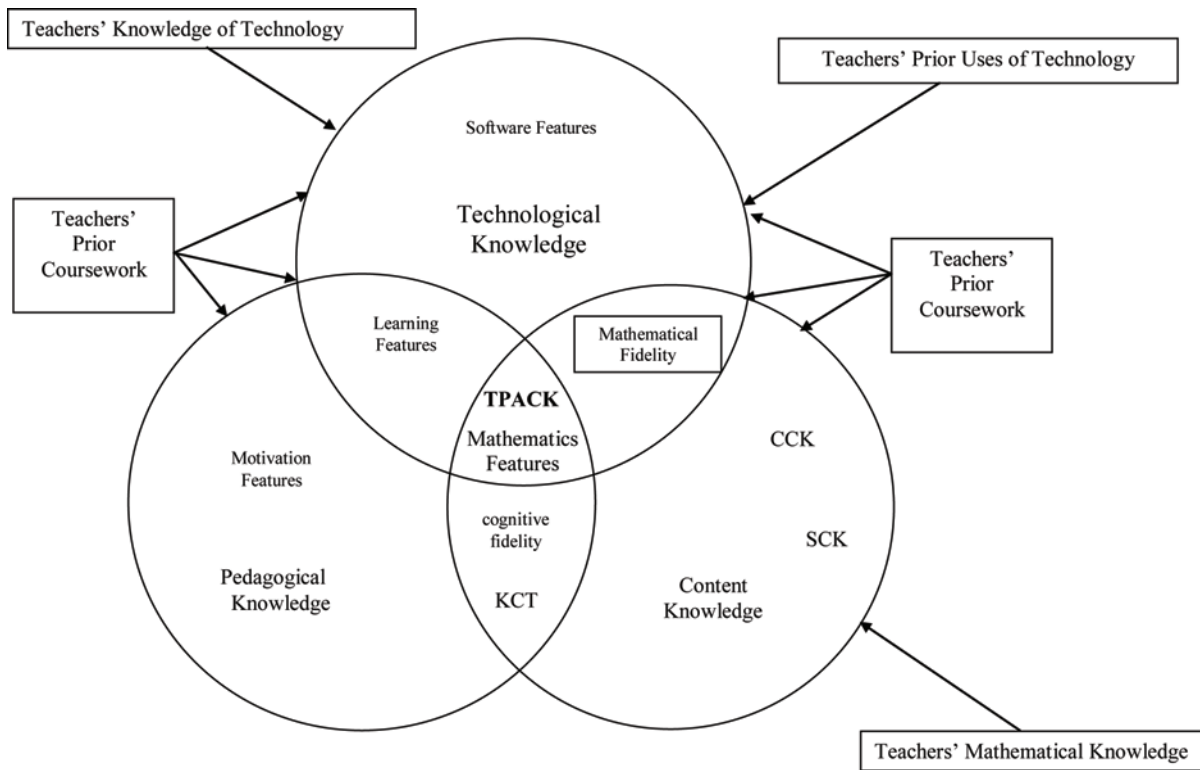
fidelity. In order for there to be high mathematical fidelity, “the characteristics of a technology-generated external representation must be faithful to the underlying mathematical properties of that object” (Zbiek, Heid, Blume, & Dick, 2007, p. 1174). In other words, the technology should model procedures and structures of the mathematical system, and be mathematically accurate. To be able to recognize mathematical fidelity in a technology tool, a teacher must have knowledge of mathematics and its underlying structures and connections. In order for there to be high cognitive fidelity, “if the external representations afforded by a cognitive tool are meant to provide a glimpse into the mental representations of the learner, then the cognitive fidelity of the tool reflects the faithfulness of the match between the two” (Zbiek et al., 2007, p. 1176). In other words, a tool with a high degree of cognitive fidelity should serve as an external model of the thinking of the user. In order for a teacher to recognize the cognitive fi-

delity of a technology tool, the teacher must have an understanding of mathematics and of the learner, including learning trajectories for particular mathematical concepts and how learners come to understand those mathematical concepts.

Proposed Model for Pre-Service Teachers' Technology Evaluations

The frameworks and constructs discussed in the previous section demonstrate the *integrated* nature of knowledge and the *complexity* of knowledge specifically as it is needed by teachers who want to use technology to teach mathematics effectively. Because each framework and construct informs different aspects of teachers learning to use technology for teaching mathematics, we propose a comprehensive model that takes into account elements of each framework in an integrated way. We refer to this comprehensive model as the *T-MATH Framework* (*Teachers' Mathematics and*

Figure 1. Conceptual Framework



Technology Holistic Framework). This model is a specific extension of TPACK, forming a model of teachers' knowledge of mathematical TPACK. The proposed model begins with the Mishra and Koehler's TPACK framework (2007), which includes Technological Knowledge, Pedagogical Knowledge, and Content Knowledge in three circles in a Venn diagram. Next we map onto this framework Ball et al.'s (2008) three domains of knowledge including: Common Content Knowledge (in the Content Knowledge circle), Specialized Content Knowledge (in the Content Knowledge circle), and Knowledge of Content and Teaching (in the intersection of the Pedagogical and Content Knowledge circles). Finally we consider the constructs of mathematical fidelity (in the intersection of the Technological and Content Knowledge circles) and cognitive fidelity (in the intersection of the Pedagogical and Content Knowledge circles). The model is presented in Figure 1.

We propose that when prior researchers (Battley et al., 2005; Johnston, 2008; 2009) reported that pre-service elementary teachers focused on various features of teaching mathematics with technology (e.g., software, mathematics, learning, motivation), their focus on these features reflects important information about the dimensions of their knowledge for teaching mathematics with technology. For example, when pre-service teachers focus their selection of technology tools for mathematics teaching on Software Features (which shows their Technological Knowledge) or Motivation Features (which shows their Pedagogical Knowledge), this is a "one dimensional" focus. That is, they are interested solely in an aspect of the technology tool that is not explicitly linked to students' learning or the learning of mathematics. For example, identifying features such as "has clear directions" (Software Feature) or "is fun for students to use" (Motivation Feature)

could apply to many different technologies or learning situations and does not consider how the features are related to learning mathematics concepts. On Figure 1, we have positioned Software Features and Motivation features in the Technological Knowledge and Pedagogical Knowledge circles, respectively. Pre-service teachers who focus on these features are exhibiting a singular focus and no intersection with other knowledge areas in the model, thus reflecting a less integrated knowledge.

When pre-service teachers focus their selection of technology tools for mathematics teaching on Learning Features (which shows their knowledge of how the technology is related to student learning), this is a “two dimensional” or integrated focus. That is, they are connecting the features of the technology to students’ learning with the technology. For example, identifying a feature such as “applicable to what we are learning in the classroom” connects the technology with the pedagogy of the classroom, considering the implications of both the technology and the pedagogy. On Figure 1, we have positioned Learning Features in the intersection of the two circles for Technological Knowledge and Pedagogical Knowledge. We propose that identifying a Learning Feature requires teachers to make a connection between technology and pedagogy, and thus reflects a more integrated type of knowledge with respect to learning and the use of technology. For example, when pre-service teachers consider the use of embedded buttons on an applet which allow the selection of “easy” or “difficult” mathematics problem items this allows for learning differentiation afforded by the technology.

Finally, when pre-service teachers focus their selection of technology tools for mathematics teaching on Mathematics Features, this is highly complex, representing a “multi-dimensional” focus and requiring highly specialized and integrated knowledge. On Figure 1, we have positioned Mathematics Features at the intersection of the three circles. We propose that identifying

a Mathematics Feature requires teachers to make multiple connections among technology, pedagogy, mathematics (including CCK, KCT, and SCK), and mathematical and cognitive fidelity. Let us further examine the complexity of this placement. The circle of Content Knowledge itself, specific to our model, includes Common Content Knowledge and Specialized Content Knowledge (i.e., mathematical knowledge and skill; Ball et al., 2008). At the intersection of Technological and Content Knowledge is mathematical fidelity (the technology adheres to procedures and structures of the mathematical system; Zbiek et al, 2007). The intersection of the Content Knowledge circle and the Pedagogical Knowledge circle integrates knowledge, and is reflective of Knowledge of Content and Teaching (i.e., combines knowing about teaching and knowing about mathematics; Ball et al., 2008) and cognitive fidelity (the match between external and mental representations of the mathematics; Zbiek et al, 2007). The intersection of the Content, Pedagogy, and Technology circles are at the highest levels of complexity because they integrate each of the types of knowledge previously discussed, thereby forming the total package. Essentially, teaching a mathematics lesson using appropriate technology requires what the recent literature describes as TPACK, Technological Pedagogical Content Knowledge.

The positioning of Mathematics Features in the three-circle intersection indicates the complexity of this focus for teachers. We propose that when pre-service teachers focus on Mathematics Features, they must have a deep understanding of technology, pedagogy, *and* mathematics. As Mishra and Koehler (2006) note:

TPCK is the basis of good teaching with technology and requires an understanding of the representation of concepts using technologies; pedagogical techniques that use technologies in constructive ways to teach content; knowledge of what makes concepts difficult or easy to learn and how technology can help redress some of the problems

that students face; knowledge of students' prior knowledge and theories of epistemology; and knowledge of how technologies can be used to build on existing knowledge and to develop new epistemologies or strengthen old ones (p. 1029).

Specifically, Mathematics Features can focus on three primary areas, as noted in our survey and in the paragraphs which follow.

Provides multiple representations of mathematical concepts. Many technology tools offer multiple representations of mathematical concepts. For example, a graphing calculator allows students to explore three primary representations: graphs, tables, and equations. As Juersivich, Garofalo, and Fraser (2009) found, pre-service mathematics teachers used technology-generated representations to support appropriate pedagogy within the context of their own instruction. For example, since "technology-generated representations are easily manipulated, pupils can visualize the relationships that are being represented and observe the consequences of their actions" (p. 17). Further, as these authors note, students are able to analyze, make connections among, and develop meaning for the representations generated by the technology. However, the ability to construct such a meaningful, technological rich task for students requires that the teacher have a deep understanding of Technological Pedagogical Content Knowledge (i.e. the intersection of all three circles in the Venn Diagram) for mathematics.

Links conceptual understanding with procedural knowledge. The five strands of mathematical proficiency (Kilpatrick, Stafford, & Findell, 2001), include procedural fluency, conceptual understanding, strategic competence, adaptive reasoning, and productive disposition. Further, Ma (1999) identifies "profound understanding of fundamental mathematics" as a highly organized package of concepts *and* procedures. How, then, does a teacher capitalize on the features of a technology tool for mathematical, take into account the prior knowledge of his or her own students,

and determine best practices for using technology as an aid to instruction? We assert that the claims made by Mishra and Koehler earlier in this section place Mathematics Features at the intersection of the three circles of the TPACK Venn Diagram because of the complexity of such issues.

Connects multiple mathematical concepts. Garofalo et al. (2000) identify two ways in which technology-enhanced mathematical activities can allow students to make connections: by making connections within mathematics, as well as to real-world situations and phenomena. For example, technology can allow students to access, manipulate, and analyze real-world data. Further, technology can be used by "teachers and students to bring together multiple representations of mathematical topics" (p.73). Once again, teachers of mathematics must capitalize on their deep understandings of technological, pedagogical, and content knowledge in order to effectively use technology to connect multiple mathematical concepts.

METHODS

The methods employed in this study included both quantitative and qualitative methodologies in the analysis of electronic survey documents to determine the criteria preservice teachers identified and ranked when evaluating technology tools for mathematical learning. These methods were used to answer the following four research questions: (1) What criteria do pre-service elementary teachers identify when evaluating technology tools for mathematical learning? And, What do these choices indicate about teacher knowledge of technology (with respect to TPACK)? (2) How do pre-service elementary teachers rank criteria, which have been identified for them, when evaluating technology tools for mathematical learning? And, What do these rankings indicate about teacher knowledge of technology (with respect to TPACK)? (3) How do pre-service elementary

teachers evaluate technology tools for mathematical learning? And, What do these evaluations indicate about teacher knowledge of technology in mathematics? (4) What teacher background factors influence pre-service elementary teachers' criteria for and evaluations of technology tools for mathematical learning?

Participants

The participants in this study were 144 pre-service teachers enrolled in nine different sections of elementary mathematics methods courses at two different universities (one eastern and one western). A majority of the participants were undergraduate students in their senior year of college earning a Bachelor's degree in Elementary Education (68%). The remaining participants had completed their Bachelor's degrees and were in a program earning teaching licensure in Elementary Education (32%). All participants were enrolled in a fall or spring section of an elementary mathematics methods course during one academic year. Consistent with the current teaching population of elementary teachers, the majority of the participants were female (94% female, 6% male). The age of the participants ranged from 19 to 56. Participants had the option to self-select, anonymously, whether or not their responses would be included in the study by choosing an item on an electronic survey that provided the following choice: "Check here if you are participating in the research study and you want your responses to be included" or "Check here if you are not participating in the research study and you do not want your responses to be included." Since there were no names requested of the participants on the electronic survey, participants remained anonymous throughout the data collection and analysis process.

Procedures

During the elementary mathematics methods courses, participants interacted with a variety

of technology tools for use in elementary mathematics classroom teaching including various computer programs and applets. Prior to asking participants to evaluate four technology applets on the electronic survey, participants had several opportunities in the universities' computer labs to explore these applets. During one class session, for each of the nine course sections participating in the study, time was provided for participants to complete the electronic survey. The electronic survey included a variety of questions about participants' criteria for selecting technology tools, their evaluation of four virtual manipulatives and applets, and information about their personal uses of technology.

Instrumentation

The primary instrument used to collect data in this study was an electronic survey constructed using Zoomerang® technology. This technology allowed researchers to link computer-based applets, or virtual manipulatives (Moyer, Bolyard, & Spikell, 2001), available on the World Wide Web, to questions contained in the survey. This feature was essential so that participants could view and manipulate the virtual manipulative applets and evaluate them without leaving or closing the electronic survey.

The survey contained a total of 17 questions. The first question was open-ended and asked participants to identify five primary criteria they would use when selecting a technology tool for use in their own future classrooms. Next, participants ranked a set of 12 given criteria for using technology in mathematics teaching. On questions three through six of the survey, participants were provided with the links to the following four virtual manipulative applets: NLVM Fractions-Adding, NCTM Illuminations Fractions Model I, NLVM Base Blocks Addition, and NLVM Sieve of Eratosthenes. These four virtual manipulatives were selected because they could be used by pre-service teachers at a variety of elementary grade levels,

and because each offered various affordances. For each of these four virtual manipulatives, participants responded to five criteria questions about each applet. Further discussion of each of the four virtual manipulatives follows.

NLVM Fractions-Adding Tool

The NLVM Fractions Adding tool allows students to explore adding fractions with unlike denominators. Students rename two fractions so the denominators are the same; at the same time, they are using a region model to show the pictorial representation for each fraction via the shaded region. The NLVM Fractions Adding tool was selected because it allows students to make connections between symbolic (numerical) and pictorial (fraction) models, links procedural and conceptual modalities, allows students to experiment in finding common denominators, allows for differentiation among students (the radio buttons include easier, harder, and hardest problems), has directions that provide guidance and vocabulary, and provides guiding feedback.

Illustrations Fraction Model I Tool

The Illustrations Fraction Model I tool allows students to make connections among fractions, decimals, and percents. Students use a slider to adjust the numerator and denominator of a given fraction, and the pictorial representation (fraction circle) is shaded to correspond to that new fraction. In addition, the corresponding decimal and percent are displayed for the student. The Illustrations Fraction Model I tool was selected because it allows students to make connections between the symbolic (numerical) and pictorial (fraction) models, links procedural and conceptual modalities, links three mathematical representations (fractions, decimals, and percents), and allows for differentiation (students can select the numerator and denominator of the fraction they wish to explore).

NLVM Base Blocks Addition Tool

The NLVM Base Blocks Addition tool allows students to add base-ten numbers using base-ten blocks (units or ones, rods or tens, flats or hundreds, and cubes or thousands). Students can practice exchanging or regrouping with the base ten blocks. For example, they can “lasso” ten units to form one tens rod. The NLVM Base Blocks Addition tool was selected because it allows students to make connections between symbolic (numerical) and pictorial (base-ten blocks) models, change the base systems and alter the number of columns, link procedural and conceptual modalities, receive guiding directions, explore composing and decomposing numbers (by moving the blocks across tens places), and create their own addition problems to explore.

NLVM Sieve of Eratosthenes Tool

The NLVM Sieve of Eratosthenes tool serves two primary purposes. Students can use this tool to identify prime and composite numbers from 2 through 200. By clicking on a number, such as 3, the tool automatically removes all of the multiples of that number. Through a guided activity, students can continue removing multiples (composite numbers) and thereby identify the remaining numbers as prime. Students can also use this tool to explore multiples of numbers without the context of prime or composite. The NLVM Sieve of Eratosthenes tool was selected because it allows students to interactively identify multiples of numbers, run a basic simulation, explore in a more open-ended fashion number patterns, highlight the prime numbers (via “Remove the Multiples”), find common multiples (via “Show the Multiples”), alter the display number of rows.

Additional questions on the electronic survey asked participants to report how often they used technology tools for personal use (i.e., text messaging, email, social networking sites, or word processing), and to rank themselves along a continuum

from “extreme tech user” to “non-tech user,” and from “tech literate” to “non-tech literate.” The final questions on the survey gathered information on the mathematics courses and technology courses participants had taken, and their age and gender. These questions were used to determine whether or not participants’ background characteristics were related to their use and evaluation of the technology tools.

Analytic Methods

Cluster analysis was selected as an analytic technique because it “groups individuals or objects into clusters so that objects in the same cluster are more similar to one another than they are to objects in other clusters. The attempt is to maximize the homogeneity of objects within the clusters while also maximizing the heterogeneity between the clusters” (Hair, Black, Babin, Anderson, & Tatham, 2006, p. 555). Because the sample included 144 participants, we sought to explore commonalities among participants using grouping techniques to understand participant clusters based on their common features. By employing the cluster analysis technique, we developed hypotheses concerning several clusters of participants, which is consistent with one of the roles of cluster analysis in conceptual development (Hair et al., 2006). Because our research questions sought to identify relationships, homogenous groups were formed. As Hair et al. (2006) note: “With the clusters defined and the underlying structure of the data represented in the clusters, the researcher has a means of revealing relationships among the observations that typically is not possible with the individual observations (p. 569). Further, the authors note this approach is appropriate when qualitative methods are employed in the methodology of the research study.

As Hair et al. (2006) note, the results of cluster analysis are not generalizable because the process is dependent upon the variables used to measure similarity. Further, they note that some critics

find cluster analysis to be subjective. We assert that while these results are not necessarily generalizable to the entire population of pre-service teachers, important findings from this study can be applied to other populations of pre-service teachers, as noted in the discussion which follows. Hair et al. (2006) also note that sample size needs to be considered when clusters are formed. In the present study, the responses of 144 participants were analyzed. Three distinct clusters emerged from the data. Since “larger samples increase the chance that small groups will be represented by enough cases to make their presence more easily identified” (Hair et al., 2006, p. 571), we are confident that all relevant groups of the population were accurately represented.

The first analysis answered Research Question #1: What criteria do pre-service elementary teachers identify when evaluating technology tools for mathematical learning? And, What do these choices indicate about teacher knowledge of technology (with respect to TPACK)? To answer this question, participants were asked to list five primary criteria for evaluating technology tools for mathematical learning. We examined participants’ responses and coded each response using the following four codes: *software feature*, *mathematics*, *learning*, or *motivation*, based on Battey et al.’s (2005) criteria for pre-service teachers evaluating mathematical software. Using these four codes gave each participant a distinct profile which emphasized the participants’ focus when evaluating the technology tools (i.e., Software Feature, Mathematics, Learning, or Motivation). Two readers independently coded the participant-identified criteria to determine the profiles. There were 720 data points coded during this process (144 participants x 5 identified criteria each = 720 data points). A subset of the data (200 data points representing 28% of the data) were double coded (i.e., coded independently by both readers) with an inter-rater reliability of 87%. Readers discussed and came to consensus on the discrepant items. Once each participant had a distinct 5-criteria

profile, we used the technique of cluster analysis to group individual pre-service teachers into similar groups or *clusters* (Hair et al., 2006), because our coded data were in the form of discrete, categorical variables. We named each of these clusters for ease of discussion in the results (Math/Learning Cluster, the Balanced Cluster, and the Software Feature/Motivation Cluster).

The second analysis addressed Research Question #2: How do pre-service elementary teachers rank criteria, which have been identified for them, when evaluating technology tools for mathematical learning? And, What do these rankings indicate about teacher knowledge of technology (with respect to TPACK)? To answer this question, we examined how the entire group of participants ranked 12 criteria provided for them on the survey, and also how each of the clusters (i.e., Math/Learning Cluster, the Balanced Cluster, and the Software Feature/Motivation Cluster) ranked the 12 criteria. We summed the criteria to determine overall high and low rankings on the 12 criteria for “assessing the quality of mathematics technology tools.” This process produced a rank-ordered list of the 12 criteria, from most important to least important, based on participants’ ranking responses. We also summed the individual criteria for each of the four main criteria categories (i.e., Software Feature, Mathematics, Learning, or Motivation) and examined participants’ rankings of these main criteria for the group overall and for the three clusters.

The next analysis answered Research Question #3: How do pre-service elementary teachers evaluate technology tools for mathematical learning? And, What do these evaluations indicate about teacher knowledge of technology in mathematics? To answer this question, we started with our three participant clusters (i.e., Math/Learning Cluster, the Balanced Cluster, and the Software Feature/Motivation Cluster) and their rating scores for the virtual manipulatives they evaluated. For each of the three participant clusters, we computed an average score for each cluster based on their

assessments of the five characteristics of the four virtual manipulatives that they examined during the electronic survey. The four tools were each evaluated on a 1-5 Likert rating scale on the following five characteristics: linking conceptual and procedural, allows for differentiation, multiple representations, maintains interest, and provides feedback. For example, when the participants in the Math/Learning Cluster ranked the NLVM Fractions Adding Tool on “the tool links conceptual understanding with procedural knowledge” on a scale of 1 to 5, the average rating given by the Math/Learning Cluster group, as a whole, was 4.23 on this characteristic for this applet. Using the average rating score on each characteristic for each applet for the three participant clusters, we then plotted these average ratings on a line graph so that we could compare and contrast how the three participant clusters evaluated the four technology tools. The purpose of this analysis was to examine how the three different clusters of participants evaluated the virtual manipulatives and determine what this might reveal about similarities and differences among the groups.

The final analysis answered Research Question #4: What teacher background factors influence pre-service elementary teachers’ criteria for and evaluations of technology tools for mathematical learning? The purpose of this question was to determine if there were any relationships among our three participant clusters (i.e., Math/Learning Cluster, the Balanced Cluster, and the Software Feature/Motivation Cluster) and their personal technology uses and background characteristics. To answer this question, we started with our three participant clusters and examined their responses to ten background questions. The first eight questions were in the form of 1-5 Likert scale ratings and asked participants to report the frequency with which they used technology and their comfort as a technology user. These questions asked participants to rate their use of instant messaging, word processing, text messaging, Facebook, and email on a scale from “never” (= 1) to “multiple

times each day” (= 5). Two other questions asked participants to report their age and the number of semesters of mathematics coursework they had taken. We entered these data, on the three participant clusters, into SPSS software to compare the responses of the three groups. During this analysis, we computed average scores for each cluster on each of the ten items, used an ANOVA to determine significant differences among the participant clusters on the ten items, and used a Pearson Correlation to determine significant relationships among the clusters and the ten items.

Potential Threats to Validity and Reliability

As Maxwell (2005) notes, two specific threats to validity exist in qualitative research. The first of these threats, researcher bias, can be minimized by “understanding how a particular researcher’s values and expectations influence the conduct and conclusions of the study (which may be either positive or negative) and avoiding the negative consequences” (p. 108). To minimize researcher bias, the researchers employed two methods suggested by Maxwell, searching for discrepant evidence and negative cases, as well as comparison. The authors independently analyzed the data and discussed any potential discrepancies or negative cases. Similarly, the authors made frequent comparisons within the clusters and between clusters to ensure the three clusters which emerged from the data were reflective of the participants in the study.

The second of these threats, reactivity, can be described as the “influence of the researcher on the setting or individuals studied” (Maxwell, 2005, p. 108). Maxwell states that eliminating the influence of the researcher is impossible, but that how the researcher might influence the participants should be addressed. Reactivity was minimized through the research design. Since the participants were engaged in independent surveys, and because there were no observations, interviews, or other interaction with the participants, reactivity was

less of a threat in this research study. At the same time, however, we would be remiss if we did not address the potential limitations and threats to validity when working with a sample consisting of a study of one’s own students. There is the potential for the data to reflect the expectation of the instructor of record; that is, the collected data might not match the actual beliefs of the participants. However, since the survey was conducted anonymously, and because the participants were aware that a researcher other than their instructor would be analyzing the data, we assert that the influence of the course instructor was minimized.

Additionally, we addressed two issues of reliability. The first issue deals specifically with the design of the data collection instrument (survey). We developed our instrument based upon previous pilot tests of similar instruments (see Johnston 2009; 2008) and adapted the instrument to specifically answer our research questions. The instrument underwent several iterations, based upon feedback from prior pilot tests. Prior to launching the survey, four independent reviewers tested the survey and offered their feedback on the instrument. The other issue deals specifically with inter-rater reliability when coding the self-identified criteria (Research Question 1). In qualitative research, coding by two independent researchers can lead to discrepancies and differing results. As previously noted, this issue was addressed in our methods.

RESULTS

Criteria Identified by Pre-Service Teachers for Evaluating Technology

Research Question 1 asked: What criteria do pre-service elementary teachers identify when evaluating technology tools for mathematical learning? And, What do these choices indicate about teacher knowledge of technology (with respect to TPACK)? As pre-service teachers identi-

Table 2. Clusters of Participants Based on Their Self-identified Criteria.

Cluster	n
Math/Learning Cluster	13
Balanced Cluster	86
Software Features/Motivation Cluster	45

fied their own criteria for evaluating technology tools for mathematical learning, they focused on those aspects of the technology which supported student learning. Participants' self-identified the following criteria (coded as *software feature*, *mathematics*, *learning*, or *motivation*; Battey et al., 2005) for evaluating and using technology tools for mathematical learning. Criteria are listed from greatest to least frequency and the numbers in parentheses indicate the number of times each criterion was identified by the pre-service teachers. Specifically, this list includes: Software Features (309); Learning (197); Motivation (113); and Mathematics (101).

From the criteria identified by pre-service teachers, three distinct clusters of pre-service teachers emerged: the Math/Learning Cluster, the Balanced Cluster, and the Software Feature/Motivation Cluster. The clusters, and the number of pre-service teachers in each cluster, are presented in Table 2.

The Math/Learning Cluster, was the smallest of the three pre-service teacher groups (N = 13). This cluster included participants who identified criteria that were focused on mathematics and learning for four or five of the five self-identified criteria for evaluating mathematical software. The Balanced Cluster, was the largest of the three pre-service teacher groups (N = 86). This cluster included participants whose criteria were a balance of all four of the criteria (i.e., *software feature*, *mathematics*, *learning*, and *motivation*). These participants identified criteria coded as learning and/or mathematics for two or three of the criteria, and software features and/or motiva-

tion for two or three criteria. The Software Feature/Motivation Cluster, included participants who identified criteria that were focused on software features and motivation (N = 45). Table 3 shows sample profiles of a pre-service teacher within each of the three clusters.

Pre-service teachers in each cluster shared similar codes and characteristics with the pre-service teachers presented in the sample profiles. For example, pre-service teachers in the Math/Learning Cluster identified five criteria which focused solely on Mathematics or Learning Features and did not list Motivation or Software Features in their identification of technology criteria. These pre-service teachers demonstrated integration by focusing on two-dimensional (Learning) and three-dimensional (Mathematics) aspects of TPACK.

Pre-service teachers in the Balanced Cluster identified a combination of Software Features, Learning, Motivation, and Mathematics. In doing so, these pre-service teachers demonstrated partial integration by focusing on both one-dimensional (Software Features and Motivation) and two-dimensional (Learning) aspects of TPACK with minimal discussion of Mathematics Features.

Pre-service teachers in the Software Feature/Motivation Cluster identified five criteria which focused solely on Software Features or Motivation and did not identify Mathematics or Learning in their technology criteria. In doing so, these pre-service teachers focused only on one-dimensional aspects of TPACK (i.e., Software Features and Motivation).

Criteria Ranked by Pre-Service Teachers for Evaluating Technology

Research Question 2 asked: How do pre-service elementary teachers rank criteria, which have been identified for them, when evaluating technology tools for mathematical learning? And, What do these rankings indicate about teacher knowledge of technology (with respect to TPACK)? Table

Table 3. Profiles of Pre-Service Teachers in Each of the Three Clusters

Cluster	Five Criteria	Code	Discussion
Math/ Learning Cluster	address the math in context using tech	MA	The participant focused on two-dimensional (Learning) and three-dimensional (Mathematics) aspects of TPACK. The participant considers technology, pedagogy, and content knowledge simultaneously.
	make connections with other mathematics topics	MA	
	use tech to incorporate multiple representations	MA	
	use tech software appropriate for age/ability	LE	
	supplement hands-on learning	LE	
Balanced Cluster	User friendly and easy access	SF	The participant focused on primarily one-dimensional (Software Features and Motivation) and two-dimensional (Learning) aspects of TPACK. The participant does mention Mathematics, but not in a specific manner. The participant does not consider technology, pedagogy, AND content knowledge simultaneously.
	Applicable to what they need to learn (math concepts)	MA	
	Applicable to what we're learning in the classroom	LE	
	Something the children enjoy doing and look forward to doing	MO	
	Children can easily figure out what they need to do so they aren't frustrated by the directions.	SF	
Software Feature/ Motivation Cluster	very easy to use	SF	The participant focused on one dimension of TPACK: Software Features or Motivation. The participant does not consider the intersection between technology, pedagogy, and content knowledge.
	clear directions	SF	
	can relate to things they are interested in	MO	
	it is a great way to save paper	SF	
	fun activity and helps to learn about technology	MO	

4 lists the 12 criteria that were provided to pre-service teachers, and shows the results from the analysis of how the twelve criteria were ranked by the group, overall, and by the three Clusters (Math/Learning Cluster, Balanced Cluster, and Software Feature/Motivation Cluster). Note that the survey question for this analysis included a total of 12 items, with three item indicators for each of the four main criteria (i.e., Software Features, Motivation, Learning, and Mathematics).

These results reveal some similarities and some differences among the three Clusters. For example, the three Clusters gave consistently high rankings to MO₁ (Maintains student interest/engages them) as an important criteria for assessing the quality of mathematics technology tools. The three Clusters were also similar in their low rankings of MO₂ (Is fun for students), LE₃ (The tool

provides challenging content), and MO₃ (Provides a game-like activity for the students) as criteria for assessing technology tools. The pre-service teacher Clusters also revealed a number of contrasts among their ratings. For example, the Math/Learning and the Balanced Clusters both ranked LE₁ (Is age/grade appropriate) as the most important criteria for assessing the quality of mathematics technology tools, while the Software Feature/Motivation Cluster only ranked this criteria as 5th most important. There were also a number of contrasts between the Math/Learning Cluster and the other two Clusters. For every Mathematics Feature (MA₁ = Provides multiple representations of mathematical concepts, MA₂ = Links conceptual understanding with procedural knowledge, MA₃ = Connects multiple mathematical concepts), the Math/Learning Cluster ranked each individ-

Table 4. Summary of Results: Research Question 2

Rank	Overall Group	MA/LE Cluster	Balanced Cluster	SF/MO Cluster
1	SF ₁	LE ₁	LE ₁	SF ₁
2	LE ₁	SF ₂	SF ₁	MO ₁
3	MO ₁	MA ₁ & MO ₁	MO ₁	LE ₂
4	LE ₂		LE ₂	SF ₂
5	SF ₂	LE ₂	SF ₂	LE ₁
6	MA ₁	MA ₂	MA ₁	SF ₃
7	SF ₃	MA ₃	SF ₃	MA ₁
8	MA ₂	SF ₁	MA ₂	MA ₃
9	MA ₃	SF ₃	MO ₂	MA ₂ & MO ₂
10	MO ₂	MO ₂	MA ₃	
11	LE ₃	LE ₃	LE ₃	LE ₃
12	MO ₃	MO ₃	MO ₃	MO ₃

Note.

Software Features: SF₁ = Provides clear instructions to the user, SF₂ = Is easy to navigate/use, SF₃ = Provides feedback to students;

Learning Features: LE₁ = Is age/grade appropriate, LE₂ = Allows for differentiation among students, LE₃ = The tool provides challenging content;

Motivation Features: MO₁ = Maintains student interest/engages them; MO₂ = Is fun for students, MO₃ = Provides a game-like activity for the students;

Mathematics Features: MA₁ = Provides multiple representations of mathematical concepts, MA₂ = Links conceptual understanding with procedural knowledge, MA₃ = Connects multiple mathematical concepts.

ual mathematics criterion higher than the rankings given by the other two Clusters. In addition, the Math/Learning Cluster ranked SF₁ (Provides clear instructions to the user) as a much less important criterion (8th ranking), while the other two Clusters identified this criterion as highly important in their rankings (1st and 2nd rankings).

When the criteria in the four main categories (i.e., Software Features, Motivation, Learning, and Mathematics) were combined, there was also a clear distinction among the three pre-service teacher Clusters. While the Math/Learning Cluster ranked the items for Mathematics Features as most important of the four criteria, overall, the Balanced and Software Feature/Motivation Clusters ranked Mathematics as least important of the four criteria, instead, identifying Software Features as most important in their rankings. As the results from Research Questions 1 and 2 indicate, the Clusters were consistent in their identification of criteria that were important to them, both when

they named the criteria and when the criteria were provided for them to rank. With respect to TPACK, the pre-service teachers in the Math/Learning Cluster seemed to consider criteria that reflected the integration of technology use with mathematics and learning, rather than focusing on the software features or motivating factors of the technology tools.

Pre-Service Teachers' Evaluations of Four Virtual Manipulatives

Research Question 3 asked: How do pre-service elementary teachers evaluate technology tools for mathematical learning? And, What do these evaluations indicate about teacher knowledge of technology in mathematics? The results for each of the four technology tools are summarized below and include a graph for each tool. The graphs show the mean ratings, by each of the three clusters, for

each of the five criteria. As stated in the survey, the five criteria were as follows:

- A. The tool links conceptual understanding with procedural knowledge. (MA)
- B. The tool allows for differentiation among students. (LE)
- C. The tool provides multiple representations of mathematical concepts. (MA)
- D. The tool maintains student interest (engages students). (MO)
- E. The tool provides feedback to the students. (SF)

Each criterion was rated on a scale from 1 to 5, with 1 indicating “I strongly disagree that the technology tool meets the criteria”, and 5 indicating “I strongly agree that the technology tool meets the criteria.” Remember that these four virtual manipulatives were selected because they integrated various learning and mathematical features representative of cognitive technology tools. Of note is that the Software Features/Motivation Cluster gave the lowest ratings of the three Clusters across all of the four virtual manipulatives evaluated.

NLVM Fractions-Adding tool. As noted in Figure 2, the Math/Learning Cluster consistently rated the *NLVM Fractions Adding tool* higher on each of the five criteria than the other two pre-service teacher Clusters. In addition, the Math/Learning Cluster ranked this technology tool higher than all of the other virtual manipulatives on all five criteria. Criteria A (MA), B (LE), and C (MA) had similar or very close ratings by both the Balanced and Software Feature/Motivation Clusters; while Criteria D (MO) and E (SF) were rated higher by the Balanced Cluster than the Software Feature/Motivation Cluster. All three pre-service teacher Clusters gave this tool the highest ratings for Software Features compared with the other three virtual manipulatives they evaluated.

Illustrations Fraction Model I Tool.

As noted in Figure 3, the Math/Learning Cluster consistently rated each of the five criteria higher than the other two pre-service teacher clusters. Criteria A (MA), B (LE), C (MA), and D (MO) had similar or very close ratings by the Balanced and Software Feature/Motivation Clusters, with the exception of Criteria E (SF) which was rated higher by the Balanced Cluster than the Software Feature/Motivation Cluster.

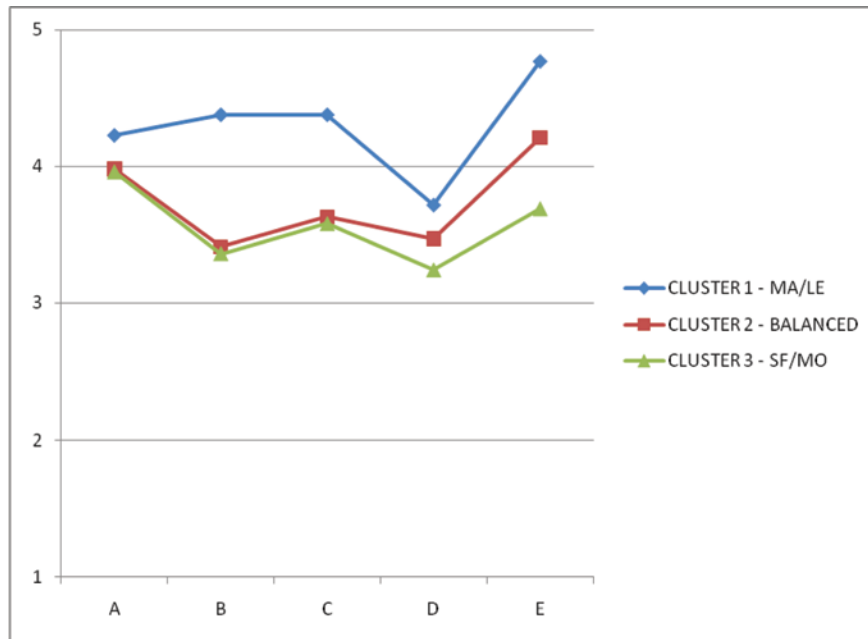
NLVM Base Blocks Addition Tool.

Figure 4 shows that Criteria B (LE) and C (MA) were rated higher by the Math/Learning Cluster than by the other two Clusters. Criteria A (MA) and D (MO) had similar ratings by all three clusters. The Math/Learning Cluster ranked the *NLVM Base Blocks Addition Tool* lowest on Criteria D (SF). This was one tool where all three pre-service teacher Clusters were in agreement with high ratings on the tool for a Mathematics Feature (i.e., “tool links conceptual understanding with procedural knowledge”).

NLVM Sieve of Eratosthenes Tool.

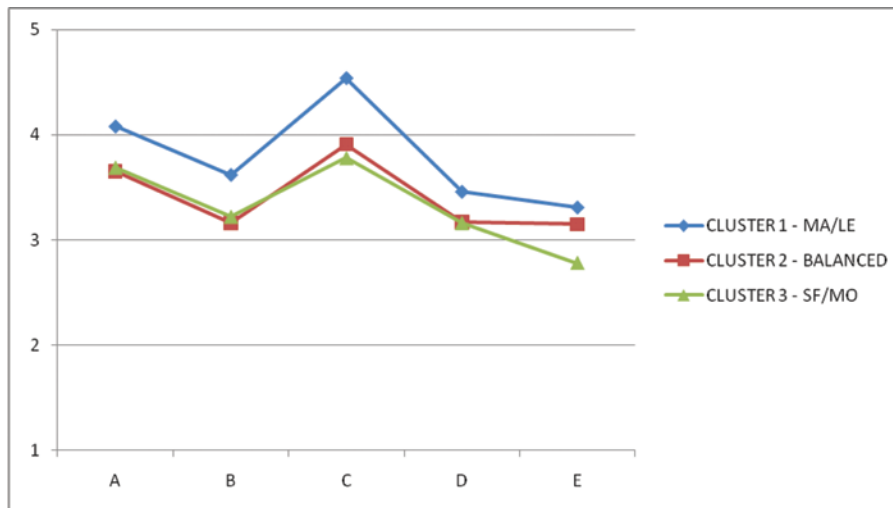
As noted in Figure 5, Criteria A (MA), C (MA), and E (SF) were rated higher by the Balanced Cluster than the other two Clusters. Criteria B (LE) had similar ratings by all three clusters. Criteria D (MO) was rated highest by the Math/Learning and Balanced Clusters. Of the four tools, this is the only one in which a cluster other than the Math/Learning Cluster ranked Criteria A and C (both MA) the highest. Overall, the three Clusters ranked this tool the lowest on all five criteria when compared with the other three virtual manipulatives they evaluated. In particular, the lowest of the low rankings were given by the Software Features/Motivation Cluster. Remember that this virtual manipulatives does not provide a guided experience through a mathematical procedure, but

Figure 2. Results of Research Question 3: NLVM Fractions Adding Tool



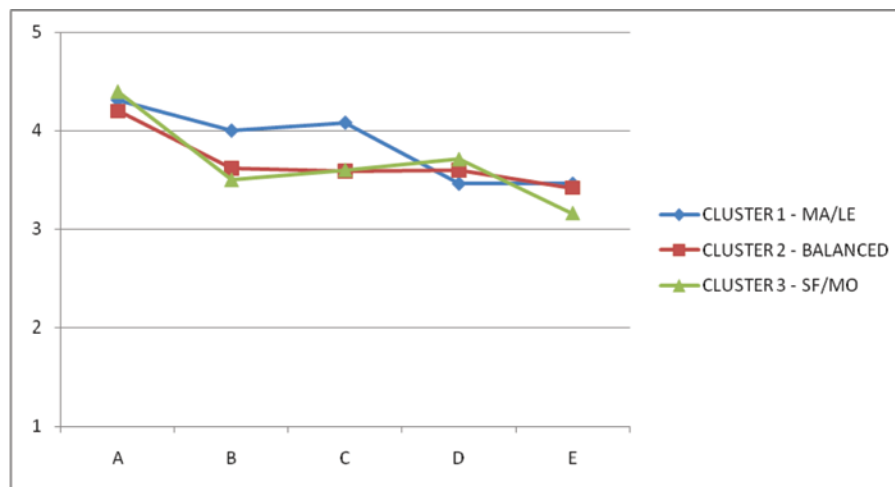
Notes: A The tool links conceptual understanding with procedural knowledge. (MA)
 B The tool allows for differentiation among students. (LE)
 C The tool provides multiple representations of mathematical concepts. (MA)
 D The tool maintains student interest (engages students). (MO)
 E The tool provides feedback to the students. (SF)

Figure 3. Results of Research Question 3: Illuminations Fraction Model I Tool



Notes: A The tool links conceptual understanding with procedural knowledge. (MA)
 B The tool allows for differentiation among students. (LE)
 C The tool provides multiple representations of mathematical concepts. (MA)
 D The tool maintains student interest (engages students). (MO)
 E The tool provides feedback to the students. (SF)

Figure 4. Results of Research Question 3: NLVM Base Blocks Addition Tool



Notes: A The tool links conceptual understanding with procedural knowledge. (MA)
 B The tool allows for differentiation among students. (LE)
 C The tool provides multiple representations of mathematical concepts. (MA)
 D The tool maintains student interest (engages students). (MO)
 E The tool provides feedback to the students. (SF)

rather it is an open-ended exploration of number primes and multiples.

Relationships Among Technology Criteria and Pre-Service Teachers' Background Characteristics

Research Question 4 asked: What teacher background factors influence pre-service elementary teachers' criteria for and evaluations of technology tools for mathematical learning? Although the Cluster Groups differed on their criteria for rating each of the four technology tools, an Analysis of Variance showed that there were no statistically significant differences among the groups on ten background characteristics,

$F(2, 141) = 1.806$, M.S.E. = .605, $p = .066$.

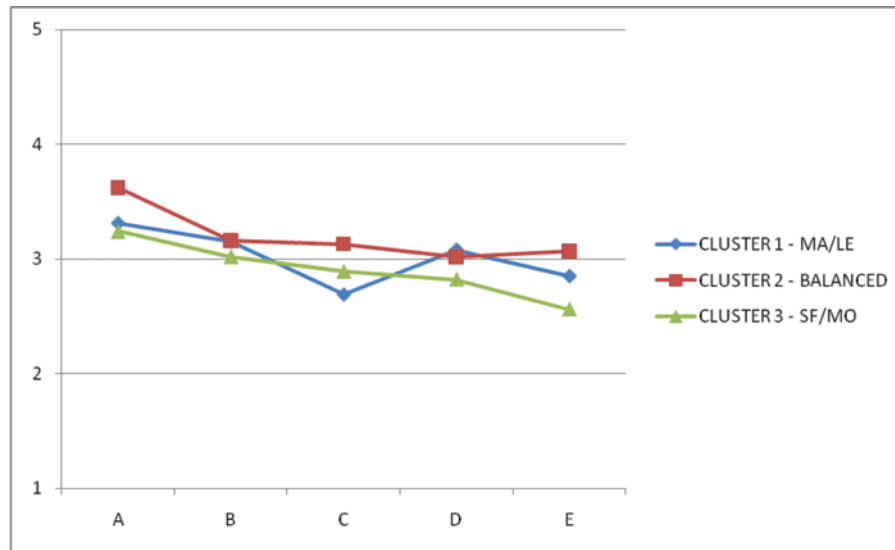
The descriptive results of this analysis are presented in Table 5.

For each of the background characteristics in Table 5, participants ranked themselves on a 1 to 5 Likert scale. On the scale, a 5 indicated the most/

greatest amount of use and a 1 indicated the least amount of use, with the exception of semesters of coursework (where the numbers represented actual numbers of semesters) and age (where the numbers represent the actual age of participants). Further analyses revealed two significant correlations between the groups and the ten background characteristics. These significant correlations were between the groups and the use of instant messaging, $r = .197$, $p < .05$, and the groups and email use, $r = -.181$, $p < .05$. The Software Feature/Motivation Cluster reported the most frequent use of instant messaging and was also the youngest of the groups, overall. Conversely, the Math/Learning Cluster reported the most frequent use of email and was the oldest of the groups, overall. For the three clusters overall, as a group they used instant messaging and PDAs rarely; they used text messaging, email and word processing multiple times each day; and, they rated themselves as frequent technology users and highly technology literate.

There were no additional significant correlations among the groups on other background

Figure 5. Results of Research Question 3: NLVM Sieve of Eratosthenes Tool



Notes: A The tool links conceptual understanding with procedural knowledge. (MA)
 B The tool allows for differentiation among students. (LE)
 C The tool provides multiple representations of mathematical concepts. (MA)
 D The tool maintains student interest (engages students). (MO)
 E The tool provides feedback to the students. (SF)

Table 5. Descriptive Information on Technology Characteristics of the Three Cluster Groups

Background Variables	MA/LE Cluster N=13	Balanced Cluster N=86	SF/MO Cluster N=45
Instant Messaging*	1.69 (.95)	2.29 (1.28)	2.66 (1.49)
Text Messaging	4.85 (.55)	4.45 (1.17)	4.36 (1.3)
Facebook, MySpace, etc.	3.31 (1.8)	3.9 (1.28)	3.91 (1.35)
Blackberry, PDA, etc.	1.92 (1.75)	1.74 (1.36)	2.18 (1.71)
Email*	4.85 (.38)	4.8 (.46)	4.56 (.84)
Word Processing	4.46 (.78)	4.49 (.78)	4.44 (.89)
Tech Use/Non Tech Use	3.85 (.80)	3.55 (.68)	3.6 (.65)
Tech Literate/Non Literate	3.85 (1.14)	3.7 (.87)	3.8 (.79)
Semesters of Mathematics Courses	3.77 (1.24)	3.49 (1.10)	3.84 (1.09)
Age	25.67 (4.19)	24.33 (5.86)	24.16 (6.60)

Note. * indicates a statistically significant correlation between the groups and the variable.

characteristics (i.e., text messaging, Facebook, Blackberry, word processing, technology use, technology literacy, mathematics courses taken, or age). There were several numerical differences of note among the three clusters. For example, the participants in the Software Feature/Motivation Cluster reported taking the most semesters of mathematics coursework. The Math/Learning Cluster reported less use of instant messaging and social networking sites, but more use of text messaging. They also ranked themselves highest as “tech users” and “tech literate.”

DISCUSSION

In the discussion that follows, we relate our proposed model, the *T-MATH (Teachers’ Mathematics and Technology Holistic) Framework*, to the results based on our three clusters of pre-service teachers, and discuss recommendations for preparing teachers to integrate technology in mathematics teaching.

Pre-Service Teachers’ Knowledge of Technology for Teaching Mathematics

When pre-service teachers were asked to identify their own criteria for evaluating technology tools for mathematical learning, they focused most on software features and least on mathematics features. Perhaps it is easier to name a “one-dimensional” feature like software, and more challenging to name a mathematics feature which requires the integration of technological, pedagogical, and mathematics content knowledge. But, one might wonder, even if pre-service teachers could not name a mathematics or learning feature, wouldn’t they be able to select a mathematics or learning feature from a list provided for them? As our results indicated, even when pre-service teachers were provided with a list of criteria that

included mathematical features, they still selected and ranked the software features as more important than the mathematical features in their assessment of the quality of the technology tools. This seems to indicate that the features of the software hold greater significance for the group of pre-service teachers in this study than the mathematics features. It may also show that most pre-service teachers do not have an integrated view of the technology, the pedagogy, and the mathematics when using technology tools to teach mathematics concepts.

Overall, the pre-service teachers in this study identified and ranked Software Features (i.e., such as clear directions, visual appeal, immediate feedback, and availability) as the most important, and Mathematics as least important. These results are similar to Battey et al. (2005) who found that pre-service teachers most often identified Surface Features, followed by Mathematics, Learning and Motivation. While Johnston’s (2008; 2009) studies concurred with Battey et al. (2005) by having Surface Features as most frequently identified by pre-service teachers, in Johnston’s studies, Surface Features were followed by Motivation, Learning and Mathematics. As these prior studies and our results demonstrate, there is a consistent focus on Surface Features (or Software and Motivation Features) by pre-service teachers. The results are consistent with a view held by many pre-service teachers that technology is the object of student learning, rather than a vehicle for developing students’ mathematical knowledge and understanding. This view of technology as the object of learning rather than the vehicle for learning is compared to the following approach:

Teaching a set of technology or software-based skills and then trying to find mathematical topics for which they might be useful is comparable to teaching a set of procedural mathematical skills and then giving a collection of “word problems” to solve using the procedures. Such an approach can

obscure the purpose of learning and using technology, make mathematics appear as an afterthought, and lead to contrived activities (Garofalo, Drier, Harper, Timmerman, & Shockey, 2000, p. 67-68).

Further, Battey et al. (2005) noted that pre-service teachers who focused on the technical features of the tools shared a view that technology was stand-alone; that is, it was separate from instruction and an activity in and of itself.

Pre-Service Teachers Focusing on One-Dimensional Features

When the pre-service teachers in the Motivation/Software Feature Cluster were asked to identify their own criteria for evaluating technology tools and when they selected from a list of criteria, they consistently selected software features as most important and mathematics features as least important. We propose that this cluster (31% of our group; $N = 45$) showed a less integrated view of using technology to teach mathematics by focusing on software or motivation features. Interestingly, the Motivation/Software Feature Cluster, gave the lowest ratings, consistently, across each of the four virtual manipulatives evaluated. This result could be explained, in part, by the virtual manipulatives selected by the researchers. Since the four virtual manipulatives were selected on the basis of their rich mathematical content and affordances, which we believed were examples of high quality virtual manipulatives that integrated effective pedagogical features in the teaching of mathematics concepts, this could account for the lower ratings given by the Software Features/Motivation Cluster. Perhaps the pre-service teachers in the Software Features/Motivation Cluster were looking for more “glitzy” software features rather than considering the mathematical and pedagogical features afforded by the virtual manipulatives.

Pre-Service Teachers Focusing on the Integration of Features

As our results indicate, only 9% of our pre-service teachers, the Math/Learning Cluster ($N = 13$), ranked Mathematics Features as most important among the four criteria. This cluster also named Mathematics and Learning Features solely when they identified the criteria themselves. We propose that focusing on Mathematics and Learning Features requires the integration of technology, pedagogy, and mathematical knowledge for teaching, rather than thinking about these areas in isolation. By naming Learning Features and Mathematics Features, the pre-service teachers in this cluster demonstrated an integrated view of various knowledge areas.

When we compared our findings on how the three clusters *identified* their criteria with our findings on how the three clusters *evaluated* the four virtual manipulatives, it was interesting to note that the Math/Learning Cluster had overall higher ratings for the four virtual manipulatives than the other two clusters. This suggests that the Math/Learning Cluster may have been using a mathematics and learning lens to evaluate the four virtual manipulatives. In essence, we believe that when pre-service teachers focus on Mathematics Features, this emphasis is more reflective of a model of teachers’ knowledge of mathematical TPACK because it is much more characteristic of Koehler, Mishra, and Yahya’s (2005) statement that “components are treated in an integrated manner, and not as separate knowledge bases” (p. 744).

As noted in the results, the NLVM Fractions Adding Tool, Illuminations Fraction Model I Tool, and NLVM Base Blocks Addition Tool, were consistently rated higher by the Math/Learning Cluster on those features which focused on mathematics and learning. This is not surprising, given this cluster’s emphasis on technical features which support conceptual understanding of

mathematical concepts. Criteria such as “The tool links conceptual understanding with procedural knowledge” or “The tool allows for differentiation among students” or “The tool provides multiple representations of mathematical concepts” may be more important to the pre-service teachers in the Math/Learning Cluster because they have a more integrated view of using technology tools for mathematical learning. Thus, their thinking integrates multiple elements of our model in the selection of and evaluation of technology tools.

Recommendations

The *T-MATH (Teachers’ Mathematics and Technology Holistic) Framework* is a specific extension of TPACK – forming a model of teachers’ knowledge of mathematical TPACK. We propose that this model can be used in examining teachers’ mathematics lessons that integrate technology and in designing experiences for teachers on the integration of technology in mathematics teaching. How, then, can we leverage pre-service teachers’ experiences in methods coursework to maximize their mathematical TPACK? Johnston (2009) found that two approaches to technology integration can be found among pre-service teachers. Typically pre-service teachers will choose a specific technology tool and then plan a lesson around that technology tool, rather than selecting an objective first and finding appropriate technology to support the mathematical learning. Or, pre-service teacher opt to modify an existing lesson plan (such as one they might find on the Internet) and simply insert technology to make the lesson plan “technology integrated.” These two approaches are consistent with the participants in the present study.

We argue that pre-service teachers ought to select a worthwhile mathematical objective, think about the pedagogy involved in teaching that particular mathematical concept which supports the objective, and review different technology tools and determine the technology tool that meets

mathematical objectives and pedagogical needs. When pre-service teachers use this approach, they are thinking in the more integrated manner suggested in this chapter. Such a manner of technology integration is in line with the *activity types* identified by Harris, Mishra, and Koehler (2009):

This approach is based on an empirical assumption that maximally appropriate and effective instruction with technology is best planned considering students’ content-related learning needs and preferences primarily, selecting and applying technologies only in service of that curriculum-based learning (p. 403).

In order to develop the TPACK of pre-service teachers they must be engaged in authentic and meaningful tasks (or activity types) to “encounter the rich connections between technology, content, and pedagogy” (Koehler et al., 2005, p. 744). Further, these researchers note that “the multifaceted nature of the TPACK framework would suggest the educational value of constructing learning environments where all three components are treated in an integrated manner, and not as separate knowledge bases” (p. 744).

Experiences for pre-service teachers learning to teach with technology can also be based on tasks that are integrated and multi-dimensional and more closely aligned with the research on TPACK. For example, Koehler and Mishra (2005) note that teachers who learn by designing educational technology tend to develop deeper understandings of the relationships among the three types of knowledge: technology knowledge, pedagogy knowledge, and content knowledge, as well as their intersections. This constructivist approach affords teachers the opportunity to do more than simply add technology to the curriculum. “Rather, the introduction of technology causes the representation of new concepts and requires developing sensitivity to the dynamic, transactional relationship between all three components suggested by the TPACK framework” (Koehler

& Mishra, 2005, p. 134). There are technology programs in which teachers can alter and design problem-based experiences to meet the needs of objectives and learning in their own classrooms.

Finally, pre-service teachers should be introduced to, and subsequently design, mathematics lessons that integrate technology in meaningful ways (Hardy, 2010; Mistretta, 2005). The types of knowledge and the features used throughout the lesson can be deconstructed so that pre-service teachers recognize the elements of successful integration versus lessons where technology is simply added to a pre-planned mathematics lesson or where technology is used as a stand-alone activity. Modeling the construction and deconstruction of well integrated technology experiences (i.e., identifying individual mathematics, pedagogy, software, motivation features, and how they work together) could provide pre-service teachers with insights into the design of these types of experiences for their own teaching of mathematics.

CLOSING THOUGHTS

Our proposed model, the *T-MATH Framework*, for pre-service teachers' technology evaluations is complex and multi-dimensional. How do we begin to move pre-service teachers from a one-dimensional view of technology (i.e. focusing on Motivation or Software Features only) to a more integrated and multi-dimensional view of technology (i.e. focusing on the integration of mathematics and student learning with the technology)? This is a lot to ask of a more experienced in-service teacher, much less our beginning pre-service teachers. Yet this is the challenge for teachers using technology effectively to teach mathematics concepts.

Activities throughout content coursework, methods coursework, and field experiences are necessary to move pre-service elementary teachers from a one-dimensional view of technology to a more integrated, multi-dimensional view of technology. The findings in this study illuminate that

there are different clusters of teachers who focus on different features as they progress throughout dimensions of technology use in mathematics teaching. We hope that our efforts to illuminate the complexity of teachers' development through our model highlights the important aspects to consider in our work with teachers as they develop the multiple dimensions of their knowledge of mathematical TPACK.

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APPENDIX: SURVEY

Part I: Criteria for Evaluation

1. Think about the technology tools you have used in your own mathematics content and methods courses. Below, identify your five primary criteria for selecting and using these types of technology tools in your own future classroom. For each of the five criteria, explain why this is important to you.
2. Next, think about the following 12 criteria. Rank the criteria from 1 (most important) to 12 (least important).
 - The tool provides clear instructions to the user.
 - The tool provides feedback to the students.
 - The tool is easy to navigate and use.
 - The tool is fun for the students.
 - The tool maintains student interest (engages students).
 - The tool provides a game-like activity for students.
 - The tool provides multiple representations of mathematical concepts.
 - The tool links conceptual understanding with procedural knowledge.
 - The tool connects multiple mathematical concepts.
 - The tool allows for differentiation among students.
 - The tool is age/grade appropriate.
 - The tool provides challenging content.

[Note the items were listed in a different order in the actual survey.]

Part II: Evaluating Virtual Manipulatives

For the next section, you will be evaluating five different technology tools according to five criteria which are identified. For each criteria, rank according to the following scale:

- 1 = I strongly disagree that the technology tool meets the criteria
- 2 = I disagree that the technology tool meets the criteria
- 3 = I am not sure
- 4 = I agree that the technology tool meets the criteria
- 5 = I strongly agree that the technology tool meets the criteria.

Tool A: NLVM Fractions Adding

http://nlvm.usu.edu/en/nav/frames_asid_106_g_2_t_1.html?from=category_g_2_t_1.html

Tool B: Illuminations Fraction Model I

<http://illuminations.nctm.org/ActivityDetail.aspx?ID=11>

Tool C: Base Blocks – Addition

http://nlvm.usu.edu/en/nav/frames_asid_154_g_2_t_1.html

Tool D: NLVM Sieve of Eratosthenes

http://nlvm.usu.edu/en/nav/frames_asid_158_g_2_t_1.html

Part III: Personal Uses of Technology

Rate how often you use each of the following tools.

Use of Technology	Multiple Times each Day	Once a Day	Several times per week	Rarely	Never
Instant Messaging (AOL, Yahoo, MSN)					
Text Messaging (via your cell phone)					
Facebook, Myspace, and other social networks					
Blackberry, PDA, etc.					
Email					
Word Processing					

Why do you use the tools you checked (as multiple or once a day)?

Why don't you use the tools you checked (as rarely or never)?

Rank yourself along the continuum, from extreme tech user → Non-tech user.

5 4 3 2 1

Extreme Tech

Non-tech User

User

Rank yourself along the continuum, from tech literate → non-tech literate.

5 4 3 2 1

Tech Literate

Non tech literate

Part IV: Academic Experiences

A. How many college mathematics courses have you completed? Select only one.

_____ None _____ 1 semester _____ 2 semesters

_____ 3 semesters _____ 4 semesters _____ 5 or more semesters

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- B. If you are currently assigned to a classroom, what grade level is it? Select only one. (However, if you teach in a multi-grade level, then select those two grade levels.)
_____ K _____ 1 _____ 2 _____ 3 _____ 4
_____ 5 _____ 6
- C. Have you taken any courses where technology was specifically the focus of the course?
_____ Yes _____ No
If yes, please list/describe them.

Part V: Demographic Information.

- A. Gender: _____ Male _____ Female
- B. Age: _____
- C. ONLY check here if you are not participating in the research study and do not wish for your responses to be included in the data set. _____

Chapter 10

Technologizing Teaching: Using the WebQuest to Enhance Pre-Service Education

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ABSTRACT

With the continuing shift of instructional media to digital sources occurring in classrooms around the world, the role of technology instruction in the pre-service curriculum of K-12 teachers is acquiring increasing salience. However, barriers to its inclusion continue to exist. In this chapter we focus on a model of hybridity designed to embed technology instruction into pre-service education. This model is known as the WebQuest and involves the development of a technology-driven learning activity that scaffolds the building of skills in content, pedagogy, and technology integration in pre-service teachers. We discuss data from an exploratory project conducted within a class of graduate pre-service teachers experiencing instruction in creating a WebQuest, and offer some preliminary findings. We place these results within a larger perspective of the CFTK and TPACK frameworks and their application to issues germane to pre-service teacher education.

INTRODUCTION AND BACKGROUND TO TECHNOLOGY INTEGRATION IN THE CLASSROOM

Technology is dramatically changing the way today's K-12 students are educated. This rising cybergeneration has unprecedented choices in

how to generate, manipulate, obtain, display, and share information. Not only has technology changed the role of students, it has also altered that of their teachers. Instead of acting only as a dispenser of information, today's teacher must be a change agent and visionary, able to perceive and harness the potential of rapidly developing technology tools and web advances, deciding how to manage these to effectively meet their

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own needs and that of their students (Angeli & Valanides, 2009; Goktas, Yildirim, & Yildirim, 2009; Wang & Hannafin, 2008).

This role-change for teachers has critical, wide-ranging implications for teacher education because, increasingly, many within and outside the education sector view teacher preparation as the linchpin in maintaining a well-informed, capable, and effective teacher force trained with necessary knowledge, skills, and dispositions. Prominent among the areas that pre-service teacher preparation programs across the United States have been encouraged to improve is technology (NCATE, 2010). Among the many questions these programs must address, one stands out: Can teacher education programs prepare the emerging teacher force to assume an instructional leadership role to accommodate the needs, capabilities, and imaginations of today's technocentric students?

To begin to answer this, a database grounded by empirical investigations with pre-service teacher education has been accruing and presented some noteworthy findings (Maddux, 2009). For example, studies with undergraduate pre-service teachers have shown that absent specific training in the educational uses of computers, undergraduates (sophomores and juniors) who were described as computer-competent were not any more skillful in designing better technology-infused lessons than freshmen who possessed competent technical skills with no specific training in the educational uses of computers. Following computer training, these sophomores and juniors outperformed freshmen in designing learning activities with computers (Angeli, 2005; Angeli & Valanides, 2005; Valanides & Angeli, 2006, 2008). Speaking to this outcome Angeli and Valanides (2009) asserted that "teacher educators need to explicitly teach how the unique features or affordances of a tool can be used to transform a specific content domain for specific learners, and that teachers need to be explicitly taught about the interactions among technology, content, pedagogy, and learn-

ers" (p. 158). Kariuki and Duran (2004) used the innovative concept of an "anchored instructional approach" to restructure technology course learning. Pairing a curriculum development class with an educational computing class, they found that when the curriculum course was used to "anchor" activities in the computing course, the result was more effective and successful when learning about teaching with technology. For even digitally native pre-service teachers, incorporating technology into effective instruction is not a natural extension of technological fluency.

School infrastructures also reflect the continuing inroads made by technology. A report entitled "Teachers' Use of Technology in U.S. Public Schools, 2009" revealed that 97% percent of teachers had one or more computers located in their classroom, daily, while 54% could bring computers into the classroom. Internet access was available for 93% of computers located in the classroom every day and for 96% of those computers that could be brought into the classroom. The ratio of students to computers in the classroom every day was 5.3 to 1 (Gray, Thomas, & Lewis, 2010).

To further demonstrate the impact of technology, a 2010 National Education Technology Plan (U.S. Department of Education, NETP, 2010a) from the U.S. Department of Education, Office of Education Technology, presented the following goal: "Provide pre-service and in-service educators with preparation and professional learning experiences powered by technology that close the gap between students' and educators' fluencies with technology and promote and enable technology use in ways that improve learning, assessment, and instructional practices" (U.S. Department of Education, NETP, 2010a, p. 11). This goal further aligns with the broader agenda advanced by the federal *Race to the Top* initiative, a part of the 2009 American Recovery and Reinvestment Act, which enumerates as one of its four assurances a priority to "increase teacher effectiveness" especially in the area of STEM (Science, Technology,

Engineering, and Mathematics) subjects (U.S. Department of Education, 2010b). Clearly, these developments are prodding teacher preparation programs to create more coherent curricular systems, tying curriculum to broader national goals, and embedding technological fluency as a primary end to improve teacher effectiveness, help narrow the achievement gap, and not only upgrade but change the way teachers manage instructional delivery.

In response to many of the aforementioned issues, the focus of this chapter is to propose a framework for integrating a technology-driven instructional strategy to advance the national goal of improving teacher effectiveness. Specifically, we outline and expand on a program to infuse the WebQuest (Dodge, 1995, 2007) into teacher preparation coursework and discuss an exploratory study that examined pre-service teachers' experience with developing a WebQuest. One of the major criticisms of teacher preparation programs has been that when technology instruction is presented, it is done so in a generic, amorphous fashion disconnected from larger curricular and programmatic concerns (Wang & Hannafin, 2008). It is imperative that "teachers, researchers, and teacher educators . . . move beyond oversimplified approaches that treat technology as an "add-on" instead to focus upon the connections among technology, content, and pedagogy as they play out in classroom contexts" (Jimoyiannis, 2010, p. 1260). Because WebQuests encourage teachers to challenge students with real-life, inquiry-based problems, framed by content standards, and encased in a technology-driven format, they are a good fit for this combination of technology, content, and pedagogy. This gives WebQuests potential to function as transformative experiences "in which the learner seeks to understand and build a network of relationships between different aspects of learning in order to construct a picture of the whole" (Allan & Street, 2007, p. 1103).

THE WEBQUEST AND THE NEW LEARNING CULTURE

Consider the following scenario:

Space Science is making significant advances in devising ideas to colonize planets for human habitation. To explore this development, a teacher creates a WebQuest, an Internet-based learning project, where students are assigned specific tasks and provided with digital resources to complete these tasks. Using the WebQuest interface, teams of students are asked to select one planet they would like to colonize and describe how they would go about this process of colonization. They must come up with a detailed and fully-supported action plan to present to a panel of experts. In completing their assignment, students are encouraged to expand their network of resources to include a broader set of "educators" and reach out to experts and other collaborators by contacting them via the Internet.

Students spring into action. One team turns to digital libraries included on the NASA website and, using their laptops, checks out progress on the Juno Spacecraft Project's exploration of Jupiter to obtain information on a launch date. Videos from sites suggested by their teachers are reviewed for recent evidence of planetary environments; teachers also help students devise an online ratings sheet to group-share an evaluation of the level of scientific evidence they feel the videos provide. Using ultraportable smart handheld devices, another team inspects online planetary satellite images to gain an overview of the solar system and various digital information updates. With this team, the teacher recommends they e-mail a NASA scientist and sign up for her microblog feed. A third team begins blogging about their project on the class website, and asks for feedback on research strategies from readers of the blog. One student downloads a book on space science via his e-reader. And another team turns to the U.S. Naval Observatory website

and begins recording data on celestial navigation utilizing a spreadsheet. Working with their teacher in using computer-aided tools, this team designs and drafts artifacts for three-dimensional visualization, sketching out a planet colony and the projected structures it will contain. Within a social networking website, they discover a class in Australia conducting a similar project and contact them via Internet telephone services to exchange information. The teacher then asks these teams to come together to share interim and final reports.

All these activities are representative of the level, scope, and reach of a new learning culture pervasive in classrooms across the globe and the instructional power unleashed by the use of technology. They are also representative of activities typically comprising a WebQuest. This instructional strategy offers genuine opportunities for teachers to develop a creative and comprehensive instructional approach in drawing on the forces of the “4Cs” and the “3Rs” that are becoming an increasingly potent force for twenty-first century learning—take the “4Cs,” creativity, collaboration, communication and critical thinking and pair these with the traditional “3Rs” for state-of-the-art instruction (Partnership for 21st Century Guide, 2008; Rotterham & Willingham, 2010).

WEB QUEST 3.0 AND CFTK AND TPACK FRAMEWORKS

The WebQuest was first pioneered by Dodge and March in 1995 at the University of California at San Diego, and since then has evolved into a significant practice in numerous K-12 classrooms around the world (Dodge, 2007). From its inception to today, the WebQuest continues to be adapted, reworked, and refined to fit the needs of teachers interested in accelerating student motivation by integrating a creative, interactive guided inquiry tool into experiential “in-the-moment” learning (McGlinn & McGlinn, 2003). It has been used to update teaching approaches offered in professional

development sessions which have been especially valuable because of connections forged between technology-informed learning and concepts such as constructivist learning principles (Simina & Hamel, 2005). It also appears as a model for projects included in undergraduate and graduate education courses, in particular those related to crossdisciplinary curriculum and instructional methodologies (Kundu & Bain, 2006; Wang & Hannafin, 2008). It also easily aligns with National Educational Technology Standards (NETS) for Teachers that is Teacher Standards recommended by the International Society for Technology in Education (ISTE) (ISTE, 2010).

Most especially, WebQuests fit into the theoretical framework advanced by the Comprehensive Framework for Teacher Knowledge (CFTK) & Technology, Pedagogy, and Content Knowledge (TPACK) Models (Koehler & Mishra, 2008; Mishra & Koehler, 2006). These models aid Information and Communications Technologies (ICT) integration in education practice and seek to incorporate representations of teacher knowledge, as this interfaces with technology, providing a more comprehensive and stable structure for requisite teacher knowledge. Due to their rapidly expanding research base, TPACK and CFTK, in the past criticized for a lack of both theoretical grounding and implementative and evaluative precision, have begun to acquire more credibility as viable constructs around which to focus and design technology-integrated instruction (Angeli & Valanides, 2009; Jimoyiannis, 2010; Mishra & Koehler, 2006). These two frameworks take on particular salience when applied to pre-service teacher education. Frequently, when asked to use technology in teaching, pre-service teachers experience cognitive and metacognitive overload because they, more often than not, separate out content, pedagogy, and technology (Brush & Saye, 2009). This is where both CFTK and TPACK paradigms combined with the functionality of a WebQuest can help to restructure this teaching behavior and make it more manageable (Jang &

Chen, 2010). In creating a WebQuest, pre-service teachers draw upon a strong, clear framework that scaffolds subject-area content with technology integration (TPACK), while incorporating teacher knowledge needed to implement the framework itself (CFTK). This helps synthesize content, pedagogy, and knowledge, in turn, increasing both teacher communication with students and instructional efficiency.

TPACK is constituted by the knowledge elements Technology (T), and Pedagogy (P), and Content (C) (Angeli & Valanides, 2009; Koehler & Mishra, 2008; Mishra & Koehler, 2006). Further, “it emphasizes the connections and the complex relationships between them and defines three new and different dimensions (areas) of knowledge; the Pedagogical Content Knowledge (PCK), the Technological Content Knowledge (TCK), and the Technological Pedagogical Knowledge (TPK)” (Jimoyiannis, 2010, p. 1261). Both TPACK and CFTK constructs are deeply rooted in classroom practice (Angeli & Valanides, 2009), and both were designed in response to an approach in teacher education that tended to isolate rather than integrate technology, marginalizing its role in supporting effective instruction (Shulman, 1986, 1987). Rather than separate out content knowledge and pedagogy into categories that are irregularly enhanced by technology, TPACK and CFTK models network “technology knowledge as situated within content and pedagogical knowledge” (Schmidt, Baran, Thompson, Mishra, Koehler, & Shin, 2009, p. 124). Angeli and Valanides (2009) further advised “this extended view of PCK is offered as a framework for revitalizing the study of teacher knowledge and for collecting and organizing data on teacher cognition about technology integration” (p. 155).

WebQuests present an intriguing amalgam of knowledge elements of pedagogy and content knowledge. Because WebQuests are, at their core, cognitively challenging tasks that promote critical thinking skills, they entail what Koehler, Mishra, and Yahya (2007) suggest is at the center of the

TPACK model: a dynamic, transactional relationship among content, pedagogy, and technology as these occur in the context of classroom practice.

Parts of a WebQuest: For the uninitiated reader, the following section describe the parts of a WebQuest and identifies major components associated with its content and how these components mesh in the manner supported by TPACK and CFTK frameworks (Koehler & Mishra, 2008; Mishra & Koehler, 2006). First, a WebQuest *Introduction* makes clear the subject matter. This content is, generally, standards-based and can span a variety of disciplinary or interdisciplinary topics ranging from Life in Ancient Egypt to the Music of Beethoven to the History of the Periodic Table. Setting the stage, the introduction is often told in story-like fashion, offering opportunities for students to identify, define, and encode the activity’s premise, much like the Space Science task that appeared at the beginning of a previous section. Based on age appropriateness, the introduction provides background information in an interesting, motivating, and pleasurable fashion.

Following the introduction, the WebQuest’s *Task* details the activities from which students must choose for conducting the quest and how to process information gathered to complete the story, solve the mystery, find solutions, or otherwise contribute to the circumstances unveiled in the introduction. These tasks can be differentiated into design tasks, decision tasks, analysis tasks, prediction tasks, or creative tasks (Dodge, 2007). Once the overall intentions of the task are understood, the *Process* is the actual step-by-step strategy students undertake to organize the WebQuest. The process is a natural means for scaffolding student learning through assigned roles, guidance on where and how information is found (e.g. through search engines, websites, bookmarks), and how to interpret what learners experience. Critical-thinking skills here include hypothesizing, organizing, reflecting, and decision-making, as students acquire and deepen content knowledge chosen for their quest. The *Resources* portion of a WebQuest lists

additional websites and instructional resources to complete the tasks. Often these resources take in hardware and software as well as reference material including bookmarked web pages, maps, trade books, videos, newspapers, and other sources that encourage learners to apply what they find as they assemble and design solutions to the challenges posed by the quest.

The *Evaluation* summarizes for students what they have created, constructed, or synthesized together with guidelines to gauge their success. Analyses, syntheses, and summaries reinforce learning by reminding students of the goals and efforts made by progressing through information vetted by their instructor. Through reflective activities, individuals articulate their progress from interest to exploration to new understanding. The process is guided by an evaluation rubric that includes performance objectives, performance levels of proficiency, and performance indicators. This emphasis on self-monitored progression infuses the experience with self-awareness, self-reflection, and metacognitive thinking. Appendix B contains a listing of websites where WebQuests may be accessed.

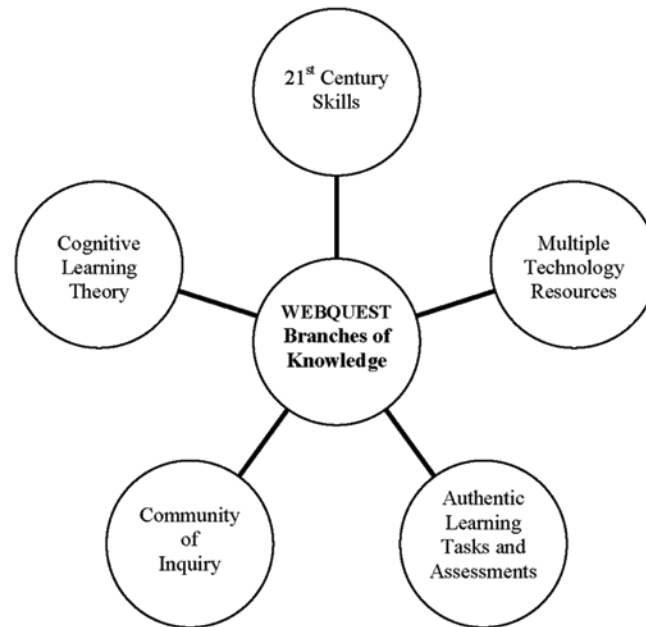
WebQuest 3.0. Now that they have matured and been reinvented by teachers, curriculum specialists, researchers, and education consultants, WebQuests have demonstrated exceptional staying power. With its basic template in mind, we propose that an updated and upgraded model of the WebQuest receive serious consideration for inclusion in pre-service teacher education. We call this WebQuest 3.0 and suggest that it be considered in the preparation of pre-service teachers within a cycle of teacher preparation courses including curriculum, instruction, assessment, and methodology. A key feature of this updating is embedding it within an approach using CFTK and TPACK models as overarching frames.

This new WebQuest 3.0 model recontextualizes the original WebQuest design by using the concept of a rich performance task (RPT) as a model (Doll, 2004; New Basics Project, 2008). This RPT

represents a substantive, real-life problem with recognizable value that engages the learner in both cognitive and social actions. A rich performance task differs from a regular task in the manner in which students assemble the project, display their understandings of its parts, and describe their outcomes, as illustrated by Figure 1. Whereas a regular task might call upon a standard set of more traditional learning strategies embedded in a short-term assignment, the RPT involves students in longer-term tasks centered on challenging problems using an interdisciplinary approach rich in cognitive, developmental, and social breadth. In exploring these topics in-depth, students self-manage as they refine research skills, sharpen technological competencies, and develop new metacognitive perspectives on what learning is. They are given opportunities of performance using innovative digital tools such as online decision trees, podcasts, spreadsheets, concept maps, open source asynchronous discussion forums, Bloom's Digital Taxonomy, and other Internet databases.

Because WebQuests are team efforts, they demonstrate to students concepts of collective intelligence and crowd-sourcing to drive thoughtful decision-making and complex problem solving (U.S. Department of Education, NETP, 2010a). Social connectedness is also encouraged because students have opportunities to broaden their base of support by joining with a wider circle of "educators" including not only their own teachers and peers, but experts and mentors outside the classroom with whom they are able to establish virtual communication. This aligns WebQuest experiences with approaches conceptually connected to several constructivist-driven theoretical models (Piaget, 1954, 1963; Vygotsky, 1978), one of these being a cognitive apprenticeship (Collins, Brown, & Newman, 1989; Dennen, 2004). An apprenticeship involves a mentor-like figure that assists in the WebQuest by scaffolding students through a series of steps designed to move them along a problem-solving continuum. The use of a mix of "guides" to scaffold student

Figure 1. Five branches of teacher knowledge



performance encourages multiple mentors to assist in the project. The appeal of the overall RPT paradigm, as it relates to TPACK, is underscored by Koehler et al., (2007) who point to the necessity for students to be engaged in rich instructional designs in order to experience, understand, and value the interrelationships among content, pedagogy, and technology as constructs in and of themselves.

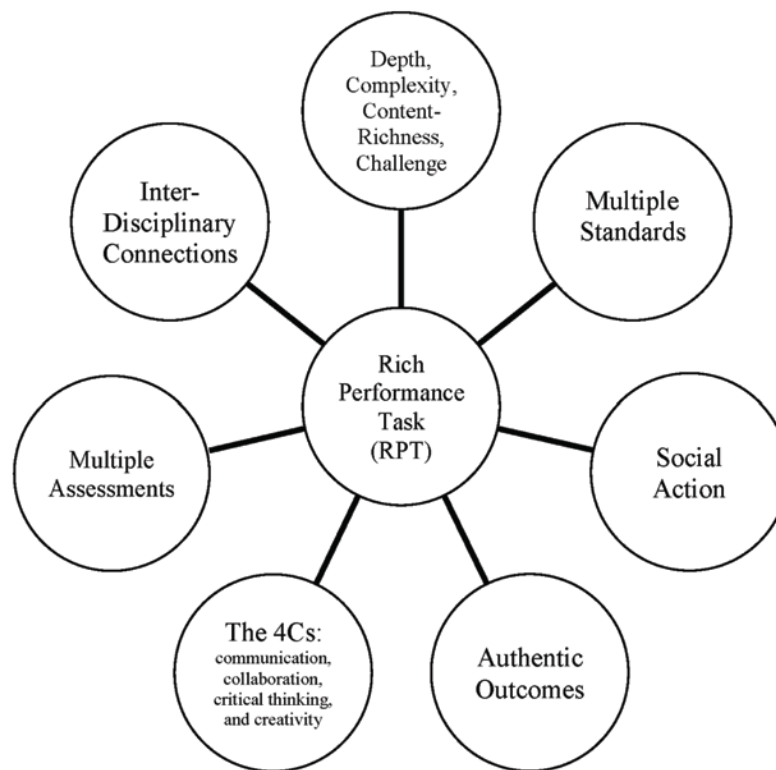
KNOWLEDGE BRANCHES OF THE WEBQUEST MODEL

We have identified five “branches of knowledge” we believe are advanced through the construction of a WebQuest, as is illustrated in Figure 2. Each of these five branches represents a dimension of basic TPACK knowledge elements, specifically Content (C), Technology (T), and Pedagogy (P). These elements further interconnect to develop pedagogical content knowledge (PCK), technological content knowledge (TCK), and technological pedagogical knowledge (TPK) (Angeli & Valanides, 2009). We

now discuss the contributory role to the WebQuest of these five branches, especially as they relate to the transactional process embodied by the TPACK model as well as “Field,” “Mode,” and “Context” dimensions of the CFKT Model.

Learning Theory. With the introduction of “scientifically-based learning” directives in *No Child Left Behind* (2001), familiarity with data from learning theory research has become essential to ensure that classroom teaching and learning are supported by sound theoretical frameworks. Teachers need to create organizational structures supported by these data in order to ensure that their teaching does not consist only of a series of disparate lessons and assessments, but a dynamic, interactive learning system that captures the true complexities of learning. Pre-service teachers are encouraged to approach WebQuests through cognitive learning theory since WebQuests exemplify many constructivist principles (Piaget, 1954, 1963; Vygotsky, 1978). For example, curricular activities rely closely on teacher-created dilemmas promoting analytical thought. Social negotiation is addressed with an

Figure 2. Components of a rich-performance task (RPT)



emphasis on group work. During a WebQuest, the teacher, also, behaves in an interactive manner mediating the learning experience for the students, scaffolding its steps, and engaging in classroom dialogue throughout the process ensuring that knowledge is productive not reproductive.

Injecting this type of cognitive dynamic speaks to the “Mode” dimension of CFTK. Mode refers to the knowledge teachers come to rely upon as they grow and refine their craft. In general, this means knowing how students learn best and how classroom instruction can become targeted and responsive to the needs and styles of the individual learner. We will address this aspect in more detail in the exploratory study, which follows this section.

Twenty-First Century Skills. Global yardsticks are now being used to reform, redefine, and redesign education pushing us to rethink how children learn. Children must be prepared to think and reason using “big-picture” thinking tied to

a global context. Essential skills to negotiate a rapidly globalizing and technologizing knowledge economy include the “4 Cs” of communication, collaboration, creativity, and critical thinking, as well as respect for cultural diversity and the need for cross-cultural competence. WebQuests, whose themes and content can be centered on the study of human differences through the lens of different cultures, offer broad benefits in this regard. Pre-service teacher education programs structured to include training in designing these kinds of WebQuests can encourage teachers to incorporate these essential skills as well as direct their impact beyond a limited academic space and into a global environment (Williams, Foulger, & Wetzel, 2009). This type of instructional strategy neatly aligns with the TPACK stage of “Exploring” where teachers integrate content area instruction with appropriate technology, using original ideas to foster student directed activity (Niess et al., 2009).

This action also clearly speaks to the “Orientation” mode of CFTK that addresses beliefs, values, and dispositions underscoring their connection to learning. When teachers become sensitive to and recognize dispositions and values that influence broader learning behaviors in students, they create more authentic and fluid contexts allowing learning to flourish. Understanding the importance of incorporating twenty-first century dispositions such as collaboration, communication, and respect for cultural diversity into content and pedagogy is crucial. Building a type of learning environment that addresses new global values gives children those survival skills necessary to engage in good citizenship and participate fully in the construction of a vibrant and civil society.

Multiple Technology Resources. Why teach using technology? The growing collection of available technology resources answers this question by providing opportunities to embed greater diversity into classroom lessons making them more engaging and robust. For example, WebQuests can build teacher capacity in using presentation software, collaboration tools, website construction programs, and, depending on the complexity level of the WebQuest, with video-editing, podcasting, vodcasting, 2D/ 3D animation, and multimedia mashups.

This takes on meaning at the TPACK stage of “Adapting” where teachers engage in instructional decision-making (Niess et al., 2009). Because pre-service teachers are likely to bring with them their own history of technological content knowledge and preference from past personal and professional experiences, a WebQuest presents them with a new canvas to apply and broaden prior knowledge in ways that will advance pedagogical content knowledge. Refining decision-making skills by having teachers select technology resources with potential to facilitate student learning outcomes encourages more meaningful learner-centered approaches.

Authentic Learning Tasks and Task Assessments. Authentic tasks and assessments urge

pre-service teachers to think about the thematic approach selected to drive their WebQuest and ensure they include real world tasks demonstrating the application of essential knowledge and skills (Brush & Saye, 2009). One of the most important steps the pre-service teacher takes in constructing the WebQuest involves the first levels of the TPACK process, “Recognizing and Accepting” that content knowledge can benefit from the infusion of a technology component (Niess et al., 2009). The teacher initially researches, “vets,” and presents information students will be accessing throughout the task, and then recognizes ways in which the added value of technology will both speed and improve the learning process as well as assist in assessment. This moves the teacher’s role from authoritative to facilitative (Kumar & Kogut, 2006), and affords valuable practice in instructional decision-making and planning. This task aligns with the final TPACK stage of “Advancing” where decisions on revisions to curriculum are made based upon student capabilities or, in this case, on task assessments.

For example, when a locally-themed WebQuest is designed, teachers may devise “authentic,” real-world tasks that reference questions accommodating community issues such as housing development or public works projects. This could involve the capture of screenshots or audio- and videocasts that introduce, illustrate, or expand on these topics. This example relates to the CFTK aspect of “Environment” where teachers attend to relevant external factors in learning about a specific context (Niess et al., 2009). That teachers understand the impact of societal issues that take in local cultural, economic, or sociological concerns, ensuring these are well-matched to cognitive capabilities, establishes a dynamic interplay between content and student meaning-making and makes the project more genuine.

In assessing these types of aforementioned tasks, pre-service teacher educators usually construct a rubric that enumerates those skills they wish to develop, upgrade, or advance through

Figure 3. Rubric for WebQuest

	INCOMPLETE	DEVELOPING	PROFICIENT	ACCOMPLISHED
UNDERSTANDING AND USE OF STANDARDS	No reference to NYS content and/or performance standards evident	Few references to NYS content and/or performance standards evident	Good reference to NYS content and/or performance standards evident	Comprehensive and clear reference to NYS content and/or performance standards evidence
ESSENTIAL QUESTION(S)	No Essential Question(s)	Essential Question(s) partially developed	Essential Question(s) addresses a topic important to know and do	Essential Question(s) addressed enduring understanding, extends across disciplines and requires ongoing reflection
WEBQUEST INSTRUCTIONAL OBJECTIVES	None apparent	Poorly written; no evidence of measurability; Ineffective; Do not address levels of understanding; little cognitive complexity	Adequately written and measurable; Generally addresses levels of student understanding; sufficient cognitive complexity	Well-written, focused, measurable and student-centered; Addresses multiple levels of cognitive complexity
TASK AND PROCESS	No logic, sequence or focus in Tasks or Process; learner is not engaged	Some logic, sequence and focus in Tasks and Process; learner is marginally engaged	Good logic, sequence and focus in Tasks and Process; learner is well-engaged	Some logic, sequence and focus in Tasks and Process; learner is highly engaged and challenged
GRAPHIC ORGANIZER	Module does not include graphic organizer	Graphic organizer is disorganized and unclear	Graphic organizer is clear and well-presented	Graphic organizer is appropriate and greatly adds to the quality
USE OF QUESTIONS AND QUESTIONING	No questions are scaffolded	Questions are scaffolded but are unfocused and poorly constructed	Questions are well-scaffolded and focused	Questions greatly extend student thought and learning product through scaffolding
USE OF LEARNING TAXONOMY	Use of Bloom's Digital Taxonomy is not apparent	Bloom's Digital Taxonomy is occasionally used, somewhat understood, and somewhat integrated with other taxonomic versions	Bloom's Digital taxonomy is adequately used, understood, and integrated with other taxonomic versions	Bloom's Digital Taxonomy is frequently used, well-understood, and well-integrated with other taxonomic versions
EVALUATION STRATEGIES	No evaluation strategies	Some evaluation strategies including a rubric	Evaluation strategies are well-used and rubrics are well-defined	Differential evaluation is evident and embedded throughout the module and rubrics are exceptional
OVERALL WEBQUEST FORMAT AND CONTENT	WebQuest is unchallenging, uncreative, and does not engage students	WebQuest is somewhat challenging, authentic and creative and slightly engages students	WebQuest is challenging, authentic, and creative and engages students	WebQuest is very challenging, highly creative, and authentic and does encourages a high degree of student engagement
OVERALL QUALITY OF WEBQUEST	WebQuest needs considerable revision	WebQuest needs partial revision	WebQuest is of high quality	WebQuest is exceptional

a WebQuest unit. Figure 3 outlines an updated version of the rubric we have used with our own pre-service teachers to determine their level of competency and skill pertaining to the WebQuest they designed.

Community of Inquiry. This concept, with roots in Dewey's (1998) social pragmatism, is uniquely important as a knowledge branch in WebQuest training for pre-service teachers. An educational Community of Inquiry embraces a diverse group of individuals who collaboratively engage in purposeful critical discourse and reflection to construct personal meaning and confirm mutual understanding. The "Community of Inquiry" (CoI) model has been applied, primarily, to distance learning (Garrison & Anderson, 2003), but has meaning in the context of a WebQuest. In general, a Community of Inquiry involves the interdependent relationship of three *presences*: social, cognitive, and teaching. These three presences

come together to generate a community of learners "transacting with the specific purposes of facilitating, constructing, and validating understanding, and of developing capabilities that will lead to further learning" (Garrison & Anderson, 2003, p. 23).

This CoI framework demonstrates particular attachment to the "Discernment" piece of the CFTK Mode of Dimension (Ronau & Rakes, 2009; Ronau & Wagener, 2009). Discernment encompasses behaviors of knowing about what and how to teach while remaining sensitive to modalities by which students learn. Establishing any community of learners is dependent on Discernment if the learning experience is to have any long-term, meaningful impact. In addition to Discernment, the CoI framework also speaks to the CFTK "Individual Context" aspect. WebQuests are generally group enterprises. Selecting a group with sensitivity to such features as gender, learning styles, age, and

student background allows flexibility in deciding which students would benefit from working together. It also gives teachers the opportunity to further customize WebQuests so that they are a good match between individual student traits (age, gender, learning style) and essential instructional outcomes. The comprehensive learning experiences embedded in a WebQuest promote natural group communication, where participants network collective intelligence to construct meaning and confirm mutual understanding through sustained reflection and discourse all enveloped within a schema of social connectedness (Anderson, Rourke, Garrison, & Archer, 2001; Garrison, 2009; Garrison, Anderson, & Archer, 2000).

WEBQUESTS IN TEACHER PREPARATION: AN EXPLORATORY STUDY

Introduction

To enhance our pre-service teachers' knowledge threshold for employing technology within an instructional activity blending content, pedagogy and technology, a WebQuest was introduced. We were guided by studies suggesting that the underlying design principles of WebQuests hold promise for activating authentic student learning (Wang & Hannafin, 2008), promoting critical thinking (Abbitt & Ophus, 2008), and encouraging high levels of engagement (Allan & Street, 2007). The literature also suggested that WebQuests have potential to increase pre-service teacher adoption of technology (Brush & Saye, 2009; Goktas, Yildirim, & Yildirim, 2009), and understanding of constructivist problem-solving principles (Zheng, Perez, Williamson, & Flygare, 2008).

Design groups of three to four students were guided through the process of choosing a learning theme and developing a collaborative WebQuest. The authors met with each class during an intro-

ductory session, again for a hands-on tutorial of Google Sites (Google Sites, 2010), and for two to three additional support sessions for troubleshooting technology problems and WebQuest design issues. They were also present at the final WebQuest presentation session.

In preparation for conducting a more thorough study of the efficacy of WebQuest instruction, in this exploratory phase we were interested in understanding pre-service teacher attitudes and competencies around technology and instruction. With a research question centered on the role of exposure to scaffolded instruction in creating a WebQuest that might increase pre-service teachers' skill sets in technology integration, we set out to ascertain preliminary measures for future testing in large populations of students.

Participants

Graduate students majoring in education ($n=23$), enrolled in two literacy courses which met once a week for two hours over a sixteen week semester, were introduced to the concept of a WebQuest. Most of the students were female ($n=21$); approximately half were within the 18-to 25-year-old age range. The remaining half ranged in age from 26-50. Nine students were actively teaching, either as a result of employment or through student teaching assignments. Most participants predicted they would be teaching in a suburban, middle-income school district at the kindergarten to fifth-grade level of elementary education. Pre-service students were well distributed across academic majors in the education spectrum, including early childhood, elementary, literacy and special education areas. Similar to the undergraduate students in Salaway and Caruso (2008), all students had access to a home computer with half reporting spending up to 14 hours per week using them for the purposes of personal enrichment, communication, and productivity.

Survey Instrument

Students all responded to an anonymous survey posted on Survey Monkey (Survey Monkey, 2010). This instrument was designed to collect basic demographic information, students' self-assessment of the importance of technology in teaching and learning, and data on perceptions of learning theory and teacher knowledge. These all relate to concerns addressed by TPACK and CFTK models. Beginning with metrics to ascertain individuals' current technology usage drawn from a previously cited report (Salaway & Caruso, 2008), items about perceived relevance of specific software and hardware tools both in teacher training and professional application were included. Our instrument concluded with student ratings on the importance of pedagogical principles and teacher knowledge for future careers.

Constructivist principles as outlined in a variety of foundational documents guided the survey creation (Bruner, 1960, 1966; Dewey, 1998; Piaget, 1954, 1963; Vygotsky, 1978). Survey instrument content was based on suggestions from education experts including university professors and master K-12 teachers. We also referenced data from the Institute of Education Sciences (IES) of the U.S. Department of Education including the Practice Guide "Organizing Instruction and Study to Improve Student Learning" (Pashler et al., 2007) which contained research on learning and memory. These practice guides result from panels of experts who examine best available evidence on a selection of topics and make actionable recommendations. These recommendations are subject to rigorous external peer review to determine the quality and currency of the evidence. Students responded using five-point Likert scale ratings ranging from 1 (*not important*) to 5 (*extremely important*) to questions designed to identify underlying constructs they held with respect to technology teaching and learning. The purpose of this exploratory study was to identify measures upon which we could

generate hypotheses for future studies. The full survey is available in Appendix A.

Results

An exploratory factor analysis was performed using Stata 11.1 with a principal factors method on the variables. Based on Kaiser's stopping rule (i.e., eigenvalue > 1.0), six factors were extracted. The extracted factors were then rotated orthogonally using the varimax method with Kaiser normalization. Orthogonal rotation was employed to isolate uncorrelated factors exclusive of one another. Factor loadings exceeding .50 were considered in interpreting and labeling the factors.

The factor analysis revealed an underlying structure with six latent variables that explain 87% of the variance in the data, as shown in Table 1. Using the factor scores from the orthogonal rotation, the following latent constructs were identified: (Factor 1) Acquired Teaching Strategies (eigenvalue 4.17), which explains 27% of the shared variance; (Factor 2) Exposure to Technology (eigenvalue 2.44), which explains 16% of the shared variance; (Factor 3) Practices in Teaching Effectiveness (eigenvalue 2.19), which explains 14% of the shared variance; (Factor 4) Cognition and Technology (eigenvalue 2.18), which explains 14% of the shared variance; (Factor 5) Technological Synthesis (eigenvalue 1.47), which explains 9% of the shared variance; and (Factor 6) Pre-instructional questioning (eigenvalue 1.16), which explains 7% of the shared variance. As expected from the results of the varimax rotation, a pairwise inter-factor correlation matrix found no statistically significant correlations, indicating the six factors manifest excellent discriminant validity and are appropriate for use as measures in our exploration.

Additional statistical tests were performed for differences between areas of students' academic majors by performing an analysis of variance (ANOVA) for each factor. None of the students' stated areas of concentration were significantly

Table 1. Rotated factor loadings

Item	F1	F2	F3	F4	F5	F6	<i>U</i>
It is important to develop metacognitive skills in students.	.9495						.0840
I am able to scaffold questions based on Bloom's Taxonomy.	.8685						.1743
I think it's important to make use of short quizzes or tests to re-expose students to key course content.	.7987						.1816
I can engage students in critical and creative thinking skills.	.7197						.3412
I am comfortable differentiating instruction among students in a classroom.	.6723						.2652
I am able to challenge my students by questioning to get them to think deeply about knowledge.	.6466						.3982
WebQuests have been important in my learning.		.8753					.1745
Graphic organizers have been important in my learning.		.7861					.2757
Smartboards have been important in my learning.		.6793					.3183
It is important for a teacher to space learning episodes over time.			.8753				.1833
I can distinguish between traditional and authentic assessments among students in a class.			.6158				.1903
It is important to mix solutions and problem-solving exercises throughout the lesson.			.5467				.3155
As a student, it is important to learn about teaching using technology.				.8939			.1514
As a teacher, it is important to employ technology in teaching.				.7792			.2789
It is important to know the psychological basis of how individuals learn in order to shape instruction; e.g., Vygotsky, Piaget, Skinner, Gardner.				.6814			.3011
Authoring tools have been important in my learning.					.8797		.2159
Website creation has been important in my learning.		.6161			.5189		.1093
It is important to make use of "pre-questions" to activate prior knowledge on material that will be taught in class.						.7307	.4274
Eigenvalues	4.17	2.44	2.19	2.18	1.47	1.16	
Proportion of variance explained	0.27	0.16	0.14	0.14	0.09	0.07	0.87

Note: Blanks represent values <.50. "*U*" explains factor uniqueness.

different for any factor. Independent samples *t*-tests were then performed to compare the mean scores on the factors to categories of students' ages. Factors 2-5 were not significantly different. For Factors 1 and 6, we found statistically different results between the two age categories. Responses for students aged 26 years and older on Factors 1 ($t_{(21)}, p = .05$); and 6 ($t_{(21)}, p < .005$) were statistically significant in comparison to students 25 years of age and younger. Interpretations on these differences are discussed below.

Discussion

An exploratory, hypothesis-generating study based on a small convenience sample was performed. Our goal was to produce hypotheses measures for validation in larger studies with random samples of

pre-service teachers. Twenty-three students were surveyed prior to WebQuest instruction to gauge their understandings of the role of technology in teacher preparation and pre-service instruction. Factor analysis of the survey as well as related analyses are discussed below.

Factor 1 (Acquired teaching strategies) is comprised of items relating to methodological strategies in teaching and accounted for 27% of the explained variance. A detailed itemization is available in Table 1; however, all items refer to constructivist practices and are phrased in such a way as to elicit agreement from students as to how confident they were in having acquired these skills. Therefore, we have labeled Factor 1 "acquired teaching strategies" because of its high loadings on survey items related to the fluency teachers develop as they interact and grow in peda-

gological confidence and expertise. Example items include “it is important to develop metacognitive skills in students,” and “I am able to scaffold questions based on Bloom’s Taxonomy.” Factor 1 also proved sensitive to differences in ages of our participants. This issue takes on importance because of the increasing intergenerational nature of the pre-service teacher population in the United States, perhaps due to the economic climate, and what it suggests for teacher preparation programs, (Associated Press, 2009). Due to this heterogeneous nature of today’s graduate level student populations, it may be that life experiences gained by older students shift perspectives in learning about teaching. Increased exposure to children and parenthood, as well as metacognitive maturation, may be influential for older students and this, in turn, may impact on their perceived importance of specific pedagogical skills.

Factor 2 (Exposure to technology) is comprised of items relating to technology integration in students’ own education and accounted for 16% of the variance. WebQuests, graphic organizers, interactive white boards and website creation comprise instructional technologies students have encountered, learned about, or believe are important to teaching preparation. Factor 2, in turn, relates to the TPACK and CFTK frameworks which seek to integrate content knowledge into technological practice.

Factor 3 (Practices in teaching effectiveness) yielded 14% of the explained variance. These practices are, basically, methodologies students have acquired that speak to task authenticity ensuring meaningful learning. High loadings on these statements implicate research findings on improving student learning by arguing that teachers should be aware of research findings in cognition and child development (Pashler et al., 2007). Thus, Factor 3 can be interpreted in relation to TPACK in building a sound pedagogical blueprint for designing and delivering effective instruction.

We perceive elements relating to Factor 4 (Cognition and technology) as accounting for 14% of the explained variance. Attitudes in integrating technology in instruction are situated within an awareness of constructivist principles. These have been operationalized by pre-service teachers in employing technological pedagogical knowledge as it associates with constructivist principles of learning theory. Pointing to technology as an enabler in demonstrating higher cognitive complexity, this factor displays recognition of the value of technology in providing integrated instruction.

Factor 5 (Technological synthesis) yielded 9% of the explained variance. Factor 5 is comprised of items relating to authoring and website creation technologies. We understand this factor to represent students’ application and synthesis of technology in instruction. It is distinguished from Factor 4 in that websites and authoring tools are more mechanistic and transcend tool usage as described in Factor 3. Factor 5 also relates to an incorporation of interactive technology that inspires pre-service teachers to employ tools directed toward knowledge production rather than content consumption.

Factor 6 (Pre-instructional questioning) accounted for 9% of the explained variance. While it consisted of only one item, specifically the statement “It is important to make use of “pre-questions to activate prior knowledge on material that will be taught in class,” it is of particular interest, especially in light of the highly significant difference between age categories. Whereas older participants (>26 years of age) viewed these pre-instructional questions as important lesson components, younger participants (18-25 years of age) viewed it as somewhat of less important. It may be that the pedagogical knowledge base of the older age category included some exposure to the strategy of pre-instructional questioning, with this exposure absent or somewhat limited in younger students. This may present some reflective opportunities for revised design and content of pre-service coursework which, in view of an

increasingly diverse population base of non-traditional students, may benefit from some programmatic fine-tuning in longitudinal development of teachers (Darling-Hammond, 2000; Koeppen & Griffith, 2003; Manos & Kasambira, 1996).

Finally, we again note our efforts in this study are exploratory and greater diversity of demographic types and sample sizes will likely add to the database of similar empirical studies investigating related questions. Readers are reminded this exploratory study was not designed to test an instrument but to generate a set of preliminary, hypothetical measures for testing in larger populations of pre-service teachers. We are not concluding these factors exist, but rather present strong empirical evidence these factors were found in our small convenience sample. Furthermore, we suggest that refining items for greater distinction is appropriate to capture the subtlety of pre-service teacher attitudes on technology, teaching and learning as well as aligning these with TPACK and CFTK constructs.

FINAL THOUGHTS AND FUTURE PROJECTIONS

The role of technology in pre-service teacher preparation will continue to escalate in importance. As schools proceed with technologizing instruction, pre-service programs must respond to the opportunities and challenges of e-initiatives. The National Technology Education Plan announced by the U.S. Department of Education in 2010 enumerates the spaces technologies already occupy in many students' daily lives: their mobile access to information, the creation and sharing of content, and the social networking allowing them to collaborate and share ideas. The report also advises "the challenging and rapidly changing demands of our global economy tell us what people need to know and who needs to learn. Advances in learning sciences show us how people learn. Technology makes it possible for us to act on this knowledge

and understanding" (p. vi), again underscoring the bond between technology infusion and the learning sciences.

Authentic learning, contextualized in real-world practice and purpose and steeped in individual interest, continues to enliven students today as it always has. Where lesson planning is a necessary step in teacher training, we believe the activity of designing WebQuests represents the next evolutionary progression for pre-service teachers as they develop pedagogical competence, content-area expertise, and technological fluency, in sum, an ideal synthesis activity for teacher education. Further, building a WebQuest using CFTK and TPACK constructs provides an ideal opportunity for pre-service teachers to operationalize a comprehensive toolkit of skills-development training received in pre-service programs. This instructional design, in general, encourages participatory pedagogy, reinforces learning theory, and incorporates technological innovation all united toward the goal of building purposeful, practical, and potent instruction that has potential to transform student learning. These two models take us past a "best practices" approach and into a "flexible access to highly organized systems of knowledge" (Mishra & Koehler, 2006, p. 102) designed to support, advance, and change learning. With the layering of TPACK and CFTK models into pre-service education curriculum, institutions have paradigms around which to organize instruction, evaluate goals and objectives, and present viable outcomes that become generalizable to a large population of student learners.

In 1932, George Counts, an American educator, theorist, and social critic, published a pamphlet entitled "Dare the School Build a New Social Order." In this account, he spoke of the power and promise of education and viewed schools as the one social institution that could profoundly and positively influence society at large. In one prescient observation, he noted since life would be transformed by technology, schools were in the best position to train students to manage this

transformation and make it work for the general good of society. We would be wise to keep this observation close at hand as we continue to devise new ways to educate teachers who will be at the vanguard of school and society. That technology will be part of their instructional arsenal is a given—how universities and other institutions will train them to make rich, meaningful, and productive use of this will not only be their sometime responsibility but their prime duty.

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APPENDIX A

Demographic Data:

1. What is your age? ☐ 18-25 ☐ 26-30 ☐ 31-39 ☐ 40-49 ☐ 50-59
2. Are you: ☐ Male ☐ Female?
3. List your highest degree earned: (undergraduate, master's/graduate certificate, Ph.D. Ed.D., J.D., other).
4. Content area or area of specialization: _____
5. Are you currently teaching as an in-service professional? ☐ Yes ☐ No
6. What type of school do you teach in, or plan to teach in? (rural, suburban, urban)
7. Grade Level (e.g. pre-K, K-5, 6-8, 9-12): _____
8. Is your school designated as a high needs or "Title I" school: ☐ Yes ☐ No

Computer usage – self:

9. Do you have a computer at home? ☐ Yes ☐ No
10. Approximately how many hours do you spend using your home computer both professionally and recreationally? _____
11. If no, do you have access to a computer lab? ☐ Yes ☐ No
12. Do you use the Web for your own purposes?
☐ personal enrichment; e.g., research, keeping up with news, etc.
☐ communications and social networking, e.g. e-mail, Facebook
☐ personal productivity, e.g., shopping, banking, file storage, etc.

Technology importance as a student (both pre- and in-service):

Rating Scale:

1 (not important) 2 (somewhat important) 3 (as important as every other subject)
 4 (very important) 5 (extremely important)

13. How important has learning about teaching using technology been as a student?

1 2 3 4 5

Please indicate the types of technology tools and instruction you have used as a student and rate each in importance to you as a student:

PowerPoint presentations 1 2 3 4 5

Graphic organizers 1 2 3 4 5

Smartboards 1 2 3 4 5

Webquests 1 2 3 4 5

Website creation 1 2 3 4 5

Blogs/Wikis or

other authoring tools 1 2 3 4 5

Other: _____ 1 2 3 4 5

How important is employing technology to your teaching (or future teaching if you are pre-service)? 1 2 3 4 5

Computer usage – classroom: “If you are currently teaching...”

14. Do you have a computer in the classroom? ____ Yes ____ No

number of computers _____

15. If no, do your students have access to a computer lab? ____ Yes ____ No

16. Do you have students develop their own Web pages? ____ Yes ____ No

17. Do you create WebQuests for your students? ____ Yes ____ No

Do you use WebQuests in your classroom? ____ Yes ____ No

Technologizing Teaching

For the remaining questions, please think about your training to become a teacher and rate your assessment of importance for each statement.

19. It is important to know the psychological basis of how individuals learn in order to shape instruction; e.g., Vygotsky, Piaget, Skinner, Gardner.

1 2 3 4 5

20. I am comfortable differentiating instruction among students in a classroom

1 2 3 4 5

21. In my teaching, I employ pictures, text and other visuals to aid student cognition and memory retention.

1 2 3 4 5

22. I am able to engage my students in critical and creative thinking skills.

1 2 3 4 5

23. I am able to scaffold questions based on Bloom's Taxonomy.

1 2 3 4 5

24. I am able to challenge my students by questioning to get them to think deeply about knowledge.

1 2 3 4 5

25. It is important to develop metacognitive skills in students.

1 2 3 4 5

26. I am comfortable in distinguishing between traditional and authentic assessments among students in a class.

1 2 3 4 5

27. I believe it is important for a teacher to space learning episodes over time.

1 2 3 4 5

28. If I teach subjects like mathematics or science, I think it's important to mix solutions and problem-solving exercises throughout the lesson.

1 2 3 4 5

29. I think it's important to make use of "pre-questions" to activate prior knowledge on material that will be taught in class.

1 2 3 4 5

30. I think it's important to make use of short quizzes or tests to re-expose students to key course content.

1 2 3 4 5

Appendix B

WebQuest Sites

<http://webquest.org/index.php>

<http://bestwebquests.com/>

http://www.teach-nology.com/teachers/lesson_plans/computing/web_quests/

<http://www.eduscapes.com/tap/topic4.htm>

<http://questgarden.com/>

Chapter 11

A Theoretical Framework for Implementing Technology for Mathematics Learning

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ABSTRACT

This chapter details a theoretical framework for effective implementation and study of technology when used in mathematics education. Based on phenomenography and the variation theory of learning, the framework considers the influence of the learning context, students' perceptions of the learning opportunity, and their approaches to using it upon measured educational outcomes. Elements of the TPACK framework and the CTFK model of teacher knowledge are also addressed. The process of meeting learning objectives is viewed as leading students to awareness of possible variation on different aspects, or dimensions, of an object of mathematical learning.

INTRODUCTION

Implementation and study of technology within the mathematics curriculum must consider an appropriate theoretical framework. Leading theories of mathematical learning tend to focus upon one particular aspect of learning: cognition, social interaction, or context. Further, technology use

and educational research based upon these theories limit focus to the primary considerations of the chosen theory, with limited scrutiny or examination of alternatives. The view of learning taken by the phenomenographic research approach and its associated variation theory (Bowden & Marton, 1998; Marton & Booth, 1997; Prosser & Trigwell, 1997; Runesson, 2005) avoids these limitations. Phenomenography and variation theory share a unique relationship; the fundamental assumptions

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of the phenomenographic view of learning are detailed in the recently developed variation theory, which itself evolved from the findings of empirical phenomenographic research studies (Bowden & Marton, 1998; Marton & Booth, 1997; Runesson, 2005). As an approach to research, phenomenography searches for the qualitatively different ways of experiencing an educational phenomenon. As a theory of learning, the aligned variation theory focuses upon guiding learners to an awareness of the different aspects of the learning object.

This chapter considers three essential questions regarding the implementation and study of technology within the mathematics curriculum:

1. How is the application of a learning theory influential in the implementation and study of technologically enhanced mathematical learning?
2. What is the derivation of the variation theory of learning, and how does it apply to the teaching and learning of mathematics?
3. How can variation theory help to establish an effective framework for implementing and researching technology use in mathematics education?

The chapter first briefly examines constructivism and the situative perspective, two predominant theories of learning in mathematics education. This is followed by a discussion of the central tenets and historical development of variation theory from phenomenography. Next, variation theory conceptualizations of learning mathematics via technology are presented as a guide for the development of effective technology-enhanced experiences that facilitate mathematics learning, a concern of the mathematics Technological Pedagogical Content Knowledge (TPACK) Framework (Association of Mathematics Teacher Educators, 2009; Mishra & Koehler, 2006; Niess et al., 2009; Ronau, Rakes, Wagener, & Dougherty, 2009). Finally, the chapter concludes with the implications of phenomenographic methods and the pre-

sented framework for research of technology-rich learning opportunities in mathematics courses. These research considerations also align with the TPACK framework (AMTE, 2009; Mishra & Koehler, 2006).

METHODOLOGY

The initial search of the existing literature for this work was part of a comprehensive and broader doctoral dissertation literature review (Miller, 2007). Searches for recent publications on learning theories and technologies utilized the ERIC, Educause, and JSTOR databases to focus upon issues in education. Manuscripts were included based upon two criteria: (1) examination of either the constructivist or situative perspectives, and (2) application of technology to improve learning. Article selection considered a historical view of the theories via publications from their originators alongside more recent interpretations and applications. Identification of writings regarding phenomenography and the variation theory of learning took a similar, albeit more comprehensive, approach. A more thorough review of phenomenography and variation theory was facilitated by their more recent development and the smaller body of published work.

There are both benefits and limitations to this selection method. It could be argued that inclusion of additional and more delineated learning leading theories could lead to alternative conclusions regarding their influence upon the implementation and study of technology use in mathematics learning. However, these two perspectives are regarded as dominant in the realm of mathematics education in the United States (Cobb, 1994; Cobb & Bowers, 1999; Davis & Sumara, 2002; Oregon Technology in Education Council, n.d.). Constructivism forms the basis of the Principals and Standards of the National Council of Teachers of Mathematics (1989, 1991, 2000) and the benefits of situated learning is evident in their attempt to emphasize meaningful,

realistic learning opportunities. The triangulation of primary sources with more recently authored publications aimed to further validate reported findings. With phenomenography and variation theory, triangulation of early with more recent publications, as well as theoretical with empirical conclusions, also substantiates the reliability of the source material. The validity of claims regarding the effectiveness of the derived framework for technology implementation in mathematics was further demonstrated in an empirical study conducted by the author based upon variation theory (Miller, 2007).

Predominant Learning Theories in Mathematics Education

When mathematics teachers design and implement effective, technology-rich learning opportunities for their students, they are applying their technological pedagogical content knowledge (AMTE, 2009; Mishra & Koehler, 2006). But within this structure and at a more fundamental level, teachers' conceptualizations of what it means to effectively learn mathematics are at play. A limited view of learning is established by leading perspectives such as constructivist and situative perspectives that consider the specific elements and aspects of learning. Teachers often attempt to engage students in active learning primarily via cognitive engagement that is emphasized through reflective writing activities, or with a combination of cognitive and interactive activities, such as through collaborative learning activities. These differing approaches are connected to a specific underlying view of how learning occurs.

A cognitive constructivist perspective focuses upon internal cognitive and metacognitive activity that is viewed as essential for ensuring a personal understanding of content in relation to the existing knowledge and previous experiences of the individual (Bruner, Goodnow, & Austin, 1956; Marton & Booth, 1997; Piaget, 1950; Prosser & Trigwell, 1997; Schön, 1987). Through learning

activities that provoke cognitive conflict and/or reflection, learners recognize the gaps and flaws in their understanding and work toward rectifying these issues, building upon existing knowledge (Schön, 1987). Resultantly, instructors and researchers adopting a cognitive constructivist view do not focus upon the structure of the learning environment or the encouragement of interaction with other learners as a means for collaborative construction of knowledge (Davis & Sumara, 2002). Building a consensus of understanding or external body of knowledge is not the priority; instead, attention is given to the development of personal understanding and internal knowledge structures.

A situative perspective focuses upon the learner's engagement with the learning environment and with other learners, recognizing that mathematics content, and technology, are learned and understood within specific contexts, with social interaction and the learning context acting together as the impetus or primary mechanism of learning (Davis & Sumara, 2002; Lave, 1988; Lave & Wenger, 1991; Mishra & Koehler, 2006; Wenger, 1998; Vygotsky, 1978). Under this view, students are led to be, as the National Council of Teachers of Mathematics (1989, 1991, 2000) discusses, active learners rather than passive receptors of memorizable algorithms and rules. Interaction and collaboration are seen to result in deeper understanding through exposure to and exploration of multiple perspectives and approaches (Cobb, 1994; Cobb & Bowers, 1999). The collaborative aspect emphasizes the benefit of sharing and merging the perspectives, experiences, interpretations and viable strategies suggested by different members of the group (Kanuka & Anderson, 1999). Such groups which work, explore, and learn together have been termed communities of practice (Wenger, 1998). Typically, these learners work together with a clear goal: to find an appropriate and acceptable solution to a complex problem. Resulting knowledge is viewed as generated via collaboration as belonging to the

entire group rather than any particular individual (Edwards & Mercer, 1987).

The situative perspective also emphasizes that learning best occurs in realistic and contextual problems and scenarios, and that learning occurs naturally as a function of the context in which it occurs (Lave, 1988; Lave & Wenger, 1991). Developed understandings are tied to the context in which learning occurs. Thus, instructors and researchers focus upon the development of activities and appropriate, contextual learning environments that scaffold learning. The internal, cognitive activities of the learner are not at the forefront of instructional concerns.

Davis and Sumara (1997, 2002) observe that both situative and constructivist views of cognition lead to inference of appropriate classroom practices based upon descriptive, rather than prescriptive, foci and that the originators of situative cognition openly view learning as occurring ideally beyond the traditional classroom. For practical application in the classroom, Davis and Sumara argue, a model of learning that recognizes the greater complexity and dynamic nature of learning must be adopted. They suggest that valuable classroom applications must derive from a theory appropriate for the setting that considers the “phenomena that arise intermediary levels of social organization between self and society” (2002, p. 426). They claim learning is “dependent on, but determined by” teaching (1997, p. 115), and that the situative and constructivist perspectives fall short of recognizing that learning occurs “in the relations between the individual and the collective, between accepted truth and emerging sense, and between actualities and possibilities” (1997, p. 120-121).

As Runesson (2005) and Davis and Sumara (1997, 2002) note, adoption of an individualistic or situative theory of learning limits one’s perspective when conducting research or developing a curriculum. While cognitive constructivism and situated learning share some common origins and beliefs (Davis & Sumara, 2002; Tan, 2002),

selecting one theory over another can result in significantly different pedagogical consequences (Cobb & Bowers, 1999; Phillips, 1995). Cobb (2000) emphasizes the need for a reflexive relationship between these theories of learning when confronting educational issues. He claims that the different activities, concepts, contexts, and students involved require different theoretical lenses through which they should be viewed.

The Phenomenographic View of Learning

Learning and understanding of mathematics is intertwined with the lived experiences, existing knowledge, and context of learning experiences both past and present (Cobb, 2000; Dewey, 1938; Prosser, 1993). The phenomenographic view of learning allows for a balance of considerations from the leading learning theories, considering and establishing descriptions of learning phenomena that are “relational, experiential, content-oriented, and qualitative” (Marton, 1986, p. 33). This view of learning considers aspects of both individualistic and situative perspectives by focusing upon the academic experiences of individual learners within a learning context (Prosser & Trigwell, 1997). The learning environment, learners’ characteristics, and internal cognitive activities are recognized as dominant in the learning process (Marton & Booth, 1997; Prosser & Trigwell, 1997). Marton and Booth (1997) described learning

in terms of the experience of learning, or learning as coming to experience the world in one way or another. Such learning inevitably and inextricably involves a way of going about learning (learning’s how aspect) and an object of learning (learning’s what aspect). (p. 33)

Content and the way in which individuals go about learning it are recognized as being inter-related.

Subsequently, the focus is upon the differences in variation within and across learning experiences. Marton (1986) described the holistic perspective that phenomenography applies to learning:

Phenomenography investigates the qualitatively different ways in which people experience or think about various phenomena. This implies that phenomenography is not concerned solely with the phenomena that are experienced and thought about, or with the human beings who are experiencing or thinking about the phenomena. Nor is phenomenography concerned with perception and thought as abstract phenomena, wholly separate from the subject matter of thought and perception. Phenomenography is concerned with the relations that exist between human beings and the world around them. (p. 31)

Marton further noted that questions regarding these perceptions and experiences are inherently qualitative, and that to fully understand a learner's experience, considerations must include the learner's perspective of the experience (Marton, 1986; Marton & Booth, 1997).

Prosser and Trigwell (1997) detailed the relationship between the individual and his or her context, noting that "there is a variation in people's experiences of the same thing" (p. 42) which directly influences learning outcomes. Prosser and Trigwell (1997) discussed the phenomenographic view of learning in relation to the individual, the learning context, students' perceptions of the learning context, and their approaches to learning within the context, all influencing the outcomes of the learning experience. From this view, the existing characteristics of the student, often evolving from existing knowledge, conceptions and previous experiences, are seen as influential upon the learning process and learning outcome.

Prosser and Trigwell's (1997) depiction of learning within a learning phenomenon inherently considers the influence of peers in the learning context. Interaction with other learning

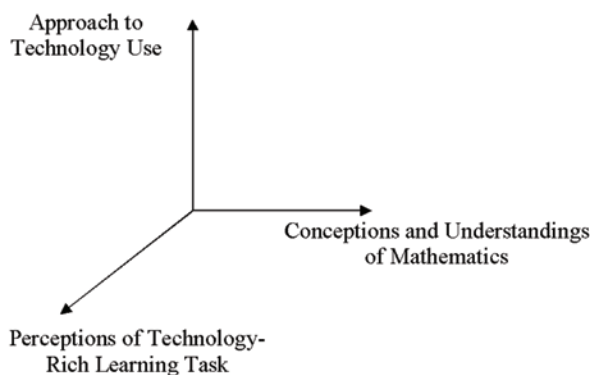
approaches, as well as potential exposure to others' beliefs, perceptions, and existing knowledge from previous experiences, directly influences how and what an individual learns (Vygotsky, 1978). Prosser and Trigwell's (1997) description of learning, however, does not explicitly address the dynamic nature of the elements of a learning experience, especially over an extended period of time. For the instructor to effectively design and implement an effective learning context that considers the characteristics, approaches, and perspectives of students, the learning opportunity must adjust appropriately.

Figure 1 addresses the central but broad elements of a learner's experience within a learning phenomenon. Here, the experience is depicted as having three dimensions: learning outcomes regarding conceptual understandings and conceptions of mathematics; approaches to using technology; and perceptions and attitudes regarding the technology-rich learning task. This model shows these three dimensions on continua, emphasizing their interaction and the degree of variation that can occur in a learning experience from one individual to another. The model represents learning as situated within a learning task, with student and context characteristics acting upon the depicted elements of the scenario. From this viewpoint, these three dimensions must be part of a mathematics teacher's TPACK when developing meaningful learning tasks.

The Tenets of Variation Theory

Variation theory builds upon the phenomenographic ideas that learning is relational, experiential, qualitative, and tied to the specific context in which it occurs, by defining what learning is and how learning occurs (Marton, 1986; Marton & Booth, 1997; Prosser, 1993). According to variation theory, someone truly learns something when he or she experiences the content in a new way (Bowden & Marton, 1998; Marton & Booth, 1997). The content under focus in the learning situ-

Figure 1. Three dimensions of students' experiences in learning mathematics within a technology-rich learning task



ation can be referred to as the *object of learning* (Runesson, 2005). By defining learning in this way, the object of learning is established as central; the teacher first considers the content to be learned, then considers what aspects of the content are important to recognize and what methods must be employed to lead students to an awareness of these aspects.

Runesson (2005) clarified that learning (i.e., experiencing something in a new way) includes a change in which the learner sees, experiences, or understands the object of learning. This change is influenced by how the learner experiences the learning situation, including his or her perceptions and assumptions of the learning activity and its goals. For any object of learning and for any learning situation and context, many aspects or dimensions may be considered. At any given time, a learner may be aware of numerous aspects, but only a small number of these are at the forefront, or focus, of the learner's consideration and attention (Bowden & Marton, 1998; Runesson, 2005). The aspects or dimensions considered and focused upon help to define the learner's experience and are the foundation for what is learned. From a variationist perspective, learning activities must reveal to students the appropriate aspects of the mathematics that they are learning.

From Runesson's claims and the previous discussion of the phenomenography, the meaning of learning clearly involves the variation of experiences among learners. But *what* is experienced and *what* is learned? Bowden and Marton (1998) claimed, "to experience something is to discern parts and the whole, aspects and relations" (p. 33). Here, another type of variation—the variation that is actually learned—becomes critical (Bowden & Marton, 1998; Marton & Booth, 1997; Runesson, 2005). To understand something in a new way, there must be a change in the pre-existing understanding through exposure to variation of a particular aspect of the object of learning. The variation of this aspect or dimension is what is learned. The process of learning variation involves, in part, the necessity advanced by Marzano, Pickering and Pollack (2001) of leading students to discover similarities and differences among concepts and learning opportunities.

To learn by variation means to learn distinctions within a dimension or aspect of the object of learning. That is, a learner becomes aware of the variation of particular dimension of the learning object. But to become aware of such variation, the individual must be able to discern that the dimension exists (Bowden & Marton, 1998; Pang, 2003; Runesson, 2005). To learn, students must become aware of a dimension as defined by

its variation, which must be experienced by the student (Bowden & Marton, 1998). Thus, learning experiences must bring desired aspects and their variation to the attention of the learner.

As an example, consider an analysis by Runesson and Marton (2002) examining two different classroom lessons on fractions. The first teacher focused upon different problems throughout the lesson; values were changed as students were led through examples. The second teacher focused upon different solution methods; students demonstrated their solution strategies during a class discussion about a single problem. Two different types of variation were implemented. The first teacher varied the problem, leading students to practice application of a particular solution strategy with different sets of numbers. The second teacher varied the approach to solving a single problem, leading students to think about and discuss the different valid mathematical interpretations and solution processes for the scenario.

The learning objectives of these two approaches correlate well with what Skemp (1976) describes as instrumental and relational understandings (respectively) of mathematics. The two groups of students were made aware of significantly different dimensions of the concept of fractions. The first group was made aware that numbers could change. The second group became aware of the different approaches to solving the problem, which Runesson and Marton conclude leads to a better conceptual, or relational, understanding of mathematical ideas. The teachers' approaches to instruction in these examples also reflect what the Comprehensive Framework for Teacher Knowledge, or CFTK (Ronau et al., 2009), describes as *discernment*. The CFTK describes discernment as the ability of teachers to reflect upon, judge, and compare/contrast available alternatives for making informed and effective decisions for the classroom. This discernment is crucial for selecting appropriate tasks that introduce desired and appropriate types of variation to students, and hinges upon teachers possessing the knowledge necessary for

inquiry and reflection upon their craft, both for lesson planning and for in-the-moment decision making in the classroom (Brew, 2001; Dossey, 1992; Fennema & Franke, 1992).

Runesson and Marton's (2002) examples also demonstrate the importance of making variation explicit in a learning task. If an individual is unaware of variation along a dimension, he or she may not come to recognize the existence of that dimension. While both teachers in the example employed their pedagogical content knowledge to construct a learning opportunity in which students learned mathematics, the teachers were focusing upon different aspects of the content, which in turn influenced their selection of teaching methods. Without exposure to the possible variation in solving the problems, the first group of students remains unaware that other methods exist and may fail to develop a holistic, conceptual understanding of the subject matter. Leading students to recognize and identify dimensions of an object of learning be accomplished in different ways. Two of these, in particular, are: (a) distinguishing between the different dimensions of an object of learning or a learning situation, and (b) recognizing differences in the dimensions of multiple objects of learning or multiple learning situations.

The first approach suggests a focus upon new or different dimensions not previously emphasized. This could concern an aspect never before considered by the individual or within the course. Recognition of this dimension may come through one's own exploration with the object of learning, the design of the learning activity or context, or the contributions of others (the instructor or peers). Students may also come to recognize a new aspect of the current learning situation itself. Such aspects could include the perceived value of the activity, assumptions of intended learning goals, or the expectations and opportunities within the learning context. These changes in perceptions and assumptions will further affect subsequent learning outcomes.

The second approach more closely aligns with the argument made by Marzano, Pickering and Pollock (2001) that students should be led to discover similarities and differences across course content. Here, two possibilities hinge upon the previous experiences of the learners. One possibility would be a comparison of the object of learning with another (previous) object of learning, becoming aware of variation of a common aspect of these objects. For example, two objects of learning could be examined in terms of their common and differing variation on a shared aspect. The other possibility requires recognition of variation from one learning situation to another. An individual may come to appreciate the different functions that a particular object of learning serves in different learning situations, or the different perspective from which that object was examined.

The variation theory of learning recognizes that groups of learners have qualitatively varied experiences in learning situations, and that there are a finite number of categories of these experiences. What is learned is dependent, in part, upon what dimensions or aspects of both the object of learning and the learning context are brought to the forefront through exposure of the learners to variation along these focal dimensions. Through experience with this variation, individuals can discern the dimensions, and learn the variation along these dimensions. Should a student fail to learn something, this suggests that he or she is unable to discern the associated dimension of the content, meaning that he or she has not explicitly experienced sufficient variation along that dimension. Exposure to variation does not ensure that a learner has experienced that variation. The learner must be consciously aware of the variation, and the teacher should strive to bring it to the forefront for this purpose. The mathematics teacher's pedagogical content knowledge, in practice, can lead to the development of meaningful lessons and tasks that lead to this awareness. As technology is integrated into these meaningful lessons, the interactions of teachers' technology knowledge with pedagogical

content knowledge (i.e., TPACK) may determine effectiveness of the lesson for student learning.

A Framework for Technology in Mathematics Learning

Variation theory suggests, then, that technology be used in the teaching of mathematics to engage students in the learning process and expose them to new dimensions of mathematics content. Students may then become aware of and learn the variation along these dimensions. To achieve these goals, the instructor must focus students upon those necessary dimensions of the object of learning and the learning situation, as well as the potential variation of these aspects. Different components of the teacher's knowledge are required to develop appropriate and effective learning opportunities that lead to an awareness and understanding of these dimensions. Often, variation is introduced over time, over multiple classes, and over years of mathematical learning in school. As time passes, students' experiences with mathematics both inside and outside of the classroom evolve and the refining and learning of mathematical concepts occurs.

Two principles of teaching to experience detailed by Marton and Booth (1997) should guide the integration of technology into the mathematics curriculum. The first concerns building a relevant structure by creating situations for students to encounter new abstractions, theories and explanations. Connections can be made to students' everyday lives and previous experiences while emphasizing the usefulness of technology. Mathematical ideas can be developed through exploration before being formalized. The second principle concerns the "architecture of variation." Emphasis is placed upon building upon the expected variation among students and their varied approaches to solving problems. Often, sources of variation include students' previous contributions in class and the teacher's past experiences in teaching the course content. Learning opportunities should

enable students to consider and explore variation across their viewpoints and frames of reference within class work and discussions. Technology use can lead students to recognize and confront assumptions about course content and the nature of mathematics that could impede development of deeper and conceptual knowledge. The benefits and aspects of available technology should be exploited to introduce a variety learning activities that attract the interest of as many students as possible.

Mathematics instruction aims to lead students toward mastery of mathematical concepts, improved communication with mathematical ideas, and/or the readjustment of their conceptions of mathematics. All of these are affected by students' perceptions of and approaches to learning tasks. Variation theory argues that a lack of proficiency in these categories results from a lack of variation along these dimensions in students' previous mathematics courses. The collection of learning activities must explicitly vary conceptualizations of mathematics, so that students must begin to view mathematics as a way of thinking rather than a subject that consists only of memorization, computation, and procedure application.

As Runesson (2005) concluded, the essential and relevant dimensions or aspects of the content and the learning situation must be brought to the forefront through the design of the learning opportunity. To achieve these educational objectives, teachers must apply sophisticated levels of content and pedagogical content knowledge (Shulman, 1987). To facilitate this process and to effectively make use of technology, teachers must also rely upon a strong foundation of technological pedagogical content knowledge (Mishra & Koehler, 2006).

When implemented, technology must then act as a key and integral component of the learning context, which the CTFK model delineates into two aspects: *individual* and *environment* (Ronau et al., 2009). Teachers, therefore, must possess knowledge regarding the multiple levels of

external influences upon learning opportunities (Bryk & Driscoll, 1988). Concerning individual contextual factors, teachers must consider technology implementation alongside individuals' needs, when and how students should work together or alone, and the teachers' goals associated with developing meaningful learning communities (Ball, 1996; Bryk & Driscoll, 1988; Lave & Wenger, 1991; Stemler, Elliott, Grigorenko & Sternberg, 2006). Consideration of individual factors can lead to implementation of technology-rich learning opportunities that allow unique approaches to learning not afforded by more traditional methods of instruction. Learners can be encouraged to take personally appropriate time for reflection upon mathematical content, to develop personally meaningful understandings of course content that are tied to the technology-rich learning context, and to eventually demonstrate understandings and abstractions while continuing to interact with the instructor and other learners (Bender, 2003; Cobb & Bowers, 1999; Mishra & Koehler, 2006; Zenios, Banks & Moon, 2004).

Tasks can be included which require practice of mathematical algorithms. Learning opportunities can lead students to recognize and explore new representations of familiar concepts. These activities can promote the sharing and exploration of various solution strategies of mathematical concepts. Topics can be addressed that explore the nature and application of mathematics through expression of personal experiences, resulting in reconceptualization of these ideas. Electronic communication tools, for example, can provide a means for students to reflect upon their mathematical understandings and communicate using mathematical ideas, leading them to achieve this desired educational objective.

Environment, the second aspect of context as identified by the CTFK model, considers the influence that organizational structures and characteristics of learning opportunities themselves have upon student learning and academic outcomes (Ronau et al., 2009). Students' beliefs

and perceptions concerning the nature of mathematics, the technology used, and the goals of specific learning tasks can significantly influence their interest, motivation, and behavior (Ball, 1996; Byrk & Driscoll, 1988; Philipp, Clement, Thankheiser, Schappelle & Sowder, 2003; Prosser & Trigwell, 1997).

These contextual considerations are evident in the phenomenographic and variation theory views of learning and in the three aspects of effective technology implementation in mathematics learning presented in Figure 1: (a) promoting positive student perceptions of the technology-rich learning context; (b) providing students with the opportunity to participate in diverse ways, sharing, expressing, and building upon their existing knowledge, conceptions, perceptions and previous experiences; and (c) demanding that students consider, apply, and correlate their viewpoints with those of others through active learning opportunities and development of new knowledge and understandings. These necessities place responsibility upon the instructor to understand the existing characteristics of the students to participate in learning opportunities with appropriate participation requirements and an inviting atmosphere, so as to engage students through both familiar and new learning approaches and experiences. This requires teacher knowledge of the individual context (Ronau, Rakes, Wagener & Dougherty, 2009). Additionally important is acknowledgement and modification of students' conceptions of the nature and teaching/learning of mathematics as well as the technology itself.

For effective implementation of technology into the process of learning mathematics, just as with implementation of strategies that do not include technology, teachers must possess mathematics content knowledge, pedagogical knowledge and pedagogical content knowledge as detailed by Shulman (1987). In addition, teachers must also be aware of the types of technology

available and the mechanics of their operation, which Mishra and Koehler (2006) describe as technological knowledge. But to integrate technology in a meaningful way that promotes relational learning and leads to an awareness and exploration of the different dimensions of mathematics and mathematical concepts, teachers must rely upon a strong foundation of what Mishra and Koehler (2006), Ronau et al. (2009), and the AMTE position statement on TPACK in mathematics (2009) describe as technological pedagogical content knowledge (TPACK). This operational knowledge hinges upon the intersection of teachers' content, pedagogy, and technology knowledge. Development of a robust TPACK leads to consistent implementation of meaningful and relevant learning opportunities that make use of integrated and necessary technology.

TPACK is developed by teachers in five stages (Niess et al., 2009). During the second and third stages of accepting and adapting, teachers are regularly determining whether or not they find the technology easy to work with and a good fit for the academic outcomes they wish to address. To do so, teachers may identify the variation they wish to make evident to their students and the role(s) that the technology can play in leading to discovery and awareness of this variation. The remaining stages, exploring and advancing, lead to implementation of the technology by designing technology-rich learning opportunities for students. Several types of variation in technology implementation are discussed next, with select examples highlighted. For each type of variation discussed, students are led to be engaged with the course content in different ways. While many of these types of variation can be achieved to some degree without technology, the integration of technology can enhance or facilitate the process, allowing for learning opportunities that lead to an awareness of further variation.

Different Problems

Runesson and Marton (2002) demonstrated that variation is not a panacea for developing relational understanding in mathematics. Consider, for example, providing computation practice via a number of exercises across which numerical values or the level of difficulty varies. If the variation used simply involves showing multiple problems aimed at producing mastery of a skill, computation, or algorithm, then the only resultant learning is what Skemp (1976) referred to as instrumental understanding; that is, mathematical skill without conceptual understanding.

Many commercially available computer programs, often provided with textbooks, are designed to provide this type of variation in the learning process. These programs lead students toward a program- or instructor-determined level of “mastery” of the problems students work on individually via their computer. These programs continue a long history of what was initially considered “computer aided instruction” in mathematics by focusing on computer “tutoring” of students via extra problems. Today’s software can provide students with specific tutorials when they encounter difficulties and generate additional, similar problems for the students to work before going on to slightly different or more challenging problems.

Selection of such programs can occur at the exploring stage of TPACK development (Mishra & Koehler, 2006; Ronau et al., 2009; Niess et al., 2009) to meet specific learning objectives. However, there is little variation possible for the ways in which these programs are utilized or the way in which students interact with the technology or content. Dependence upon this type of implementation can lead only to instrumental understanding of mathematics. Teachers who solely choose technology toward goals of instrumental understanding may be demonstrating a lack of advanced levels of TPACK, failing to recognize the potential and means of more effective technology use.

Different Solution Methods and Approaches

Runesson and Marton (2002) also examined a teacher who focused upon a single problem while encouraging the students to share and explore a variety of valid solution strategies for the problem and leading toward relational understandings of mathematics (Skemp, 1976). From Shulman’s perspective (1987), this approach to implementation would demonstrate deeper levels of both content and pedagogical content knowledge. A strong foundation of TPACK is critical for teachers to regularly and successfully integrate technology toward such goals (Mishra & Koehler, 2006). In variation theory terminology, the dimension varied would be the solution strategy. Here, computer software associated with mathematics textbooks is less helpful. Such programs do allow freedom for students to use their own methods to reach the correct solution, since students typically do not enter their work but only provide an answer. But these programs do not lead students to discover, attempt, or practice different solution strategies. They do not lead to relational understanding.

Collaborative forums, however, can provide a means through which students can be exposed to alternative solution strategies. Online chat sessions and asynchronous discussions are all readily available to lead students to work with others on particular mathematics problems (Brett, Woodruff & Nason, 1999; Kosiak, 2004; Miller, 2007). These forums can provide a valuable extension of traditional group work on problem sets or more advanced mathematical projects. By collaborating via electronic communication, students are led to more carefully and thoroughly craft their own interpretations, approaches, and explanations to share with others in the group. A transcript of discourse documents the solution process, and students may review and reflect upon this transcript to better understand the problem-solving process (Zeinos, Banks & Moon, 2004). They also must effectively defend or modify

their approaches in response to their group mates' questions. By having each member of the group share different strategies, students can be led to appreciate and explore the benefits and limitations of various approaches and develop connections between them. Instructors can also participate, better ensuring that specific aspects of the content are encountered and discussed through the scaffolding process (Bouniaev, 2004; Fauske & Wade, 2004; Mazzolini, 2003). Asynchronous forums allow group members more time to craft questions and explanations and to contemplate the given scenario in comparison to tasks within the traditional classroom setting. Students therefore gain a deeper understanding of the approaches used in problem solving.

In these interactive forums, mathematics students are also being led to vary the way in which they communicate with mathematics. When working homework problems on paper, students are encouraged to show their work or steps. When working in face-to-face groups, students are often able to "show" what they mean on paper without necessarily using formal or proper mathematical language. But when communicating electronically, students are forced to explain their thinking behind their steps until their group mates understand their approach, and the use of proper, readily-understood mathematical terminology becomes critical to the progress of the group (Kosiak, 2004; Sloffer, Dueber & Duffy, 1999). Reflection upon the solution process becomes a more natural component of the learning experience as well.

The "anytime, anywhere" nature of asynchronous tools, in particular, allows for a Vygotskian approach to learning, enabling a user to take as much time as desired for reflection upon online postings, personal knowledge, and interpretations, to eventually demonstrate deep understandings and high levels of abstraction (Vygotsky, 1978; Zeinos et al., 2004). An individual can self-regulate reflection time based upon his or her own learning style and the complexity of the concepts involved. The frequency and depth of this reflection occurs

via an increasing degree of learner autonomy and scaffolding of the learning process (Zenios, Banks, & Moon, 2004) facilitated by careful, pedagogically appropriate implementation of the technology. Thus, characteristics of the individual and interaction within the learning context can be considered in creating learning opportunities that include these types of forums. From these types of technology-rich learning opportunities, students explore various strategies and their considerations when encountering new mathematical scenarios are broadened.

Different Representations and Models

Available technology can aid the exploration of new representations of mathematical concepts. Graphing calculators and graphing software, for example, enable students to efficiently and visually explore how equations representing different real-world phenomena are altered by changing an underlying assumption or input value. The ability to explore dynamic representations and models allows for development of conceptual understandings. In her meta-analysis, Ellington (2003, 2006) found that when students use graphing calculators in both testing and instruction, both conceptual and procedural skills improve. Additionally, students' attitudes toward mathematics improved. Through problem based learning, students can explore aspects of data sets, compare multiple sets of data, and evaluating and critiquing the appropriateness of different measures of central tendency and visual representations of the data sets (Shore & Shore, 2003). Students do not need to make these decisions initially; they can quickly create different representations and calculate different measures before selecting the desired or "better" option which they then rationalize.

Many technologies, including graphing calculators, allow multiple representations of mathematics content to change simultaneously before the user's eyes, helping to diminish the compartmentalization of different fields of

mathematics promoted by the k-12 curriculum structure and leading to deeper understandings and developed connections between concepts (Roschelle & Singleton, 2008). Programs allow students to interact with geometric and algebraic representations of mathematics interchangeably. Online applets and virtual manipulatives allow students to “predict” where images of figures will align after specified or selected transformations. These applets provide various representations of the same concept, yet go beyond the elementary stage of drawing figures that result from a given transformation. Technologies such as these computer programs, applets, and calculators can lead to significant gains in students’ academic achievement (Rakes, Valentine, McGatha & Ronau, 2010).

Different Contexts and Applications

Opportunities to learn mathematics via technology must not feel contrived to students. Students’ perceptions of the learning situation will influence their motivation and the value they place on the learning phenomenon (Crawford, Gordon, Nicholas & Prosser, 1994; Prosser & Trigwell, 1997). The assortment of technology at the instructor’s disposal can — and should — reduce the need for using contrived contexts and problems in the classroom, providing a gateway to real-world contexts and applications.

Implementation, therefore, should consider using technology within the contexts of real-world scenarios, with the use of technology appropriately matched with the given task (Herrington, Herrington, Sparrow & Oliver, 1998). In the classroom, graphing calculator technology and personal response system clickers enable students and the teacher to interact and participate in new ways that allow for more anonymous interaction (from classmates’ perspectives) and more immediate feedback regarding students’ understandings of course content. For presentation of advanced applications and career-based use of mathematical ideas, relevant video clips can be shown. Guest

speakers can be included in class via current conferencing tools. Students can go on virtual tours of mathematical applications using online communication networks or visiting websites that provide prepared viewable materials. Tasks can be implemented that require students to develop mathematical models using hands-on activities and mathematical software, with follow up projects to use standard office applications to prepare summary reports of their findings. As students become increasingly familiar with movie editing software, they can also be asked to prepare short video presentations.

Finally, projects and assignments can make full use of the internet and software packages by overcoming traditional limitations of textbook mathematics problems (Oliver & Herrington, 2000). Historically, textbook problems provide students with all necessary and relevant information for solving the problem for the sake of time and efficiency or are limited to easy-to-manipulate data. The vast information readily available via the internet and technology-equipped classrooms allows for tasks that expect students to first research and gather relevant quantitative online to use in the problem-solving process. Software allows for analysis of more realistic and less simplistic data and advanced calculations. A unit on installment loans, for example, may ask students to research online the type of car they would like to purchase, the associated costs, and the current interest rates and restrictions associated with automobile loans at local financial institutions. Using this personalized information, students can then explore the financial implications of purchasing an automobile.

Different Interactions with Technology

Variation in the types of technology used is critical in preparing students for efficient and effective application of mathematics content. But perhaps more important is variety in the ways that students use this technology when learning and applying mathematical concepts (Wenglinsky, 1998). As

a result, students come to recognize the different ways in which technology and mathematics are valuable and relevant in the real world. In turn, they gain a better appreciation for mathematics and realistic learning opportunities that are provided. Via technology, collaboration should explore new dimensions of mathematical content while demanding evaluation and reconciliation of differing conceptions and perceptions of both the content and the learning opportunity. The dynamic nature of technology-rich learning facilitates this process. These aspects of learning reciprocate upon the perspective of the instructor and, in turn, the design of the context. This modification also allows for a conceptualization of learning from a longitudinal perspective. The characteristics and elements of technological innovations, in conjunction with the instructor's perceptions and intentions, interact with unique characteristics of the individual learner, together forming the learner's perception of the learning context. As Prosser and Trigwell (1997) noted, the learner's approach to learning is influenced not only by previous experiences and existing beliefs and knowledge of the individual, but also perceptions of the learning context (Marton, 1986).

Additionally, students should be engaged with a variety of technologies in the learning process, and come to recognize technology's dynamic nature and value (Wenglinsky, 1998). Students should not consistently sit alone at a computer using it solely as a word processor. Nor should they use it only for completion of practice problems to master a mathematical skill, else they come to view technology as a static evaluation tool. Learning opportunities must not treat technology as an end or in isolation, but as a means for developing mathematical processes and understandings, for exploring mathematical concepts in new ways, and for communicating with and about mathematics. An appropriate mix of technological tools that build upon the cognitive, individual aspects (sitting alone at a computer to communicate and explore mathemati-

cal ideas), collaborative participation (sharing of ideas and co-development of understanding) or the situative nature of the dynamic environment (tying learning directly to characteristics of and relations within the learning phenomenon) should be incorporated into the learning process. Introducing variation in mathematics learning through a variety of technology-rich opportunities requires a well-developed TPACK, a robust CFTK, an operational understanding of the context, and effective discernment in and about learning situations. Together, these qualities enable the appropriate use of technology toward meeting the needs of different students, varying educational goals, and examining multiple aspects of course content.

Research of Technology Use in Mathematics Learning

The implementation of technology to promote the types of variation above must be evaluated and modified as necessary, leading to research of various considerations including: students' experiences; teacher's intentions and TPACK; aspects of the CFTK model; and characteristics of the learning task. The fifth and final level in which mathematics teachers develop TPACK, advancing, regards the evaluation and revision of technology-rich learning opportunities (Ronau et al., 2009; Niess et al., 2009). Variation theory and phenomenography recognize the influence of the existing knowledge, previous experiences, and perceptions of learners and teachers upon learning. Further, this view of learning recognizes the vital role of context within the learning process, and how its influence and role are unique to each individual. The experiences of learning via technology will vary among learners, as influenced by their existing characteristics, perceptions, and actions (Marton & Booth, 1997; Prosser & Trigwell, 1997), and there will exist a finite number of identifiable "categories of experience" that can be identified (Marton, 1986, 1994). Thus, learning is an interrelated and integrated melding of these

various elements of the technology-enhanced context and the learner. Learners' thinking is interpreted via the object(s) they perceive and the content of their thoughts (Marton, 1986).

Phenomenography and variation theory, then, culminate in research questions that focus upon experiences and variation in learning phenomena. Studies regarding technology use in mathematics courses should aim to identify which of these types of variation are occurring, and in what ways technology aids the introduction and awareness of the variation. These types of variation may be of those discussed above, and may focus upon a single learning object or situation or across multiple objects of learning and/or learning opportunities. Essentially, practitioners and researchers should examine what was varied by inclusion of technology (a) from students' perspectives; (b) from the teacher's perspective; and (c) as evidenced by measured learning outcomes.

A thorough study of technology usage in mathematics learning should consider the role of students' perceptions and approaches to using the technology and the robustness of the teacher's TPACK as evidenced by the implementation and its effectiveness. Phenomenographic research aims to be as objective as possible, looking at the experience through the eyes of the learner to determine all of the categories of experience within a phenomenon (Marton, 1994; Marton & Booth, 1997). These objectives align well with current research regarding TPACK; Mishra and Koehler (2006) discuss the need for qualitative research including the voices and perspectives of those who are studied and the use of the TPACK framework for analytical categories during data analysis.

Future research may wish to examine whether the TPACK framework emerges from the iterative analysis of collected data. Particularly of interest is the alignment of a teacher's TPACK, the intentions behind a technology-rich learning task, characteristics of the implementation, and

measured educational outcomes of the activity. Variation may be a key predictor of the success of technology integration in the mathematics classroom. Examination may provide insight into teachers' existing knowledge of both the individual and environmental aspects of the CFTK model's learning context, as well as their proficiency of the its discernment aspect for selecting, designing, and conducting meaningful learning opportunities (Brew, 2001; Bryk & Driscoll, 1988; Cobb & Bowers, 1999; Davis & Simmt, 2006; Ding & Sherman, 2006; Ronau et al., 2009)

Robust research on the effectiveness of technology implementation requires collection of students' work, transcripts of their interactions, and transcripts of student interviews. Students will need to be observed in the learning task and questioned about their perceptions of the activity, the technology involved, their approach to completing the task. Similar sources of data will need to be gathered concerning the teacher's process of developing, implementing, and evaluating the task, including interviewing or surveying teachers regarding their beliefs, intentions, and existing knowledge (Brew, 2001; Bryk & Driscoll, 1988; Graham et al., 2009).

Subsequent analysis will require independent coding and iterative identification of emergent themes for the collected sources of data (Marton & Booth, 1997; Patton, 2002). A convergence of these themes will allow for development of categories of experience and an analysis of the alignment of student's perceptions of variation with those of the teacher, the realized variation of the implementation, and the intended variation behind the designed learning opportunities (Johansson, Marton, & Svensson, 1985; Patton, 2002; Sandberg, 1996). This will inform subsequent revisions to the task and future implementations of technology, including the structure and presentation of technology-rich activities, the appropriateness of technology for specific learn-

ing goals, and the sufficiency of mathematics teachers' TPACK development.

CONCLUSION

The variation theory of learning has derived from views rooted in phenomenographic research. Specific application of variation theory to the implementation and study of technology use in mathematics education remains limited. But completed research aligns with theoretical claims to suggest that a framework based upon variation theory can prove effective. By placing the object of learning at the center and focusing upon the differentiated experiences of learners, the question becomes one of discernment: What variation did or did not the students experience and learn, leading to the recognition of specific dimensions of the object of learning? Further, the question must be asked: If we wish for students to learn a particular aspect of a mathematical concept, what must we vary in their learning opportunities to ensure their focus upon the proper dimensions? How can technology aid in achieving these goals? What aspects of the CFTK model to teachers possess and put into practice? What levels of TPACK do teachers demonstrate through the technological learning opportunities they develop and implement? Have mathematics teachers sufficiently developed TPACK to create meaningful and effective learning opportunities that include technology? With appropriate TPACK, teachers can weave technology into the learning process to assist students in discovering and exploring the variation of mathematics content and learning experiences. By following the framework established by the phenomenographic view of learning and the more formal variation theory of learning, technology use can be implemented and researched in a structured yet inclusive fashion.

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Chapter 12

Successful Implementation of Technology to Teach Science: Research Implications

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ABSTRACT

In this review of recent literature on the use of technology to teach science content, 143 articles from 8 science education journals were selected and analyzed for the use of technologies in teaching science, pedagogies employed, and successes of the implementations. The resultant data provides a snapshot on how technology is being used in the teaching and learning of science, and the research methods used to explore these issues. Levels of research and levels of success were developed and applied to the article data set to characterize the types of research and technology implementations described in the literature. Articles that showed high levels of successful implementation of technology along with a high level of research were explored and explained in greater detail. The review underscores the research trend toward using technology to illustrate abstract concepts and make objects that are invisible to the naked eye, visible and malleable in computer modeling programs. Implications for successful use of technology to teach science are discussed.

INTRODUCTION

Science and technology have long been linked. New discoveries in science have helped lead to

advancements in new technologies and improvements in existing technologies, in turn, aid in new developments in science. Science education and technology have also shown the same link. Science teachers often have been eager to embrace new technologies to help students learn science con-

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tent, and engage in authentic science experiences. These early adapting teachers have believed that by embracing new technologies they can help their students better learn science. While this is one of the primary reasons for implementing technology into the science classroom, there are often residual affective factors to consider, such as increasing students' interest in science, motivating students to learn, and improving students' self-efficacy in learning science.

Not only are teachers seeking ways to use technology to improve learning in science, science education researchers also have been exploring new ways technology tools can be used to teach science. A review of the research literature in this field reveals many claims of success of technology implementation. In some cases, success is attributed to student learning gains, whereas in other studies students' engagement in, and enthusiasm for, learning science is attributed to the technology use. Studies in the field of technology use in science teaching vary greatly in how they substantiate successful technology implementation. This review is an attempt to look at the last 10 years of science education research on the use of technology to teach science to define successful implementation of technology.

BACKGROUND

Business leaders are calling for technologically and scientifically literate workers to enhance U.S. corporations' competitive edge in the global marketplace (Friedman, 2005). Technology enthusiasts tout the motivational potential of educational technologies to promote and improve students' problem solving abilities. Technology advocates have underscored the potential of computer technologies as a panacea for improving students' scientific literacy and 21st century skills—a necessary skill base for success in the increasingly competitive global marketplace (Metiri Group, 2003). Likewise, the National Research Council

(NRC, 1996) and the American Association for Advancement in Science (AAAS, 1993, 2000) recommend using technology to foster student experiences analogous to those carried out by scientists—such as data collection and analysis, constructing and manipulating models, and communicating results—as well as to help students construct conceptual understandings of abstract science concepts.

The call for increased use of technology in schools is evident in the dramatic increase in computer availability in classrooms today. From 1988 to 2009 there has been a dramatic drop in the computer to student ratio from 1:30 in 1988 to 1:5.3 in 2009 (Gray, Thomas, & Lewis, 2010). The National Center for Education Statistics (NCES) reported that in 2009 97% of all teachers had access to at least one computer in the classroom, 93% of which offered Internet access (Gray et al., 2010). With the increased accessibility of classroom computers, one might expect the instructional use of computers also to rise. A ten-year review of NCES data, however, suggests the rise in use has been less than what might be expected (NCES, 2000; Gray et al., 2010). As Table 1 illustrates, teachers have increased their use of computers from 1999 to 2009 by 44%. However, the greatest increase was attributed to their use of the Internet to support student research (64% gain). Other areas showing significant gains included the use of graphics (e.g., digital images, animations) to illustrate concepts (34% gain), the use of drill and practice programs to promote student learning (19% gain), and using computers to support problem solving and data analysis (18% gain).

These data suggest a growing number of teachers are employing technology, often referred to as educational technology, when used for instructional purposes, to support student learning in science. Although technology enthusiasts and education and government leaders promote the use of technology in schools, does its use make a difference in student learning? Do specific educational technology tools impact students' attitudes

Table 1. Comparison of NCES teacher-reported technology use in classroom practice, 1999 and 2009

Educational Technology	% of Teachers using Educational Technology in Instruction	
	1999	2009
Technology use for classroom instruction	53	97
Practice drills	31	50
Internet research	30	94
Research using CD-ROM	27	--
Design/produce technology products	24	13
Graphical presentations	19	53
Technology to demonstrate concepts (e.g., simulations)	17	33
Technology to solve problems/analyze data	27	45
Test administration	--	44
Using blogs or Wikis	--	9
Conduct experiments/perform measurements	--	25
Social networking site for classroom use	--	7

Note: -- indicates no data for this category from the given data set.

toward science, problem solving skills, or conceptual understanding of science concepts?

Previous studies on the impact of educational technology on student learning continue to provide evidence to support technology enthusiasts' assertions that these tools can make a difference in student learning. Broad scale meta-analyses on the effect of technologies on student learning have indicated that students often learn faster using computers, develop deeper understanding of the concepts when they learn with computers, and have better attitudes about themselves and their learning when using computer technology (Schacter, 1999; Sivín-Kachala, Bialo, & Rosso, 2000). In addition, Swan and Mitrani (1993) found that classes using educational technology tended to be more student-centered than classes employing traditional instruction practices. Many of these large-scale analyses have adopted a broad view of technology and address multiple content domains. Therefore, it is not possible to identify the effects of specific technology uses in relation to particular pedagogical strategies in the teaching and of learning science.

Other large-scale studies have attempted to reveal connections between students' use of computers in learning science and student achievement in science. For example, in their study of U.S. students' scores on the Program for International Student Assessment (PISA), Papanastasiou, Zembylas, and Vrasidas (2003) found that 15 year-old students reporting frequent use of computers at home or within their community (e.g., at the library) for such purposes as writing reports tended to have higher achievement in science. They also found an insignificant, but negative, effect on students' use of software programs and student achievement in science. The researchers suggested an explanation for this negative correlation could be the likelihood that teachers assign lower achieving students the use of drill and practice programs to support their learning. Such practices might explain the negative correlation in science achievement, but also underscore the need for additional studies to characterize successful implementation of specific technologies to teach science, and how the use of these technologies support learning.

Waxman, Lin, and Michko (2003) also explored possible relationships between the use of educational technology in learning science and the subsequent effects on student cognitive learning gains, attitudes, and behaviors. To standardize the findings across the 42 studies in their meta-analysis, Waxman et al. calculated the effect sizes using standard mean differences. In addition, the researcher coded 69 characteristics (e.g., gender, ethnicity, content) from the studies, which they also included in the analysis. They found technology use in science teaching and learning had a positive and significant ($p < .05$) affect on students' cognitive learning outcomes compared to traditional low-tech instructional approaches with a 95-percent confidence interval in effect sizes of 0.171 to 0.724. They also found a non-significant ($p > .05$), positive effect for student affective outcomes, and a non-significant ($p > .05$), negative effect for student behavioral outcomes when technology was used. The latter effect was negligible and required further study to characterize specific activities using technology that lead to negative student behaviors.

These studies support the assumption held by many educators, curriculum designers, policy makers, and government officials that educational technologies can improve student cognitive outcomes. These studies also underscore the need for well-designed studies exploring effects of educational technology use on students' cognitive learning gains in science, and their attitudes and behaviors toward science. Waxman et al. (2003) noted that of the 200 studies they reviewed, only 42 were selected for their analysis because of limited data describing technologies employed, pedagogical strategies implemented, usable supporting evidence attributing the technology use to student learning gains, or effect sizes of these gains. The researchers noted that many studies they reviewed were descriptive in nature and lacked evidentiary support documenting the effects of the technology use on student learning, attitudes, and/or behaviors.

In addition, Papanastasiou et al. (2003) recommended the need for research to explore how computers were used in teaching science, and the subsequent effects on student learning. The meta-analyses described earlier reveal positive trends in the use of educational technologies for supporting student learning in science. However, these studies do not identify how specific uses of educational technology employed in tandem with particular instructional strategies affect both affective and cognitive learning outcomes.

Another factor impeding our understanding of the effects of technology on student learning is the rapid growth of technology, and its implementation in schools. Allen (2001) articulately highlights limitations that arise from the fast-paced advancements in technology applications. Many studies conducted in previous decades included technologies that are seldom used today. Waxman et al. (2003) suggests that the impact of educational technologies used today is likely different than it was in the past because of the continual progression of technology tool development and implementation. The meta-analysis studies discussed previously reviewed research conducted over a decade ago, and before the new advancements in computer animations and visualizations available today. These technologies have the capability of illustrating abstract and often invisible natural phenomena in concrete, easily accessible animations for students. Bell and Trundle (2008) and Barab, Hay, Barnett, and Keating (2000) have found that students are able to grasp concepts that were well beyond the expectations for their grade level when visualizations, modeling programs, and computer simulations are employed compared to more traditional low-tech, and often didactic, pedagogies. The use of simulations and dynamic visualizations have promise for scaffolding student understanding and in helping students make deep cognitive connections across scientific and non-scientific concepts. Continual review of the research on technology integration is essential to learn best practices for its use in teaching science

and to uncover the effects of new technologies on student learning.

Over the past decade, research on the use of educational technologies in science instruction has begun to show a movement from exploring the potential uses of specific technologies toward exploring connections between specific instructional uses and the resulting effects on student learning of, and motivation and attitudes toward science. A growing number of studies have investigated the use of specific technology tools to support data collection, analysis, and problem solving in science to promote student understanding (e.g., Chang, & Tsai, 2005; Ealy, 2004; Jones, Minogue, Tretter, Negishi, & Tayolor, 2006; Kara & Yesilyurt, 2008; Keating, Barnett, Barab, & Hay, 2002; Muller, Sharma, & Reimann, 2008; Yang & Heh, 2007). Other studies have extended these applications to the Web, exploring the use of web-based virtual labs that support inquiry learning and exploration in science (e.g., Clark & Jorde, 2004; Linn, Clark, & Slotta, 2002; Songer, Lee, & Kam, 2002). With improvements in computer animations, other studies have explored the effect of visualizations, animations, and computer modeling on students' understanding of complex, abstract natural structures and phenomena (e.g., Ardac & Akaygun, 2004; Kelly & Jones, 2007; Patrick, Carter, & Wiebe, 2005; Wilder & Brinkerhoff, 2007). Computer-assisted instruction (CAI) programs also have been explored since the 1980s in order to identify possible effects these programs have on student achievement in and attitudes toward science (e.g., Huffman, Goldberg, & Michlin, 2003; MacKinnon, McFadden, & Forsythe, 2002; Steinburg, 2003; Zumbach, Schmitt, Reimann, & Starkloff, 2006). More recently, a growing number of studies have examined how the use of various pedagogical strategies in science can effect student learning when the same educational technology tools are employed (e.g., Chang, 2001; Tatar & Robinson, 2003; Zucker, Tinker, Staudt, Mansfield, & Metclaf, 2008). Studies in this latter area have the potential of identifying best practices in

the use of educational technologies for promoting the greatest gains in student attitudes toward and achievement in science.

The continual change of technologies calls for periodic reviews of the research literature to identify how educational technologies can be used effectively to support student learning in science, improve student attitudes toward science, and engage students in doing science. The purpose of this study was to conduct a detailed analysis of the science education research literature over the past ten years to identify effective uses of educational technology in teaching science, characterize the levels of research employed in the studies, and determine what constitutes success of the technology implementations. In doing so, the researchers aimed to provide a summary of powerful uses of technology in specific educational contexts in science instruction, and outline areas of research needed to extend our understanding of the power and potential possibilities for using educational technology in teaching and learning science.

METHODS

The two authors of this chapter conducted the critical review of the literature following systematic methodology (Cooper, Hedges, & Valentine, 2009) in the selection and analysis of articles for review. Given that the science education field is relatively small, after an initial search the authors agreed the most relevant articles for this research synthesis would be concentrated in the top journals in science education. After further consultation, eight journals were chosen to target for review. A list of these journals follows:

1. Journal of Research in Science Teaching
2. Science Education
3. International Journal of Science Education
4. Journal of Science Teacher Education
5. Journal of Science Education and Technology

6. Journal of Computers in Math and Science Teaching
7. The Electronic Journal of Science Education
8. Contemporary Issues in Technology and Teacher Education: Science

These journals were selected because they are the leading journals in the field of science education and/or educational technology in science education. The *Journal of Science Teacher Education* is also a leading journal in the field of science education and was reviewed in the current study; however, it did not include articles pertaining to the application of educational technology in teaching science content. The remaining eight journals are representative of science education research published over the past decade. Further, two journals (i.e., *Journal of Computers in Mathematics and Science Teaching*, *Journal of Science Education and Technology*) were dedicated specifically to research on the use of educational technologies in math and science teaching, whereas the other journals provide a representative sample of research in science education across domains and purposes. Additionally, published research across the science disciplines often cite studies published in one or more of these journals.

This review was not an exhaustive, comprehensive review of all literature pertaining to educational applications in teaching science, but rather a purposeful sample of articles represented in well-established journals in science education. The decision to focus on journals pertinent to science education was influenced by the predominance of studies included in the Waxman et al. (2003) meta-analysis that had been published in computer and technology education journals. The authors believe that this approach provided a large and representative sample of the research on the applications of educational technology employed in the teaching of science, and thus, provided a sufficient sample from which to draw generalizations in the field.

Article identification was conducted through a thorough search of each issue of the journals sampled, beginning with the January, 2000 issue and extending through the most current issue as of May, 2010. The authors chose the 2000 cutoff date due to the rapidly changing nature of technology in science education and several meta-analyses published between 1997 and 2003 (Bayraktar, 2001-2002; Cavanaugh, 2001; Christmann & Badgett, 1999; Christmann, Badgett, & Lucking, 1997; Christmann, Lucking, & Badgett, 1997; Waxman et al., 2003) on the use of technology in science instruction. Each of the 1000+ articles reviewed were analyzed for the use of educational technology; only articles reporting findings from the use of educational technologies for teaching science were selected. Articles in which technology was used solely as a vessel to advance pedagogy and where the science content was absent were excluded from the study. Using these criteria, 143 articles were selected for review and examination.

Once the list of articles was compiled, each article was carefully scrutinized. While many aspects of each article were examined, one of the lenses used was technology pedagogical and content knowledge (TPACK, Thompson & Mishra, 2007). This was applied in a unique way as the technology, pedagogy and content of each study were examined and cross-examined with the level of successful implementation of the technology to teach science.

First, each article was reviewed to identify the design of the research project and instrument(s) used to measure student learning of science content and/or attitudes toward the science. In addition, validity and/or reliability measures were recorded for the instruments used, as well as the size of the participant sample, the inclusion of control or comparison groups, and study effect sizes when reported. Based on these data, each study reviewed was assigned a research level according to the criteria summarized in Table 2. The authors derived the levels and criteria.

Table 2. Research level criteria

Research Level	Criteria
Level 1	- Exploratory/descriptive/qualitative study - No comparison group - Limited triangulation of qualitative data - No reliability or validity instrument data - Implemented/developed/designed a application technology - Technology ‘worked’ and was used - No student achievement data
Level 2	- Mostly qualitative study or quantitative study w/one instrument - Small scale implementation (<30) - Some post-implementation measure (post achievement OR attitude measure) - Anecdotal evidence might be provided to describe implementation - May have confounding factors in research design (e.g., instructional strategy and tech tool combination) - Might include survey or interview data
Level 3	- Mixed, or Quantitative study w/ more than one measure - Moderate scale implementation (30-100 participants) - Pre- and post-test content measure OR attitude survey - Content test validity/reliability reported - Control group or another comparison group - Triangulation of qualitative data - Could include, survey, interview, and/or content test (traditional)
Level 4	- Mixed or Quantitative Study - Large Scale (>100 participants) - Control or comparison group - Pre- and post-test content measure - Content test w/ validity and reliability reported - Survey attitude measure w/ Validity/reliability reported - Strong research design
Level 5	- Mixed methods or Quantitative - Very Large Scale (>100 participants) - Multiple comparison groups (2 x 2 design or greater) - Pre and post test measure - Control or comparison group(s) - Content test w/ validity and reliability reported - Survey attitudinal measure w/ validity/ reliability reported - Strong research design

These levels were not designed to pass judgment on the value of the research studies; rather they were designed to help the researchers differentiate the type of studies conducted on technology integration in science. The researchers believed all of the studies added value to the field. The use of a new technology often progresses through each level of research, outlined in Table 1, beginning with studies that document the use of a technology with one group of students and progressing along a research path in which the implementation of a technology is compared to other pedagogical strategies. After a technology

has been successfully implemented and the technology has matured, further research can be carried out on the technology to demonstrate its efficacy in the classroom. In the analysis, studies assigned to levels 1 and 2 were small descriptive studies (<30 students sampled) on the use of particular technology tools in teaching science. Studies assigned to levels 3 through 5 include samples of 30 students or larger with at least one treatment and comparison group. These studies used reliable content instruments (most often based on Cronbach’s alpha coefficient ≥ 0.70) to assess student understanding as well as perception

surveys to measure student attitudes toward the technology employed.

The technology used in each study also was classified based on the four categories Park and Slykhuis (2006) have described for the application of technology to teach science. These categories include: (A) Gathering scientific information; (B) data collection and analysis by pupils; (C) creating and using models of scientific phenomena; and (D) communication. Category A includes the use of the Internet or other electronic resources to find scientific information and real world examples, such as using the Internet to collect images of primary consumers, or to learn how a windmill can be used to create electricity. Category B includes the use of technology to collect and analyze data that can be used to identify patterns in phenomena and create explanations to support observations. Such technologies can include probeware, such as sonic rangers and temperature probes, and dynamic and static visualizations used to illustrate particular phenomena. Technologies in Category C can be used to illustrate science concepts, and offer students the ability to explore scientific concepts and phenomena through models. A prime example of a technology in category C is the use of simulations and molecular modeling software. Category D relates to technologies that support the communication of ideas. This category can include tools such as presentation software, and work processing software, or newer technologies such as the use of blogs for the communication of scientific findings. A few of the studies that were included were so broad in their application of technology to teach science that they could not be contained in a single category. These studies described the inclusion of very broad technologies such as laptops, or immersive computer environments to teach science. These categories were nominal in nature and were used to classify the technology by its use, rather than by a hierarchical level of complexity.

Studies reviewed also were analyzed for the grade level of the participants and the science

content being studied. Student levels applied to the review included elementary (prek-5), middle level (6-8), secondary (9-12), and post-secondary (i.e., undergraduate and graduate students, preservice teachers, and inservice teachers). For studies that reported on the actions of both teachers and students during the implementation of the technology, the grade level of the students in the classroom was used. Science content taught through the use of technology was categorized into the major science domains of biology, chemistry, physics, astronomy, and earth science, with a few studies focusing on engineering. Some studies reviewed, especially at the elementary and middle levels, used technology to teach general science skills or a variety of science topics. The science content in these studies was classified as general science.

The final evaluation of each study considered the success of the technology implementation in teaching the science content. As was mentioned in the introduction, the instructional use of technology can take many forms, and therefore, can be considered successful at many different levels. In the beginning stages of research on a particular use of technology, simply getting the technology to work in the classroom can be considered a success! In more advanced studies of the technology tool, a statistically significant difference between the group of students using the technology and students not using the technology is a success. Perhaps, simply getting students to enjoy the learning of science, with the hope they would continue to study science in the future, also can be considered a success. To differentiate the level of success for each implementation reviewed, criteria were established. Table 3 summarizes the levels of success and accompanying criteria developed for the review.

As was the case for the research level of the study, the levels of success were not assigned as a means to pass judgment on a particular study, but to provide insight on the sophistication of the implementation and measures. In testing a brand new technology tool or a novel technology ap-

Table 3. Summary of criteria delineating levels of success of reported technology implementation

Level of Success	Criteria
Level 1	- One-group design - Technology implemented and/or described - No measure of increased science learning
Level 2	- One-group design - No measure of increased science learning - Attitude measure showed students liked/enjoyed/appreciated the use of technology
Level 3	- One-group design - Students showed increase in science learning - No control/comparison group - No student attitude measure
Level 4	- One-group design - Students showed increase in science learning, no control/comparison group - Attitude measure showed students liked/enjoyed/appreciated the use of technology
Level 5	- Two+ group design - Students showed no difference in science learning versus control/comparison group - No measure of student attitude
Level 6	- Two+ group design - Students showed no difference in science learning versus control/comparison group - Attitude measure showed students liked/enjoyed/appreciated the use of technology
Level 7	- Two+ group design - Students showed increase in science learning versus control/comparison group - No difference in student attitude OR not measured
Level 8	- Two+ group design - Students showed increase in science learning versus control/comparison group - Attitude measure showed students liked/enjoyed/appreciated the use of technology

plication, a success at the 1 or 2 level may be a worthy goal of the research.

DEMOGRAPHICS OF STUDIES REVIEWED

The sample reviewed in this study included 143 articles that were selected and analyzed in the methods described above. The tables that follow summarize general demographic information to characterize the articles reviewed. This information includes publication dates, journal sources, grade levels of the participants in the studies reported, and the science content addressed. It is important to describe these demographics in order to provide the proper context for the subsequent analytical discussion that follows (Table 4).

Some of the studies reported in the articles involved science learners from multiple grade levels (e.g., middle and secondary). These studies were placed in the category with the majority of the learners. Similarly, some of the studies addressed multiple science content categories. As discussed earlier, studies that addressed multiple science topics were placed in the General category, whereas all other concepts were placed under the major science domain, with the exception of studies addressing science concepts in the context of engineering. These were placed in the Engineering category.

Review of the article demographics reveals several trends in the research reported over the past decade. First, not surprisingly, there has been a general increase in the number of articles on the use of technology in teaching science over the last 10 years. Second, there has been a preponderance

Table 4. Demographics of articles reviewed

Publication Year (#)	Journal (#)	Science Content (#)	Grade Level (#)
2000 (12)	Journal of Research in Science Teaching (23)	Biology (36)	Elementary (10)
2001 (7)	Science Education (7)	Chemistry (22)	Middle School (31)
2002 (10)	International Journal of Science Education (9)	Earth Science (9)	Secondary (52)
2003 (11)	Journal of Science Education and Technology (64)	Physics (45)	Post-secondary (50)
2004 (20)	Journal of Computers in Mathematics and science Teaching (35)	Engineering (3)	
2005 (9)	Electronic Journal of Science Education (2)	General (28)	
2006 (14)	Contemporary Issues in Technology and Teacher Education: Science (3)		
2007 (15)			
2008 (20)			
2009 (17)			
2010 (8)			

#- number of articles out of the total reviewed

of articles on technology applications to teach science at the secondary and post-secondary levels. Last, a disproportionate number of the articles reviewed have been related to the use of educational technologies for teaching and learning physics concepts. Considering that physics has the least number of students enrolled in comparison to other science domains, it might be expected that studies would focus on other more populated science domains, such as biology, but this was not the case. The disproportionate representation of studies addressing physics concepts might be explained by the extensive research conducted on students' conceptual understandings of concepts in this domain over the past four decades. A review of the research on students' conceptual understandings of science concepts included in Duit's (2009) database on misconceptions reveals a heavy focus on physical science. The wealth of technology studies in physics could be a continuation of this research. More specifically, researchers are exploring ways to use educational technology to

scaffold student learning of physics and improve student attitudes toward physics. Advancements in this area suggest similar research is needed in the other science domains.

ANALYSIS OF ARTICLES

Once the sample of articles was selected, careful tiered analyses were conducted to summarize the data presented in the articles. Data recorded included the technology employed, the level of research conducted in each study, and the level of implementation success reported. Findings from these analyses are summarized in Table 5. A discussion delineating these findings follows.

Both of the authors of this chapter independently applied the technology category designations to each article, which resulted in an inter-rater reliability of 92%. The authors came to a consensus on the remaining 12 articles, nine of which were assigned to the multiple category

Table 5. Summary of the article analysis

Technology Category (#)	Research (#)	Success (#)
A- Gathering scientific information (12)	Level 1 (26)	Level 1 (19)
B- Data collection and analysis by pupils (37)	Level 1.5 (4)	Level 2 (25)
C- Creating and using models of scientific phenomena (70)	Level 2 (47)	Level 3 (40)
D- Communication (15)	Level 2.5 (2)	Level 4 (5)
Multiple categories (9)	Level 3 (46)	Level 5 (11)
	Level 3.5 (1)	Level 6 (4)
	Level 4 (16)	Level 7 (29)
	Level 5 (1)	Level 8 (10)

(#) number of articles out of the total reviewed

designation and a single category was agreed on for the other three.

A second analysis was conducted to identify the level of research for each study reviewed (see Table 5). Again, the authors conducted this analysis independently. There was a 93% inter-rater reliability in the levels that were assigned. Of the 10 articles for which the authors disagreed, they were able to find consensus on three of them. The remaining seven were classified with the average rating of the two authors' designations. In all cases, any disagreement in level assignment was not greater than a single level. The designation of half points (e.g., 1.5, 2.5) indicates articles in which the two authors' designations were averaged.

The third analysis conducted on the data was to identify the level of success reported in the articles for technologies implemented (See Table 5). Again, both of the authors examined the 143 articles and applied the success levels described earlier. The inter-rater reliability for these category assignments was very high at 98%. On the three articles where there was initial disagreement in the ratings, the authors discussed their reasoning for their rating assignment and came to agreement on single level.

On initial examination of these data, what becomes clear is the low number of articles at level 4, 6, and 8. These even numbers of levels are those

that included a measure of the learners' attitude toward the implementation of the technology. At levels 1 and 2 pre- and post- test data on science content learned with the technology implementation were not reported. At these levels it is clear that the researchers emphasized student attitude or enjoyment using the technology. As evidence of this pattern, over half of the articles at levels 1 and 2 included an attitude measure. Beginning with level 3, however, a pre- and post-test science content measure was reported along with statistical significance (accepted at levels ≤ 0.05). It is interesting to note that once this testing structure was implemented, researchers were less likely to report measures of the learners' attitude or enjoyment, as levels 4, 6, and 8 contain fewer instances of attitude measures than in levels 3, 5, and 7, respectively.

RESULTS

The discussion that follows summarizes the findings from the review in the context of the types of technology used in the studies, the level of research employed, and the level of success of the implementation as reported in the literature. Table 6 summarizes this data and provides support for the discussion, which is organized by technol-

Table 6. Level of research and success by technology category

Technology Category		A- Gathering Scientific information (12 articles)	B- Data Collection & Analysis (37 articles)	C- Creating and using models of scientific phenomena (70 articles)	D- Communication (15 articles)	Multiple Categories (9 articles)
Level of Research	1	5	5	7	7	2
	1.5	-	1	3	-	-
	2	4	16	19	6	2
	2.5	-	-	2	-	-
	3	3	10	27	2	4
	3.5	-	-	1	-	-
	4	-	5	10	-	1
	5	-	-	1	-	-
Level of Success	1	3	5	4	7	-
	2	4	10	4	5	2
	3	2	4	29	2	3
	4	1	1	3	-	-
	5	-	6	5	-	-
	6	-	1	3	-	-
	7	1	6	18	1	3
	8	1	4	4	-	1

ogy category. In each category, we present the technology, science content and pedagogy used in the application of the technology.

Category A: Educational Technology for Gathering Scientific Information

Of the 143 articles reviewed, 12 (8.4%) addressed the use of technology to collect scientific information. The studies described in the articles were categorized at levels 1 to 3 in research design. The level of success of the technology implementations spanned from level 1 to level 8. Examples of the technologies employed include Internet search programs, learning objects, and electronic texts.

Two studies were of particular interest in this category. These two studies demonstrated the highest success level scores, 7 and 8, and the

highest level of research in the group, rated at level 3. The first study examined the use of online quizzes in a college chemistry course to improve student understanding (Crippen & Earl, 2004). This study included both student achievement and attitude measures. The online quizzes were available to students outside of class to help students review concepts addressed in class and develop a deeper understanding of the science content. Crippen and Earl found a correlation between the use of the online quiz system and the student's grade in the course. Survey data revealed that the students in the treatment group perceived the system as both fair and helpful in learning the concepts; they desired for the program to be further implemented in the future into more courses. The second study examined the use of computers as data sources for problem-based instruction

(Chang, 2001). Tenth grade earth science students completing the problem-based units on computers significantly out performed students learning the same concepts through direct instruction. Both of these studies employed computers to find and/or review information using pedagogies different from traditional direct instruction methods, and presented chemistry and earth science content effectively to students.

Category B: Educational Technology for Data Collection and Analysis by Pupils

Category B, including 37 articles, composed a larger subset of the 143 studies reviewed. These studies reported on implementations of technology in which pupils participated in activities analogous to work of scientists, such as using probeware and other software programs to collect and analyze data (AAAS, 1993; NRC, 1996). The level of research presented in these studies ranged from research level 1 to level 4, and the level of success of implementation ranged from level 1 to level 8. Examples of technology employed included probeware, visualizations, digital photography, and web-based remote control of scientific instruments.

The interesting aspect to the data in this category is that the primary focus of this technology is to collect data. In some aspects, this is a much more science specific application of technology than using technology to find scientific content or data online. It could be argued that the first category could be applied to any content area, whereas Category B uses technology for science-specific purposes, to collect and analyze data. This application also is interesting as this is an application of technology not to do something new, but rather to ostentatiously do it better. Data could be collected and analyzed with pencils, paper, ruler, graph paper, and other low-tech tools, but using probeware allows for more precise data collec-

tion and measurements. In essence the idea here is technology can do this better.

Category B has a cluster of articles at the highest levels of success, levels 7 and 8. So, what do these articles tell us about applying technology to gather and analyze data to learn science? One oddity that jumps out from the cluster of 10 articles is the content area. Seven of the 10 articles are related to teaching physics concepts (Dori, Hult, Breslow, Belcher, 2007; Huffman, Goldberg, Michlin, 2003; Muller, Sharma, & Reimann, 2008; Nicolaou, Nicolaidou, Zacharia, Constantinou, 2007; Royuk & Brooks, 2003; Voogt, Tilya, van den Akker, 2009; Zucker, Tinker, Staudt, Mansfield, & Metclaf, 2008). While this is disproportionate even to our seemingly physics skewed data set, the explanation could be found in the predominance of probeware in this category. While probeware exists to collect and analyze data in all science domains, historically it has been dominant and most easily applicable in physics.

The next aspect of these studies that becomes readily apparent is the heavy emphasis placed on the pedagogy of the implementation of the technology. The pedagogy being applied is student-centered constructivist methodology in each case. In four of these articles the authors clearly state that the technology in the study was accompanied with an inquiry based pedagogy or that the technology was compared to a traditional or cookbook lab setting (Dori, Hult, Breslow, & Belcher, 2007; Nicolaou, Nicolaidou, Zacharia, & Constantinou, 2007; Royuk & Brooks, 2003; Schoenfeld-Tacher, Jones, & Persichitte, 2001). This emphasis on technology enhanced inquiry learning did not happen by chance. In three of the studies set in middle and high schools the teachers involved were given training on the technology and pedagogy in the summer and follow-up training and support throughout the school year (Huffman, Goldberg, Michlin, 2003; Voogt, Tilya, van den Akker, 2009; Yerrick, Johnson, 2009).

Category C: Educational Technology for Creating and Using Models of Scientific Phenomena

Studies falling into Category C, creating and using models to study scientific structures and phenomena, is by far the largest collection of studies in the review. Seventy of the 143 articles (49%) are included. The level of research presented in these studies ranged from research Level 1 to Level 5, and the level of success of implementation ranged from level 1 to level 8. Examples of technology employed included simulations, modeling, virtual reality, robotics, and virtual learning environments.

The application of technology to create and use models of natural phenomena is quite different from its use to collect and analyze data. In a typical science classroom there are many low-tech ways to provide students at all levels ways to collect and analyze data to explore scientific concepts from all science domains. However, creating models to support students changing views as they develop a conceptual understanding in science can be very difficult using low-tech or high-tech strategies through paper and pencil modeling, or computer simulations. New technology applications offer students the ability to manipulate computer models to explore natural phenomena (e.g., plate tectonics, nature selection, linear motion) and molecular structures with substantial scaffolding to guide their exploration and conceptual understanding. When technology tools are used in this manner, the technology is not replacing typical low-tech classroom activities, rather, it is offering an entirely new activity. Therefore, it makes the use of a comparison or low-tech control group more problematic. Thus, it was not surprising to see that nearly one-half of the articles in this category claimed a level three success, science learning occurred, but without a comparison group.

The use of simulations or modeling with computers in the science classroom is very enticing

for objects or processes that are very difficult or impossible to see and observe with the naked eye or even through a microscope. So it is not surprising that while the highly successful category B articles were heavily weighted toward physics, the highly successful category C articles are heavily weighted toward biology and chemistry. In fact of the 20 studies evaluated at levels 7 and 8, nine of the studies pertain to biology (Akpan, 2002; Akpan & Andre, 2000; Akpan & Strayer, 2010; Buckley, Gobert, Kindfield, et al., 2004; Huppert, Lomask, & Lazarowitz, 2002; Jones, Minogue, Tretter, Negishi, & Taylor, 2006; Kara & Yesilyurt, 2008; Kiboss, Ndirangu, & Wekesa, 2004; Marbach-Ad, Rotbain, & Stavy, 2008) and four pertain to chemistry (Ardac & Sezen, 2002; Ealy, 2004; Barak & Dori 2005; Frailich, Kesner, & Hofstein, 2009).

The pedagogy for the implementation of the technology for the 20 highly successful studies in category C was not nearly as explicit as it was for category B. In these 20 articles, only four specifically referenced partnering inquiry-based instruction with the technology and traditional forms of instruction without technology (Frailich, Kesner, & Hofstein, 2009; Kara & Yesilyurt, 2008; Lee, Linn, Varma, & Liu, 2010; Zacharia, 2005). For example, in a pedagogy explicit study, Baser (2006) employed technology-based simulations in a study examining the effect of these modeling simulations in a confirmatory lab after a lecture in comparison to using the same simulation following a conceptual change model. While the instruction and simulation helped both groups of students make content gains over their pre-test results, the students using the simulation applied in the conceptual change model significantly outperformed the other group. Having students use technology, primarily computer simulations, to construct and test models implies an inherent level of inquiry that was not present with the category B technology. In category B, technology could be used to collect data in very traditional, non-inquiry manner. Simulations, however, by default

allow students to quickly and easily manipulate variables to explore different results. This is a key component of inquiry and therefore it is embedded in the pedagogy of instruction whether or not the inquiry is explicitly addressed.

Category D: Educational Technology for Communication

Category D, communication, was the last individual category with 15 or 10.5% of the articles. The level of research presented in these studies ranged from research levels 1 to 3, and the level of success of implementation ranged from levels 1 to 7. Examples of technology employed included classroom response systems, blogging, and mediated chat. It is interesting in this category of technology almost all of the studies are at the lower end of the research and success level scales. This might be a reflection of the recent introduction of this technology in the classroom.

The communication category also was interesting in the breakdown of science content being taught by the technology. Seven of these 15 articles were in the general category meaning they were used in very broad contexts across multiple content areas. The reason that these were very broad is often that they were using a generic technology such as some type of classroom response system, blogging, or using a computer to communicate information to the group. The advantage of these broad studies is that they can involve very large sample sizes. The seven articles in the general content area average over 650 participants (Fies & Marshall, 2008; Kay & Knaack, 2009; Leuhmann & Frink, 2009; Li, 2002; Nagy-Shadman & Desrochers, 2008; Papanastasiou, Zembylas, & Vrasidas, 2003; Qablan, Abuloum, & Al-Ruz, 2009). The research designs suggest that these studies were exploratory in nature examining the possibility of using the technology in the classroom, evaluated at research levels 1 and 2. None of the studies incorporated a pre-post test design or a comparison/control group. The success in each

case was simply the successful implementation of the technology and in some cases a measure of student appreciation of or attitude toward the technology.

The two studies at the level three of success are quite similar. Both are in the content area of Biology with smaller sample sizes of 28 and 53, respectively. One study explored the use of mediated chat in secondary Biology (Pata & Sarapu, 2006), whereas the second study explored a computer-based inquiry environment with a significant writing component to scaffold elementary students' learning (Hakkarainen, 2003). An interesting aspect about these two studies is their specific references to the pedagogy of implementation and how the technology supports and encourages inquiry-based learning. Analysis of students' online responses suggests that student learning was improved using the technology in both of these studies.

General Category: Educational Technology for Multiple Purposes

The last group of studies is the remaining nine that could not be defined by one content category. The level of research presented in these studies ranged from research level 1 to level 4, and the level of success of implementation ranged from level 2 to level 8. Examples of technology employed included laptop use, computer assisted learning, and online laboratory activities.

This combined technology area had a clear split in the highest assigned success levels with two studies in biology (Rotbain, Marbach-Ad, Stavy, 2008; Trevisan, Oki, & Senger, 2010) and two in physics (Clark & Jorde, 2004; Yang & Heh, 2007) that were at a level 7 of success or higher. Once again the pedagogy played a vital role in the high level of success achieved in these studies. In each case, the control group was described as traditional or lecture-based. The experimental group then used the technology and the technology helped to facilitate an inquiry-based learning environ-

ment. This combination produced a significant increase in the science content that was learned by the students.

One surprising finding that emerged from the analysis was the lack of a success level 0 for the technology implementation. Of the 143 articles reviewed, none of the studies suggested the technology was a less effective way to teach science than traditional or comparable low-tech approaches. Regardless of the level of the research, the technology employed, or the level of implementation (*i.e.*, from descriptive explorations to large scale comparisons between technology implementation and traditional control groups), all studies supported the use of educational technology to enhance students' learning experiences and/or attitudes toward science.

DISCUSSION

A comparison of the technology applications used in the studies reviewed suggests changes are occurring in the implementation of educational technologies in science instruction. Similar to the trend apparent in the NCES data discussed earlier (NCES 2000; Gray et al., 2010), research studies reviewed illustrated a trend toward using educational technologies to illustrate science concepts and support student exploration of natural phenomena through simulations, visualizations, and other dynamic animations. Of the 149 studies reviewed, 49% involved the use of computer simulations, modeling programs, and other animations to illustrate science concepts. Another 25.9% of the studies addressed pupils' use of technology to collect and analyze data and identify patterns in natural phenomena, applications of technology that help to make abstract concepts concrete and make objects that are otherwise invisible readily apparent and visible (Flick & Bell, 2000). Five studies in particular explored the use of haptic feedback on students' understanding of viruses (Jones, Andre, Superfine, Taylor, 2003; Jones,

Andre, Kubasko, et al., 2004; Jones, Minogue, Oppewal, Cook, & Broadwell, 2006; and Jones, Minogue, Tretter, Negishi, & Taylor, 2006) and thermodynamics (Clark & Jorde, 2004). These studies illustrate how advancements in technology offer new and innovative approaches to learning science not before possible, and likely affect student learning outcomes in ways not offered in the past (Allen, 2001; Waxman et al., 2003).

Pedagogical strategies employed with the implementation of technology varied across the studies. Larry Cuban (2001) asserted that teachers seldom used computers in their instruction, and when they were used, the strategies employed were similar to those used in their traditional instructional practices, such as the writing of papers and supporting student research using the Internet. While several studies explored the use of blogs and virtual labs to support student discussions of the data, many studies focused on applications of dynamic visualizations and interactive models to explore abstract science concepts. Some studies used full immersion experiences through computer gaming to engage students in authentic learning experiences, whereas other studies used probeware, electronic microscopes, and other data collection and analysis tools to support students *doing* science. Classroom response systems were another area of research addressed to explore the effects of this technology for engaging students in their learning and providing formative assessment to help students monitor their learning.

Pedagogical strategies also presented complexities in the studies that limit the scope of the findings. Through research on conceptual change we have learned that children construct their understandings through their experiences both in school and outside the classroom. They bring to their learning preconceived understandings that often differ from scientifically accepted understandings. Their preconceived notions can hinder students' ability to construct scientifically accepted understandings of natural phenomena. The research literature recommends helping stu-

dents identify their preconceived notions before learning new concepts, and incorporating concrete, sense-making experiences and interpretive discussions to help them construct an understanding (Driver, Asoko, Leach, Mortimer, & Scott, 1994; Vosniadou, 2007). In addition, supporting metacognitive awareness (Beeth, 1998) and motivation (Nolen, 2003; Pintrich, 2003) also are important factors supporting students' learning. The treatment-control experimental design studies reviewed in the current study often compared constructivist strategies incorporating technologies to low-tech didactic methods. It is not surprising that nearly all of the studies using this research design reported significant learning gains of treatment students. The question that remains regarding these outcomes is to what extent the learning gains were influenced by the technologies implemented. Constructivist pedagogical strategies were most often employed with the treatment groups, whereas traditional didactic approaches were more often employed with control groups. Using this research design it is not possible to tease out what effect the technology has on student learning. Were the learning outcomes influenced by the technologies employed, the pedagogical strategies used, or a combination of the two? Would the control groups have shown similar learning gains if they had been taught through low-tech constructivist strategies? More research is needed in this area to better understand how the use of specific technology tools and pedagogical strategies influence student learning.

Several studies attempted to address this issue by comparing low-tech and high-tech constructivist strategies to a traditional didactic approach using similar technologies. For example, Marbach-Ad, Rotbain, and Stavy (2008) compared the use of static computer illustrations and dynamic animations to traditional didactic instruction in teaching molecular genetics. The study included 248 eleventh and twelfth grade students from 20 high schools in Israel. Students in the animation and illustration groups attended classes in which

short lectures were presented on topics regarding molecular genetics after which students had time to manipulate dynamic animations, or view digital illustrations in their respective groups. The control student group attended traditional lectures on molecular genetics with no follow-up exploration of the concepts. All students used the same textbook in all of the classes. The researchers reported that the two technology groups showed similar significant learning gains in comparison to the control group. In addition, students using the dynamic animations reported less difficulty with the content than what students reported in the static illustration group. Students in the control group reported the greatest difficulty with the content. The design of this study provides an example of how multiple comparison groups can be used to explore the effect of technology on student learning, and students' attitudes toward their learning.

The progression of research on new technologies and/or innovative uses of technology in teaching science often begin with small scale exploratory and design studies to investigate the use of technologies in science teaching. The research progression in this field should then continue on a continuum toward developing more in-depth qualitative studies to explore possible gains in students' cognitive understanding of, and attitudes toward science, and mixed methods experimental studies to compare effects of different pedagogies using the technology to similar low-tech pedagogies. The studies reviewed in the current analysis suggest more research is needed at levels 4 and 5. In addition, the authors of this chapter found many articles lacked sufficient detail to support the efficacy of measurement instruments employed. Validity and reliability data were rarely provided, and in some cases when these data were reported, they minimized the strength of the findings because of lower reliability levels of the instruments (e.g., Crombach's alpha coefficient of 0.55). Further, only a few studies provided effect sizes to substantiate claims of significance in learning gains of treatment group students.

Research on student motivation and attitude toward science underscores connections between student learning gains and their self-efficacy in science, and motivation to learn science. Nolen (2003) reported positive achievement levels for students in classrooms focusing on learning for understanding and supporting independent thinking. Conversely, she noted that classrooms stressing correct answers and promoting the belief that only the most able students could succeed negatively predicted student achievement. Further, research indicates that girls tend to develop an aversion toward science earlier, and to a greater extent than boys (Osborne & Simon, 2003). Other researchers suggest that girls do not have the same opportunities as boys to observe natural phenomena and play with technical instruments in their everyday experiences (Johnson, 1987; Kahle and Lakes, 1983; Osborne & Simon, 2003; Thomas, 1986). Many of the instructional activities incorporating educational technology in teaching science described in the studies reviewed in the current analysis support the development of problem solving skills, learning through inquiry, and student-centered approaches; strategies that are likely to promote positive student self-efficacy in science for both genders. In addition, teachers often report that students are more motivated and engaged in their learning when using technology. Thus, exploring the effect of technology use on students' attitudes and motivations in learning science should be as important a component of research studies as the effects on student achievement. Additional research studies on technology implementation in science should explore both achievement and attitudinal effects on students. These studies would add to our understanding of the success of the implementation and benefits of its use in the classroom, and might provide guidance on strategies to foster student interest in science in the middle and secondary grades.

CONCLUSION AND IMPLICATIONS

The goal of this literature review was to identify research trends on technology implementation in teaching science with specific focus on the types of technologies used, level of research employed, and success of implementation. The findings indicate exciting growth in the use of computer visualizations, modeling, and virtual environments to engage students in authentic learning experiences and support their learning. Research designs used in the studies also suggest more robust studies are needed to illuminate how the use of specific technology tools can support student learning and the effects on students' self-efficacy in learning science. This review also supports the growing trend of using technology tools to foster the development of critical thinking and problem solving skills, and student-centered classrooms for learning science.

Research reviewed in this study also suggests there is much more to learn about the use of technology tools at the elementary and middle school levels. A majority of the research over the past decade has focused on innovative approaches in teaching and learning science at the secondary and post-secondary levels. Future research is needed to explore the effects of technology implementation in teaching science at the lower levels. To balance the body of literature on instructional uses of technology in science teaching, future studies need to focus on content areas outside the domain of physical science to address the learning effects on even larger populations of students in biology and earth/environmental science. Further, there is a need for research on student motivation and attitudes toward learning when using technology in science. As the use of technologies matures, research needs to progress up through the research and success scales used in the current analysis to identify best practices for its use and resultant effects on student learning and attitudes in science.

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Chapter 13

The Effects of Teacher Content Authoring on TPACK and on Student Achievement in Algebra: Research on Instruction with the TI-Nspire™ Handheld

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ABSTRACT

A year-long PD program was provided to four NYC integrated algebra teachers. The PD comprised of teacher authoring of curriculum that incorporated TI-Nspire™ technology. Teacher TPACK levels were measured through a TPACK Levels Rubric, created and validated by the authors. The rubric was used to assess the teachers' written artifacts (lesson plans and authored curriculum materials) and observed behaviors (PD presentations and classroom teaching through observations). Results indicated that, first teachers' TPACK scores for written artifacts paralleled those of PD presentations. Second, the classroom teaching was either at the same level or lower than written artifacts. Third, teachers did not improve with every lesson they developed; instead, their scores vacillated within the two or three lower TPACK levels. Finally, the students taught by the teachers with higher TPACK level had higher average score on the NYS Regents exam and higher passing rates.

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INTRODUCTION

Despite the sizable number of emerging technologies for teaching mathematics, few teachers have had the experience of utilizing them in the classroom. In fact, many mathematics teachers are themselves novices in the domain of pedagogical technologies, and could therefore greatly benefit from a program designed specifically to develop their Technological, Pedagogical, and Content Knowledge (TPACK). Such a program would help them to think strategically in planning, organizing, implementing, and critiquing a curriculum that integrated technology in guiding student learning with specific content. Furthermore such a program would aim to meet the needs of all the students in a given class, regardless of their initial proficiency in the subject (Mishra, & Koehler, 2006; Niess, 2008). Professional Development (PD) would be one way to ensure that teachers acquire TPACK.

In this chapter we describe a study of a year-long PD program provided to four teachers teaching integrated algebra in a New York City public school. The context of the PD was the authoring by the teachers of a curriculum incorporating TI-Nspire technology. TI-Nspire is a low-cost personal handheld computing device for mathematics and science supporting a broad range of instructional models as well as a number of advanced modes of assessment. Three important layers of analysis provide the basis for research in the use of the TI-Nspire: (1) *Effectiveness*. Graphing calculators enhance student learning (Ellington, 2003; Khoju, Jaciw, & Miller, 2005). (2) *Enhanced representation and communication of important mathematics*. TI-Nspire's linked representations help teachers to focus student attention on the relationships among multiple representations, such as algebraic equations, geometric constructions, graphs, and tables of data. (3) *Deeper opportunities to learn*. By using the new document features of TI-Nspire, teachers would find they can almost certainly increase the time in the classroom students spend doing

mathematics in an environment possessing the ingredients that promote success - namely, increased support for mastering difficult concepts and skills, high student participation, and tools for reflective practice. Finally, TI-Nspire capabilities extend beyond the familiar graphing calculator. Additional instructional models allow teachers to support project-based learning, engage in participatory simulations, and encourage students to build mathematical models. The need remains to build cumulatively on our existing understanding of teaching secondary mathematics with graphing calculators. By developing PD programs that concentrate not only on teachers integrating technology into their teaching but also on their actually authoring their own materials that need can be directly addressed.

Given the unique characteristics of the PD program we developed, we were able to test the following research questions:

1. To what extent is a designed model of PD in which teachers author original materials that integrate TI-Nspire technology associated with changes in teachers' TPACK levels as measured by external assessment of teaching artifacts (lesson plans and TI-Nspire documents) and observed behaviors (classroom teaching and PD presentations)?
2. Is there a relationship between a teacher's TPACK level and student achievement?

BACKGROUND

In this section we provide background information on the PD model used in the study. We discuss first the importance of the teacher content authoring. We then review the context of the study i.e., the role within it of the TI-Nspire technology. Lastly we provide background on our two dependent variables, namely, TPACK and student achievement.

Professional Development Model

Advanced technology and curriculum-related decisions create a unique set of challenges for teachers. Kastberg, & Leatham (2005) warn teachers that the mere addition of technology in and of itself is not enough to guarantee that students will gain more than a superficial understanding of the mathematical materials, and thus an understanding of the more advanced mathematics to come. It takes considerable education and experience to achieve a comfortable level of expertise in the use of technology as a teaching tool in order to perform markedly better than without the use (Fleener, 1995; Thomas, & Cooper, 2000; Lyublinskaya, & Tournaki, 2010). The classroom teacher must usually undergo a detailed introduction to the relevant technology, one that anticipates the multifaceted issues that are certain to come up before and during the change process (Mitchell, Bailey, & Monroe, 2007). Studies have shown that the integration of innovative technology that produced improvement in student learning only when teachers had: a) strong interest in technology (Rice, Wilson, & Bagley, 2001); and b) on-going support and professional development (Wolf, 2007). Successful PD programs build on previous activities, offer teachers opportunities to discuss classroom experiences with other teachers, and encourage ongoing professional communication dealing with similar concerns (Birman, Desimone, Garet, & Porter, 2000). Education researchers invariably recommend collaborative learning as a way to build knowledge in a community of practice (Lee, 2005). The support of reflective collegial learning communities is crucial for teachers as they attempt to implement new techniques (Darling-Hammond, 1997). Garet, Birman, Porter, Yoon, and Desimone (2001) specifically refer to the need for teachers to seriously discuss among themselves student work as well as instructional methods. Learning communities that focus on content and take time to understand exactly how students learn were found to be the most effective

for changing teacher practice for the better (Corcoran, 1995). The developers of the PD of the present study made an effort to incorporate many of the components of effective PD mentioned in the literature, all the while supporting the teachers as they authored their own curriculum materials.

In this study teachers attended a three-day intensive summer professional development workshop. After the beginning of the school year, teachers met on a weekly basis at professional development workshops in order to develop inquiry-based lessons. The purpose of the workshops was to have the teachers work cooperatively with their peers in planning and developing their own lesson activities incorporating the TI-Nspire technology. The workshops were guided by a facilitator, a master teacher with over 25 years of experience in teaching mathematics and a specialist in TI-Nspire technology. The professional development workshops cycled through the following stages of content development with TI-Nspire technology: 1) a review of the curriculum sequence for the two weeks following the workshop in order to select the topic of the lesson, teaching objectives, and to brainstorm lesson activities appropriate for the TI-Nspire environment (as a whole group or in pairs, – varied by time of the year); 2) meeting together as a group for finalizing the development of a lesson plan based on an inquiry-based activity and activity documents for the lesson; 3) presentation of the lesson at the workshop to the group, facilitator, and/or one of the researchers with a demonstration of the TI-Nspire activity, for peer review and critique – followed by any necessary modification of the lesson plan and documents; 4) teaching the lesson in class during the same week, while being observed by the facilitator and/or one of the researchers; 5) reflection about and discussion of the teaching and learning experience at the group meetings following the teaching of the lesson; and 6) finalization of the developed curriculum materials based on the teaching experience and peer feedback.

Teacher Content Authoring

Teachers are responsible for tailoring instructional activities to meet curriculum standards as well as the particular educational needs of their students. It is often asked, if we don't expect teachers to write their own textbook, why do we expect them to design their own technology-based materials (Bratina, Hayes, & Blumsack, 2002)? Ainsworth, and Fleming (2006) reply to this question by arguing that in fact teachers do customize their respective textbooks for use in their classrooms by selecting the order in which chapters are to be read, explaining difficult terms, providing exercises and worksheets etc. These authors propose that much is to be gained by providing teachers with authoring tools.

Teachers as authors have been variously used in the process of integrating technology into pedagogical practice. In fact, researchers have suggested that instructional software templates can positively affect the efficiency of the development process and compensate for the developers' lack of experience (Boyle, 2003; Merriënboer, & Martens, 2002). Making people with low software production skills author instructional software can be beneficial to them by getting them more involved in the process. Teacher involvement in the development of online learning resources has received attention only recently (Akpınar, & Simsek, 2006; Muirhead, & Haughey, 2005; Recker et al., 2005). Researchers have suggested that with the use of simple templates, teachers will be able to make their own objects (Dunning et al., 2004; Jones, 2005). While a number of design features in the literature have been incorporated by developers of learning objects, only a few studies have carried out a formal descriptive evaluation of the final learning object (LO) product (e.g., Krauss, & Ally, 2005). Few existent studies examine the impact on students' achievement of learning objects developed by teachers.

The advantage of giving teachers the opportunity of contributing content to the learning

experience is that it transforms them from passive users of technology into active co-authors (Brusilovsky, Knapp, & Gamper, 2006). The involvement transforms the technology, earlier seen as the teacher's potential competitor, instead into a powerful collaborator in the teacher's hands. A teacher may even get the feeling he or she controls the technology—technology as a friend, not a rival.

As a result of the PD, teachers developed a total of thirteen lessons which were peer reviewed and field tested. The lesson materials included detailed lesson plans, student worksheets, and TI-Nspire documents. The topics of the lessons are included in Table 1.

The Context of the Study: TI-Nspire Technology

The NCTM Standards advocate a unified approach to mathematics education with emphasis on the use of technology, visual thinking, and the connection between geometric and algebraic representations (NCTM, 2000). This study used as its platform Texas Instruments' newest generation of the TI-Nspire handhelds. This technology enables exploration, overcomes the artificial separation between algebra and geometry, and provides easy access to mathematics, while still challenging the user. It challenges students on a wide range of performance levels, allows advanced mathematical concepts beyond the current school mathematics curricula to enter the discussion, and permits teachers to assess student performance at the different stages of their problem solving skills. The TI-Nspire represents not only a new generation of graphing calculator technology. It also embodies a major advance in the capabilities of a low-cost personal computing device in that it is reliable, easy-to-use, and supports a broad range of instructional models and advanced modes of assessment for teaching mathematics. The TI-Nspire incorporates two entirely new features. First, the TI-Nspire displays linked multiple representations. The multiple representation capability dy-

Table 1. Topics and sequence of the lessons developed by the teachers in the study

	LESSON	Developed By	DATE
1	Writing Function Rule	Whole group	October 2007
2	Similar Figures	Whole group	November 2007
3	Solving Equations Graphically	Whole group	December 2007
4a	Modeling with Real Function Rule	A and C	February 2008
4b	Finding Rate of Change	B and D	February 2008
5a	Predicting Using Trend Lines	A and C	March 2008
5b	Using the Line of Best Fit to Make Predictions	B and D	March 2008
6a	Discovering Exponential Functions	A and D	March 2008
6b	Exploring Leading Coefficient of Quadratic Graphs	B and C	March 2008
7a	Discriminant	A and D	April 2008
7b	Axis of Symmetry, Parabola	B and C	April 2008
8a	What are trigonometry ratios?	A and D	May 2008
8b	Discovering Trigonometry Ratios	B and C	May 2008

namically links graphical curves, axes, equations, and tables in simultaneous displays, such that a change in one representation is transmitted to the others, a capability not as fully developed in other software technologies. The feature allows teachers to design new tasks for their students that address NCTM standards focusing on connections between algebraic and geometric representations, and also on inquiry-based approaches to teaching and learning mathematics.

Second, the TI-Nspire also features document management. This feature makes possible an organized presentation of multiple mathematical screens, which can be saved, shared, annotated, and revisited, giving teachers new ways of assessing students understanding of the mathematics and the technology. Small-scale studies with such tools have demonstrated that the multiple representations approach can contribute to a deeper understanding of sophisticated mathematical concepts by diverse children across a range of settings (Roschelle et al., 2000). Initial empirical evidence has demonstrated that the use of TI-Nspire handhelds in mathematics classrooms leads to higher achievement (Lyublinskaya, & Tournaki, 2010). Furthermore, TI-Nspire technology can

structure student activities through the introduction of complex concepts or data sets, and thereby provide a supportive context that allows teachers to focus on mathematical argumentation and not just manipulation of symbols and algorithms.

TPACK Framework

Technological, Pedagogical, And Content Knowledge (TPACK) describes the body of knowledge that teachers need for teaching with technology in their assigned subject areas (such as mathematics) and grade levels. TPACK is identified with knowledge that relies on the interconnection and intersection of content, pedagogy (teaching and student learning), and technology (Margerum-Leys, & Marx, 2002; Mishra, & Koehler, 2006; Niess, 2005a; Pierson, 2001; Zhao, 2003). The framework must be viewed as constituting more than a set of multiple domains of knowledge and skills that teachers require for teaching their students particular subjects at specific grade levels. Rather, TPACK defines a way of thinking that integrates the multiple domains of knowledge of mathematics, pedagogy and technology.

Significant differences have been observed in the actions of teachers teaching mathematics with various technologies (Niess, 2005b). On the other hand, the diverse actions do not indicate whether or not a given teacher has achieved TPACK for teaching mathematics with appropriate technologies. Teachers differ in their actions with respect to each of the components teaching as they confront whether to use any of various technologies in teaching mathematics. Their differences are a function of their knowledge of mathematics, their knowledge of the technologies, and their knowledge of teaching and learning (pedagogy). Rogers (1995) envisioned a five-step process in the ultimate decision of whether to accept or reject a particular innovation. Niess, Suharwoto, Lee, and Sardi (2006) suggested this five-step process formed a beginning framework for assessing a teacher's development of TPACK focused on teaching mathematics with appropriate technologies. These authors describe five levels of a teacher's TPACK for teaching mathematics with spreadsheets, using the Rogers (1995) scheme:

1. *Recognizing* (knowledge), whereby teachers are able to use the technologies and recognize alignment of the capabilities of the technologies with mathematics content.
2. *Accepting* (persuasion), whereby teachers form a favorable or unfavorable attitude toward teaching and learning mathematics with appropriate technologies.
3. *Adapting* (decision), whereby teachers engage in activities that lead to choosing whether to adopt or reject teaching and learning mathematics with appropriate technologies.
4. *Exploring* (implementation), whereby teachers actively integrate teaching and learning of mathematics with appropriate technologies.
5. *Advancing* (confirmation), whereby teachers evaluate the results of the decision to integrate teaching and learning mathematics with appropriate technologies.

Niess (20010, p.4) extended Grossman's four central components of PCK (1989, 1991), which helped in understanding and describing TPACK as the knowledge and beliefs that mathematics teachers demonstrate when integrating appropriate technologies.

1. *An overarching conception about the purposes for incorporating technology in teaching subject matter topics. This conception deals with what the teacher knows and believes about the nature of the subject such as mathematics, what is important for students to learn, and how technology supports learning. The concept serves as a basis for instructional decisions.*
2. *Knowledge of student understanding, thinking, and learning in subject matter topics with technology. In this component, teachers rely on and operate from their knowledge and beliefs about student understanding and thinking with technologies in specific mathematical topics.*
3. *Knowledge of curriculum and curricular materials that integrate technology in learning and teaching subject matter topics. With respect to the curriculum, teachers discuss and implement various technologies for teaching specific topics. In addition, they examine how mathematical concepts and processes within the context of a technology-enhanced environment are organized, structured, and assessed throughout the curriculum.*
4. *Knowledge of instructional strategies and representations for teaching and learning subject matter topics with technologies. Teachers adapt their teaching to guiding students in learning about specific technologies at the same time as they are used in learning mathematics."*

These four components indicate that mathematics teachers need to be engaged in reconsidering the content and the processes along with the impact

of the specific technology. In fact, PD programs need to attend to the knowledge, beliefs, and dispositions that teachers have and thus to guide the development of their TPACK for teaching mathematics with technologies.

Assessing TPACK

Three types of data are used in research to assess teachers' TPACK: self-report (via interviews, surveys, and other generated documents such as reflective journal entries); observed behavior (via observations protocols, narratives, etc.); and teaching artifacts (via lesson plans, curriculum materials, etc.). Since teacher knowledge is typically reflected through actions, statements, and artifacts, rather than being directly observable, instruments and techniques that assist the assessment of teachers' TPACK should provide ways for assessors to discern the dimensions and extent of teachers' TPACK in systematic, reliable, valid ways. Since teachers' stated pedagogical beliefs do not always align with their instructional practices (Lawless, & Pellegrino, 2007), external assessment of those practices and their artifacts, correlated with the contents of teachers' self-reports, should help by inference to better understand the nature of their TPACK.

Most of the published instruments that assess TPACK development and have been tested for reliability and validity are of one type: the self-report survey. Schmidt, Baran, Thompson, Mishra, Koehler, and Shin (2009), and Archambault, and Crippen (2009) developed self-report instruments with multiple items keyed to each of the seven types of knowledge represented in the TPACK construct: technological (T), pedagogical (P), content (C), technological pedagogical (TP), technological content (TC), pedagogical content (PC), and technological pedagogical content knowledge (TPACK). Schmidt et al.'s survey was designed for repeated use by pre-service teachers as they progress through their teacher education programs. It was also found

to be reliable and valid for use at the beginning and end of shorter-duration summer courses in technology integration. Archambault, and Crippen's survey instrument was designed to be used by in-service instructors, and was found to be reliable and valid with a nationally representative sample of approximately 600 K-12 online teachers. Though the testing of these two instruments proved them to be quite robust measures, the challenges inherent in accurately estimating teacher knowledge via self-reports — in particular, that of inexperienced teachers — are well-documented (Archambault, & Crippen, 2009). Unfortunately, research has shown that measured gains in teachers' self-assessed knowledge over time are more reflective of their increased *confidence* regarding a particular professional development topic rather than their actual increased *knowledge in practice* (Lawless, & Pellegrino, 2007; Schrader, & Lawless, 2004). Self-report data should therefore be correlated with external assessments of teacher TPACK knowledge.

Only recently, Harris, Grandgenett, and Hofer (2010) constructed and validated an instrument that assessed the TPACK of pre-service teachers based on analysis of their lesson plans. Their product modified the Technology Integration Assessment Instrument (TIAI) developed by Britten, and Cassady (2005). The TIAI is a rubric that can be used to assess technology integration in a lesson plan across seven dimensions: planning for technology use, content standards, technology standards, differentiation, use of technology for learning, use of technology for teaching, and assessment. Harris, Grandgenett and Hofer developed a reliable instrument that helps assessors to infer a teacher's TPACK by examining an instructional plan. The instrument measures the Technological Pedagogical domain (TPK); Technological Content domain (TCK); and Technological, Pedagogical, And Content Knowledge domain (TPACK).

Furthermore, Niess (2010) developed a schema with detailed qualitative descriptors for the five

levels of TPACK (i.e., recognizing, accepting, adapting, exploring, and advancing), and for each of the four components of TPACK (i.e., overarching conception, student understanding, curriculum, and instructional strategies). Niess used this qualitative schema to analyze the development of pre-service teachers' TPACK in teaching mathematics with spreadsheets for each of the four components of PCK (Grossman, 1989, 1991).

In our study we adapted Niess' (2010) schema that has been effectively used to assess TPACK levels of pre-service teachers using Excel spreadsheets in teaching mathematics. Based on this schema we developed a rubric to assess in-service teachers' levels of TPACK teaching algebra with TI-Nspire technology. The two TI-Nspire specific descriptors were developed for each cell of the rubric based on both, qualitative descriptors developed by Niess (2010) and the principles for guiding use of TI-Nspire by Dick and Burrill (2009) who established the research basis for the effective use of TI-Nspire technology. Content validity and inter-rater reliability of the rubric was tested using the teaching artifacts (teachers' developed lesson plans and curriculum materials) and teachers' observed behavior (PD presentations and classroom teaching) for in-service algebra teachers in the study. Predictive validity was tested by examining the relationship between teachers's TPACK level and student achievement.

Student Achievement

The purpose of every PD is to facilitate a pedagogical practice that ultimately leads to higher achieving students. Often PD studies assess changes in practice but do not assess student achievement (e.g., Desimone, Porter, Garet, Yoon, & Birman, (2002). In fact, in a recent statement, Desimone argued that "... we need more work that links professional development and changes in teaching practice to student achievement" (2009, p. 192).

In the present study, a school initial mathematics test was used to establish equivalence

of student groups taught by different teachers. Student achievement was measured by the scores and passing rates on the New York State Regents Algebra exam administered in June. All high school students in New York City are required to take Regents Algebra exams. A minimum score of 55 is required for the local diploma and a score of 65 or above is required for a Regents or Advanced Regents diploma (<http://www.emsc.nysed.gov/osa/reports/>).

STUDY DESIGN

The purpose of the study was to analyze the effects of the yearlong PD program described above on changes in teachers' TPACK and on the relationship between teachers' TPACK and student achievement. The independent variable of the study was the PD program. The dependent variables were a) the teachers' TPACK level, and b) the student scores and passing rates on NYS Regents Integrated Algebra exam.

The study was carried out as part of ordinary mathematics teaching, using the school's existing algebra curriculum, supplemented by TI-Nspire lessons developed by the teachers as part of their PD workshops. Data were collected from the teachers and their students. A One-Group Time Series design was used to analyze changes in teachers' TPACK level. The baseline for the teachers' knowledge of TI-Nspire technology was determined using TI-Nspire proficiency surveys administered during the first day of summer PD. The surveys indicated that the teachers had no prior knowledge of TI-Nspire technology. The data that described changes in teachers' TPACK were collected over a period of a school year. A one group time series design uses the treatment group as its own control. With this design there is no need for a separate control group as long as baseline data are available. To control for potential disadvantages the data collection methods remained the same over time. A threat to the validity of this longitudinal

design is that factors other than the intervention might influence changes in teachers' behaviors for example, changes in teacher responsibilities, technical difficulties.

The student achievement data were compared using 4x1 design, treating the teachers as four separate TPACK treatment conditions. The equivalence of these four groups was established using school initial assessment. Due to small sample size, this design had low statistical power and thus did not establish a strong causal relationship between students' performance and teachers' TPACK level.

The teachers who volunteered to participate were assigned to their class sections by their immediate supervisor based on their teaching assignments and availability. Still a small non-randomized sample of convenience presents a threat to the internal validity of the study. To address threats to the internal validity due to participant selection, only the same level sections of integrated algebra for each teacher were included in the study. Further, these sections were compared using initial school assessment to establish group equivalence. There was no attempt to control for Hawthorne effect, a form of reactivity whereby teachers modified their behavior simply in response to the fact that they were being studied, not in response to our intervention. We assumed that history related to TI-Nspire technology was not a factor affecting teachers' responses since it was a newly introduced technology but there was a possibility of regression on the part of the teachers, given that over time they might have gotten tired and not performed to their potential.

Teacher TPACK levels were measured with a researcher-developed rubric to assess teachers' lesson plans, student activity pages, TI-Nspire documents, PD presentation narratives, and classroom observation narratives at different moments of time during the study. Student achievement was measured by the scores and passing rates on the NY State Regents Exam administered at the end of the study.

In order to control the instrumentation threats to the validity of the study, the researchers tested content validity and inter-rater reliability of the researcher-developed TPACK rubric. The student achievement was measured using scores and passing rates on NYS Regents Integrated Algebra exam. The development of New York State Regents Exams assured their content validity and item calibrations (<http://www.emsc.nysed.gov/osa/new-math.htm>).

Given the study design, the selection of participants, and use of instrument we can conclude that the external validity is high in that the TPACK levels rubric can be generalized to middle school, high school, or college educators in various school settings teaching any level of mathematics with TI-Nspire technology.

Participants

Teachers: Four integrated algebra teachers from a New York City public high school volunteered to participate in the study. The teachers' demographics are presented in the Table 2.

Students: A total of 67 students were enrolled in four integrated algebra sections taught by the teacher-participants. The students' demographics are presented in the Table 3.

Table 2. Teacher demographics

Teacher	Gender	Age	Teaching Experience (years)	Course Level Taught	Number of students
A	F	23	1	R	22
B	F	26	3	A	11
C	F	30	10	R	16
D	M	37	13	R	18

Note: The study was conducted with 4 sections of Integrated Algebra at two similar attainment levels in the school that included low achieving students: (a) Level R: reduced size freshmen Integrated Algebra for students who performed below grade level (levels 1 and 2) on the 8th grade city mathematics exam – 3 sections; (b) Level A: repeater section of Integrated Algebra for students who did not pass the NY State Mathematics A Regents exam as freshmen – 1 section.

Table 3. Student demographics

Race	African American	47%
	Hispanic	42%
	White	10%
	Asian or Pacific Islander	1%
Gender	Male	48%
	Female	52%

Procedure

During the Fall semester, the teachers' group met twelve times for two hours each time. The teachers worked together and developed total of three lessons as a whole group. Their PD presentations of each of these lessons were assessed by two observers. One of these lessons was selected by the teachers to be observed as they taught it in the classroom.

During the Spring semester teachers met thirteen times for two hours each time. For the first two lessons teachers worked in groups of two, when each experienced teacher was paired with a new teacher. For the last three lessons the groups were switched keeping pairing of experienced and new teachers. PD presentations of all 10 lessons developed during spring term were assessed by two observers. Each group of teachers selected one group lesson (total of 2 different lessons per teacher) to be observed in the classroom.

The NYS Regents exam was administered to the students in June after the treatment was completed.

Description of Measures and Instruments

TPACK Levels Rubric

In order to assess changes in how teachers integrate technology into mathematics teaching and learning, the authors developed the TPACK Levels Rubric (see Appendix). The structure of

the rubric is based on the TPACK framework for teacher growth for technology integration in the classroom through five progressive levels in each of the four components of TPACK as identified by Niess (2010). We organized the rubric as a matrix where each cell represented specific TPACK level of one of the four components of TPACK. Thus, each row of the rubric represented a specific component of TPACK and each column of the rubric represented specific level of TPACK. For each cell of the matrix we developed two TI-Nspire specific performance indicators that were consistent with both qualitative descriptors developed by Niess (2010) and the principles for a practical application of TI-Nspire technology developed by Dick and Burrill (2009). The purpose of this rubric is to assess teachers' TPACK level based on qualitative data collected from teachers, such as written artifacts, descriptions of observed behaviors, and teachers' self-reflections. This instrument is not intended for direct data collection.

The following scoring procedure is applied when using the rubric. The possible range of scores for each component is 0 – 5, where the component score can be an integer (both performance indicators are met) or half-integer (one out of two performance indicators are met). The score is assigned for each component independently. In order to achieve a particular level of TPACK, teacher must meet both indicators of that level for each component. Thus, the teacher's TPACK level is determined by the lowest score across all four components. For example, consider the teacher with the scores 3.5, 4, 4.5, and 4 on the four components of TPACK. Although in three out of four components the teacher met both performance indicators of *Exploring* level (score of 4 or 4.5), the lowest score is 3.5, and thus this teacher is still in transition from *Adapting* to *Exploring*. The TPACK level of the teacher is *Adapting*.

This rubric was newly constructed and thus tested for reliability and validity. Content validity was addressed by employing two TPACK experts. The experts were both researchers who

were involved in the initial development of the TPACK conceptual framework for mathematics educators. They reviewed the rubric and provided written comments in response to three specific free-response questions about the rubric. We revised some of the rubric's items according to the experts' comments. In order to test for inter-rater reliability, two different experts in the field used the revised rubric to score the 45 documents of this study (13 lesson plans with supplemental TI-Nspire documents, 13 narratives of lesson presentations at PD, and 19 narratives of classroom teaching observations). Each expert was provided with specific instructions and explanations on using the rubric. Both experts found the rubric to be easy to use with all artifacts provided to them for scoring. The range of correlations between the scores of two experts on the same components was from $r = 0.613$ to $r = 0.679$ $p < .01$. Correlations that examined whether there was a relationship among the four components of the rubric for each expert were also found statistically significant, i.e., the range of correlations for Expert 1 was from $r = .85$ to $r = .94$ $p < .01$ and for Expert 2 was from $r = .93$ to $r = .97$ $p < .01$. The significant correlations between the four components of TPACK could mean that teachers move to a higher TPACK level only after they achieve the previous level on all components.

Of course, caution has to be used with such an interpretive statement. Since the introduction of the four components of PCK by Grossman in 1989 there has been an absence of research in order to empirically validate their existence. These components have been adopted in the field and many researchers accepted them at face value (e.g., Niess, 2005a). Our interpretation of high correlations among the four components of the TPACK rubric is based on the assumption that the four components are independent of one another. To the best of our knowledge, confirmatory factor analysis has not been performed in the studies that used Grossman's four components of PCK. Due to small sample, this analysis was not possible in

the current study as well. It is, however, our intent to analyze the components of TPACK using factor analysis in a larger study in the future.

The TPACK Levels Rubric was used by two external experts to assess teachers' TPACK levels based on data collected from the teachers and observers.

New York State Regents Exam

New York State Regents Exams are commencement-level assessments aligned with the State's learning standards and core curricula. The mathematics graduation requirement for a Regents Diploma requires students to earn three units of credit in high school mathematics and pass one Regents Exam in mathematics with a 65 or higher. Credit granted for Integrated Algebra is limited to two units. Thus, all students must participate in the Regents Exam in Integrated Algebra except the 1% of the population of students with disabilities that participates in the New York State Alternate Assessment as recommended by the Committee on Special Education.

The development of New York State Regents Exams assured their content validity and item calibrations (<http://www.emsc.nysed.gov/osa/new-math.htm>). The questions on the Regents Exam in Integrated Algebra assess both the content and the process strands of New York State Mathematics Standard 3. Each question is aligned to one content performance indicator and also to one or more process performance indicators, as appropriate for the concepts embodied in the task. The Regents Exam in Integrated Algebra includes multiple-choice and constructed response items. The 30 multiple-choice and the 9 constructed-response items have different weights with total of 87 credits for the exam. Schools must make a graphing calculator available for the exclusive use of each student while that student takes the Regents Exam in Integrated Algebra. The specific psychometric data on the NYS Regents exams are not available.

Data Collection

The following data were collected from the teachers:

1. *Lesson Plans*. Teachers presented their self-developed curriculum materials in the format of a detailed lesson plan that included overview, objectives, materials, description of inquiry based activity, and summary (N = 13 lesson plans).
2. *Student Activity Pages and TI-Nspire Documents*. Each lesson plan was accompanied by the student activity worksheets and pre-made TI-Nspire documents if applicable.

The following data were collected from the observers:

1. *Presentation Narratives*. The narrative description of the teachers' presentation of the lesson at the PD workshop for the peer review was completed by an observer for each developed lesson prior to the classroom teaching. Each narrative was a non-evaluative, scripted record of what teachers did at the presentation (N = 13 presentation narratives).
2. *Classroom Observation Narratives*. Observers used observation protocol that included both specific open questions for the observer to address and instructions to provide non-evaluative, scripted narrative descriptions of the lesson. Each teacher was observed by both observers 4 – 6 times for a total of 19 observations.

The following data were collected on student achievement:

1. *School Initial Assessment*. A content-based, multiple-choice test given to all students by the mathematics department of the school in order to assess their knowledge level at the

beginning of the school year. This assessment was also used by the school to adjust student placement in various levels of courses. The properties of the test were not provided to the researchers.

2. *NY State Regents Exams* (NYSED, n.d.). The scores and passing rates on the exam administered in June, at the end of the school year, were provided to the researchers by the school for all students who took the exam.

Analysis and Findings

Analysis of Lesson Plans and Presentation Narratives

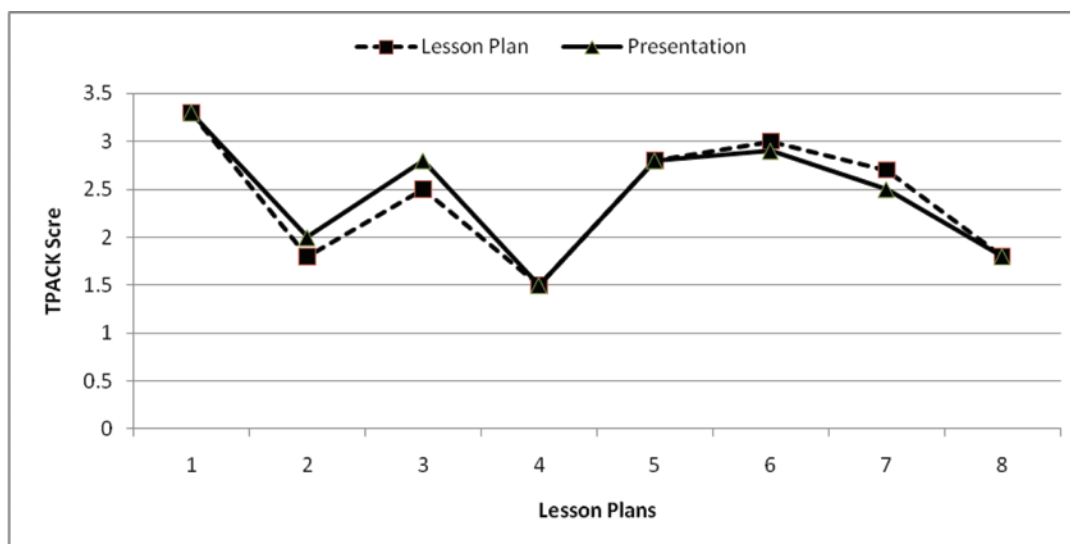
Based on medium inter-rater reliability of the TPACK Levels Rubric for all external assessments, the components scores of the lesson plans and corresponding presentation narratives were computed as averages of scores reported by two external experts (Table 4).

Analysis of the four component scores showed strong positive correlations between all compo-

Table 4. Descriptive Statistics for TPACK Scores (N = 13)

Component	Data Type	Minimum	Mean (SD)	Maximum
Conception	Lesson Plan	1.0	2.5 (0.718)	3.5
	PD Presentation	1.0	2.4 (0.695)	3.5
Students	Lesson Plan	1.0	2.6 (0.845)	3.8
	PD Presentation	1.3	2.5 (0.732)	3.5
Curriculum	Lesson Plan	1.3	2.8 (0.819)	4.0
	PD Presentation	1.5	2.7 (0.742)	3.8
Strategies	Lesson Plan	1.0	2.6 (0.855)	3.8
	PD Presentation	1.5	2.6 (0.718)	3.8

Figure 1. Changes in teachers' TPACK levels over the period of a school year



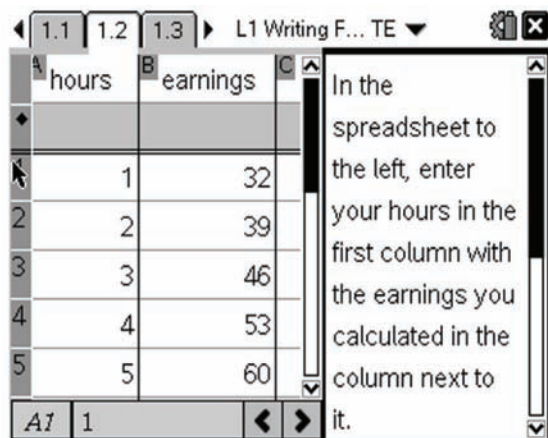
nents ($0.911 \leq r \leq 0.968, p < .001$) for both, lesson plans and presentation narratives. The largest difference in scores between any two components was 1.5 points. This is consistent with the theoretical prediction that teachers do not move to the next level of TPACK unless they reach the previous level on all components. This analysis also justifies the “conservative” procedure of determining overall TPACK score and level for each teacher as the lowest score on any of the four components for a given lesson plan or narrative.

Next, analysis of level of technology integration in the lesson plans and in the corresponding presentation narratives showed a strong positive correlation ($r = 0.980, p < .01$). The changes in overall TPACK levels on both measures over time are shown on Figure 1. In this chart the level of TPACK for the Fall semester, when all teachers worked together, was determined as the lowest score of all four components, while for the Spring semester (starting in February, when the teachers worked in groups of two) it was calculated as the average overall score of two teams. The Average TPACK Level Scores for the teachers and pattern of changes in the TPACK level scores were the same for the lesson plans and the presentations.

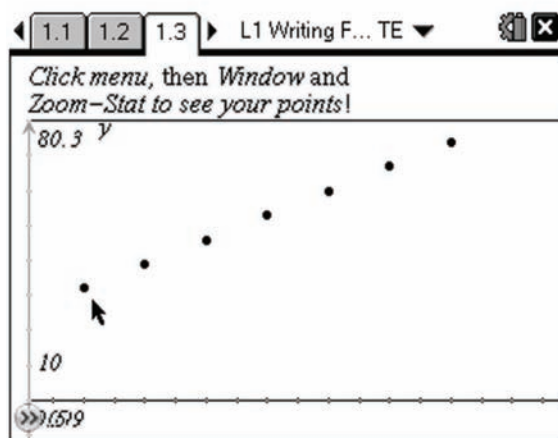
Fall Semester

The first lesson plan which was developed by all four teachers, “Writing Function Rule,” received a TPACK score of 3.3 (level: adapting) – one of the higher scores. The objective of the lesson was to develop student understanding of a connection between slope and rate of change. The inquiry-based activity presented students with real-life word problems and asked them to determine the relationship between the number of hours worked and total earnings given an hourly pay rate and fixed bonus. The TI-Nspire is a unique tool that not only has graphing capability but also can be used to create and link a number of types of displays such as: documents, spreadsheets, lists, and graphs. In this lesson students used teacher-made TI-Nspire document that consisted of multiple pages the tabs for pages 1.1→1.3 can be seen in Figure 2a. Page 1.1 instructs students to calculate earnings for different number of working hours. They then moved to page 1.2 to enter the hours and earnings into the Lists & Spreadsheets application as shown in the left frame in Figure 2a. Note that this page was divided into two frames, Lists & Spreadsheets on the left and Notes applications on the right. In the Notes application frame, the teachers provided

Figure 2. Lesson Plan 1: TI-Nspire screenshots for “Writing Function Rule”



a)



b)

students with additional instructions on entering their data into the Lists & Spreadsheets frame. Page 1.3 was setup by the teachers as a Graphs & Geometry application so that a scatter plot was automatically created as students were entering the data as shown on Figure 2b.

Students were then expected to draw a line through the points to determine the equation of the line, which gives them the function rule for the word problems. This represents teachers’ intent to use multiple linked representations and the dynamic nature of the technology in order for students to acquire new knowledge, which is an

indicator for the *adapting* stage. Another indicator of the *adapting* stage is the fact that teachers still use the traditional curriculum approach: calculating earnings for given hours of work and creating a scatterplot of the data, but instead of paper and pencil they use technology.

This lesson plan was presented in October. All four teachers worked on this lesson plan for four weeks. Multiple drafts of this lesson plan were submitted and, with significant feedback from the group facilitator, the lesson was modified to its final form, the one which was assessed. This could be one of the reasons for an unusually high score for the first lesson plan—extended effort with expert feedback leads to improved knowledge.

The teachers continued to work in a single group on the next two lesson plans. However, due to a pacing calendar, they were not able to spend as much time or include as many revisions on the consequent lessons. The 2nd lesson plan, “Similar Figures,” presented in November, is more representative of the teachers’ TPACK level at that time. The lesson focused on identifying corresponding sides in similar figures and setting up a proportion in order to find a missing side. The TI-Nspire document developed by the teachers represented a set of pages with images and instructions.

In this activity, TI-Nspire technology is mostly used for motivation rather than for mathematics learning; the former is representative of both the *recognizing* and *accepting* levels. In three out of four components, this lesson plan met indicators of *accepting* level. The activity had no inquiry tasks using technology. Rather, it only included practice such as measurements of the sides of the triangles and calculating the ratios of the sides. The problem was taken directly from the textbook; students were to observe the pictures of two triangles and to answer questions about the side measures. TI-Nspire technology was used by the teachers as an add-on to the traditional approach to the problem. The instructional strategies component of the lesson plan was at the *recognizing* level, since

a lot of the instruction centered on how to use technology, and the TI-Nspire document provided students with only routine practice rather than exploration and reflection opportunities. Thus, this lesson received a score of 1.8 (*recognizing*).

In December, around the middle of the Fall semester, the teachers' level of TPACK increased to 2.5 (*accepting*). The third was the best lesson plan during this semester developed by the teachers independently. This lesson, "Solving Equations Graphically," addressed the topic of solving equations using graphical methods. The lesson focused on making connections between algebraic and geometric approaches to solving equations. Based on the scores of the external evaluation, teachers achieved the *adapting* level on two components of TPACK, knowledge of students and curriculum. This is evidenced by the fact that students were expected to use the TI-Nspire document on their own, in order to learn about graphical solution of the linear equation. The technology was used as a replacement of a traditional non-technology approach to similar problems. Still, the activity did not have inquiry tasks and had limited opportunities for student exploration, which explains the overall TPACK level of *accepting*.

Spring Semester

In the Spring semester, teachers started working in pairs. For the next two lesson plans, teachers A and C formed one team (team AC) and teachers B and D formed a second team (team BD). The fourth lesson plan, "Modeling with Real Life Functions," developed by team AC in February, used a textbook problem dealing with the cost of a dinner. The technology was added for students to create a table of data, plot the scatter plot of the data, and graph the function. The lesson plan received a score of 2.0 (*accepting*). Team BD focused on "Finding the Rate of Change." The TI-Nspire document consisted of a series of pages with data tables and questions. Students used it the same way they would use textbook information. The only time students used technology was for

basic calculations. This lesson received a score of 1.0 (*recognizing*).

By the middle of the Spring semester, teachers' lesson plans improved – that is, they started using dynamic features of the TI-Nspire technology. Team AC developed a fifth lesson plan, "Predicting Using Trend Lines," in which students discover the relationship between the diameter and circumference of a circle. Students were asked to create a scatter plot of circumference vs. diameter and to use a movable line to determine the best fit line for the data. By dragging the line to find the best fit and observing the equation of the line, students were able to discover circumference formula of a circle. Presented on March 3, the fifth lesson received a score of 3.0 (*adapting*).

Team BD used a similar approach to explore relationships between the shoe size and height of students. Students were asked to create a scatter plot and to find the line of best fit, and then use this line to make predictions. In contrast, there was very little discovery in the lesson. In the TI-Nspire document, students were instructed to enter the data and calculate the regression line following specific steps provided to them in the worksheet. The dynamic features of the technology were not used. Most of the lesson plan focused on how to use technology to achieve the desired product, rather than on exploration and reflection about the mathematics of the best fit line. The lesson plan did include questions that probed students understanding of how best fit line could be used to make predictions. Thus, this lesson, "Using the Line of Best Fit to Make Predictions," received a score of 2.5 (found to be in transition from *accepting* to *adapting*).

For the next three lessons, the teams changed, so that teachers A and D now formed team AD and teachers B and C formed team BC. At the end of March, team AD presented their sixth lesson, "Discovering Exponential Functions". The lesson plan used the traditional textbook problem of folding a paper sheet and finding a pattern for the number of layers as a function of the number of

folds. The technology was used as an add-on, replacing paper and pencil graphing method. Students were instructed to create a scatter plot of the data and plot the function $y = 2^x$ on the same graph. They were expected to observe that the graph of the function goes through all points of the scatter plot, thus providing students with the “look” of the exponential function. The approach is teacher-centered and does not provide student with inquiry and explorations. The lesson received a score of 2.5 (*accepting*).

In the lesson plan “Exploring Leading Coefficient of Quadratic Graphs,” presented by the BC team, students were expected to use the “grab and drag” feature of the Graphs & Geometry application to explore the effect of coefficient a in the equation $y = ax^2$. The equation of the parabola and its graph appeared on the same screen. The algebraic and graphical representations of the function were linked, allowing students to grab the parabola, change its shape, and immediately see the change in the numerical value of a .

The questions included in the lesson assessed student understanding of the shape of the parabola and the existence of a maximum or minimum value achieved by the function for different values of a , including positive and negative values of the parameter, and values larger and smaller than 1. Through the use of technology, students were expected to discover on their own how the magnitude and sign of a affect the shape of parabola. This lesson received the score of 3.5 (*adapting*).

The seventh lessons, prepared in April, were at a similar level. Team AD’s lesson plan, “Discriminant,” received a score of 3.3 (*adapting*), and Team BC’s lesson plan, on the axis of symmetry of the parabola, received a score of 2.0 (*accepting*). As also occurred in the Fall semester, the scores at the end of the Spring semester went down. The eighth and last lesson plans prepared in May on trigonometry (team AD’s “What are trigonometry ratios?” and team BC’s “Discovering Trigonometry Ratios”), attained lower levels than

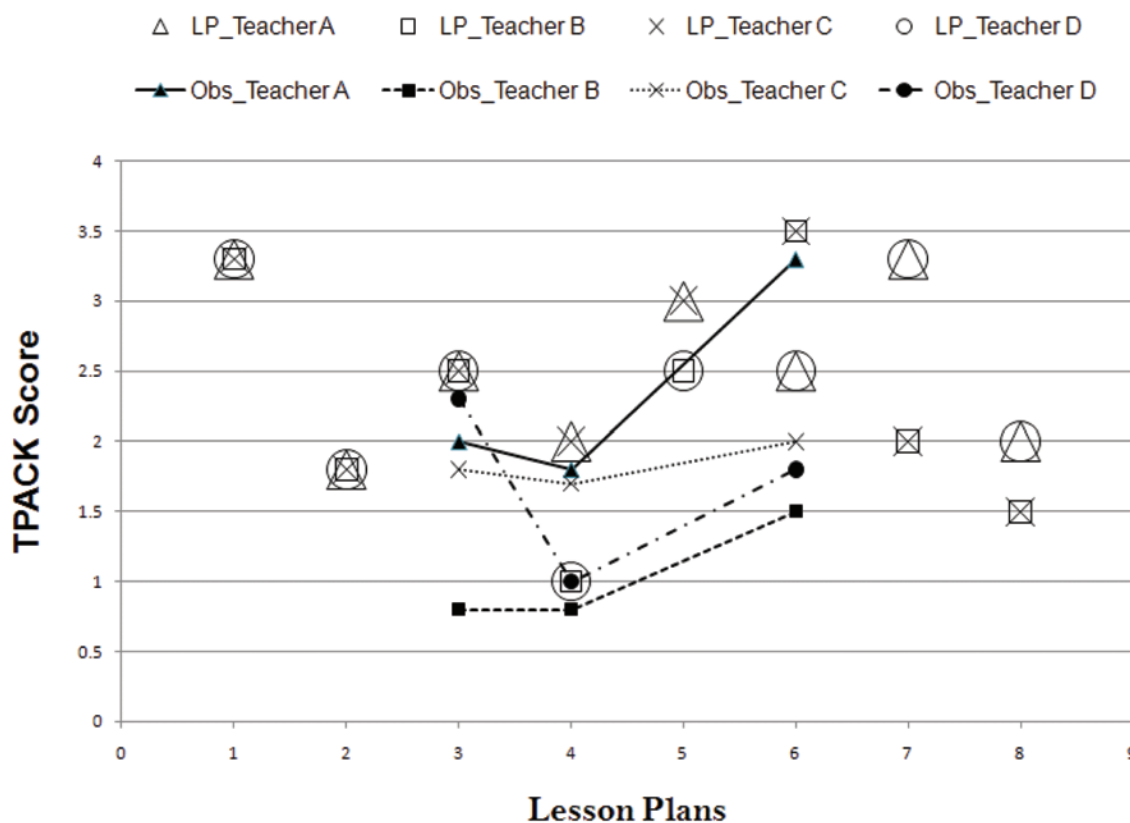
the lessons developed and presented in the middle of the semester, with a score of 2.0 (*accepting*) for team AD and 1.5 (*recognizing*) for team BC.

Thus the analysis of TPACK levels of written lesson plans shows that the pattern of changes in teacher TPACK was non-linear. Teachers did not improve with every lesson. Instead they vacillated within a range of two or three lower levels of TPACK over the period of a school year. The factors producing these changes require further investigation. The unusually high TPACK score on the first lesson plan can be explained by the fact that all the teachers worked on it for a long time; furthermore they received extensive feedback from the group facilitator. With the exception of the first lesson, the highest TPACK score achieved by the teachers in the Spring was on average higher than the highest score of TPACK in the Fall. The lesson plans throughout the year ranged from *Recognizing* (1) to *Adapting* (3). Teachers did not get to the *Exploring* or *Advancing* (5) levels. This is represented by the fact that the teachers only adapted personal experiences that they have had in their learning by replacing traditional approaches with technology. The transition to higher levels of TPACK requires teachers to envision on their own how curriculum might be taught with the technology. At the highest, *Advancing* level, teachers actually challenge the traditional curriculum by engaging students in learning quite different topics using the technology, at the same time eliminating some of the topics traditionally taught. At this level, teachers recognize that perhaps learning mathematics in the traditional way may be skeptically confronted, and that important novel topics may be presented using the newly available tools.

Analysis of Classroom Observation Narratives

Teachers were observed in December, February, and March by one or two observers. The

Figure 3. Teacher TPACK scores on written lesson plans and classroom observations



classroom observation narratives were assessed using the *TPACK Levels Rubric* by the same two external experts. The overall TPACK scores for the observations are shown in Figure 3.

All four teachers worked together in the first three lessons and worked in pairs on the remaining five lessons making a total of 13 different lessons developed but each teacher worked on eight of them. Figure 3 shows the TPACK level scores for the eight lessons for which each teacher participated labeled LP_TeacherX as well as scores for the observations of each teacher teaching three of those eight lessons labeled Obs_TeacherX. Note that since all four teachers worked together in the first three lessons that all their scores are the same on the graph. Starting

with lesson four, the teachers worked on lessons in pairs and the TPACK level scores diverged. Each teacher's TPACK score can be tracked across the eight lessons. The TPACK score for Teacher A remained relatively high across all the lessons. As seen in Figure 3, teacher A reached the highest level of TPACK over the course of the year (score of 3.3, *adapting* level). Only 0.1 off the same level was teacher C (score of 2.9, *level accepting*). On the contrary, teacher D reached *accepting* level as his best (score of 2.3) and teacher B only achieved *recognizing* level (score of 1.5). Overall, following the same pattern as that of the lesson plans, teacher's observation scores vacillated within a range of the first three levels of TPACK for a whole year.

Comparisons of TPACK Levels of Lesson Plans and Classroom Observation Narratives

In addition to analysis of lesson plans, PD presentations, and classroom observations, we compared changes in the TPACK level of classroom observations to scores a teacher received on the lesson plans developed by the team that included the particular teacher.

During the December observation, Teacher A demonstrated how to use the handheld to explore linear functions, led students to explore linear functions by modeling the work with the technology, and then gave students an opportunity to apply what they learned to new problems, all the while assessing their work by asking students to explain their work. The way students handled technology clearly indicated that they had been using TI-Nspire. Students were enthusiastic and engaged, and the teacher provided them with a lot of guidance and help when they worked independently. Thus her classroom observation score was 2.8, slightly above the lesson plan score of 2.5, both at *accepting* level (Figure 3). During the February observation, the same teacher used TI-Nspire for teacher demonstrations and student practice. Students were comfortable with the basic technology skills, so the lesson focused on development of concepts through mostly teacher-led activities. The interactive and dynamic features of TI-Nspire were not utilized. This particular lesson plan was only at the *recognizing* level, with a score of 1.5, and the teacher was not able to improve the integration of technology in her teaching, receiving a classroom observation score of 1.8. During the March observation, she conducted by far her best of three lessons, one that sustained motivation and carried through exploring, experimenting, and practicing integrating technologies as mathematics learning and teaching tools. In this lesson she used Data and Statistics Application with points already graphed, but without variables selected. When students started to select independent and

dependent variables, the dots on the graph started to line up, producing a tremendous visual impact on them. The next strong impact was produced by the movable line. These two TI-Nspire features were critical in getting students' attention and interest. Although the lesson plan itself was at the *accepting* level, the teacher was able to improve it through teaching. She received a classroom observation score of 3.3, thus moving up to the *adapting* level.

Teacher B's teaching was below the level of the lesson plans on all three lessons. Even at the lowest level of technology integration for the written lesson plan, she was not able to integrate technology into her lessons (Figure 3).

During the December observation, teacher B used TI-Nspire in her classroom for the first time. She could not help students with even basic skills questions about using the handheld. During class she spent most of the time trying to maintain discipline, and she blamed technology for having problems with classroom management. Her main focus was on procedural skills. The teacher presented a very negative attitude towards TI-Nspire in class. For example, when students had basic technical questions and required help, she wasn't able to help. At one point she commented aloud, "I knew it was not going to work." The negativity evidently influenced the students' attitudes towards the technology. The February observation revealed that teacher B used the TI-Nspire only when observed; consequently her students had a hard time using the technology for learning. Most of the lesson was spent on "pushing buttons" and unsuccessful discipline techniques. Students appeared distracted and disengaged. During the March observation, major changes seem to have occurred. The atmosphere in her class was different. The teacher and the students used TI-Nspire technology to explore trend lines in a real-life situation. Several students commented, "I like it," while engaged in the activity. The teacher had fewer problems with classroom management. She still had difficulty with pacing the lesson and was

not able to finish the planned activities within the allotted time. She also experienced some technical problems, and she still didn't seem confident in general about the technology. Teacher B reached level *recognizing*, supported by the TPACK score of 1.5 for the third observation.

Teacher C received lower classroom observation scores than lesson plan scores in December and February, but taught at the same level as the lesson plan by the middle of the Spring semester in March (Figure 3).

In December and February, teacher C's observations indicated that her lessons lacked proper management of classroom technology. Although she intended to focus on conceptual skills in learning mathematics, she did not effectively implement technology to achieve the goal. A lot of class time was spent on teaching technology rather than mathematics. In the second lesson plan, the technology was integrated synergistically into planning, but was not directly implemented into the actual lesson. This puts teacher C at the *recognizing* level for both lessons. Her third observed lesson, on the other hand, showed a considerable improvement. The technology was used as an integral part of the lesson, for demonstration, hands-on learning, student independent exploration, and assessment of student understanding of mathematics concepts. Students appeared to enjoy the class. The lesson again ran short due to a problem of time management, thus the students did not have an opportunity to apply what they learned. Overall, however, the observation received the score of 2.9, almost at *adapting* level.

Teacher D's observations indicated that he taught the first two lessons at the same level as the lesson plan, but did not teach to the level of the lesson plan on the third lesson (Figure 3).

In December, teacher D did not manage time well and as a result converted the lesson into a teacher-directed lecture that lacked interaction with the students. That put teacher D at the *accepting* level with a score of 2.3. During the February observation, the same teacher did not use software

or the handheld himself. His students worked on handheld units following written instructions that were projected onto the SmartBoard. Many students were not sure what to do, seemed confused, and did not get much help from the instructor. There was no development of mathematical knowledge in the lesson, which put teacher D at the *recognizing* level of TPACK. In March, the teacher tried to provide the students with an opportunity to explore subject matter on their own. However, with the hitherto rare use of TI-Nspire technology in class, students were confused and could not follow written instructions. The lack of teacher guidance and poor time management led to students struggling to understand the technical tasks before them and never getting to the next stage, focusing on constructive, discovery-based activities. The teacher tried to recover the situation in the middle of the lesson, but there was not enough time left in the class. This placed teacher D at a March *recognizing* level score of 1.8.

In conclusion, it is evident from Figures 1 and 3 that:

1. The quality of teaching with TI-Nspire technology followed the same pattern as the quality of technology integration presented in the lesson plans: all teachers had higher scores in mid-semester and lower scores at the beginning and the end of the semester.
2. Teachers A, B, and C improved quality of technology integration from the Fall to the Spring semester, which followed the general pattern of the lesson plan TPACK levels. However, teacher D's level declined. A possible explanation for the decrease in teacher D's scores is that he serves as the Assistant Principle for Mathematics at the school, and his administrative duties prevented him from focusing on the PD activities. As a result he did not benefit from the program, this especially reflected especially in his classroom observation scores.

- Only teacher A demonstrated teaching at the same TPACK level as the lesson plans for all three observed lessons. Observations for the rest of the teachers were either at the same level as the lesson plans or below.

Analysis of Student Achievement

The mean scores on the initial school assessment for the students in all four classes were analyzed using one-way ANOVA. The test indicated that there was no significant difference in the scores, so the groups were considered equivalent at the beginning of the school year, before the treatment.

Student achievement at the end of the year was analyzed using scores and passing rates on the Regents Algebra exam that students took in June. Analysis of scores indicated that the average score teacher A students was the highest, followed by teacher C students, followed by teacher D students and finally, teacher B students (Table 5). This pattern was consistent with the TPACK level achieved by each teacher during the year: teachers with higher TPACK level had students with higher average score on the exam showing medium effect size ($\omega^2 = 0.074$). However, a one-way ANOVA of the Regents scores indicated no significant difference among the students of the four teachers – possibly due to the small sample size of the study. With a larger sample, the trend might become significant.

Analysis of passing rates on the Regents exam was performed for both local diploma level (score

of 55 or above) and Regents diploma level (score of 65 or above). The percentage of students achieving passing rates is shown in the Table 5.

As it is evident from the data, the percentage of students who passed the Regents exams at both levels is higher for the teachers with higher overall TPACK level, as determined by the highest observation TPACK score achieved during the year.

CONCLUSION AND DISCUSSION

In this chapter we described a year long PD that was provided to four teachers teaching integrated algebra in a New York City public school and its effect on their TPACK development as well as on their student achievement. The context of the PD was the authoring of curriculum by the teachers that incorporated TI-Nspire technology. In particular, two questions were examined:

- To what extent is a designed model of PD, in which teachers author original materials that integrate TI-Nspire technology, associated with changes in teachers' TPACK levels as measured by teaching artifacts (lesson plans and TI-Nspire documents) and observed behaviors (workshop presentations and classroom teaching)?
- Is there a relationship between teacher TPACK levels and student achievement?

Table 5. Student Achievement Descriptive Statistics

Teacher	N	NYS Regents Algebra Exam		Local Diploma
		Mean (SD)	Pass Rate	Pass Rate
A	22	61.14 (9.896)	45.5%	77.3%
B	11	55.82 (10.048)	27.3%	54.5%
C	16	59.88 (15.478)	50.0%	68.8%
D	18	56.06 (14.980)	27.8%	55.6%

DISCUSSION OF STUDY RESULTS

The first conclusion that we can draw from our results indicates that the scores of the observed lessons were either at the same level or lower than the scores of the lesson plans (except one out of the eight). These results underscore the importance of lesson preparation. It seems unlikely that a teacher can teach a better lesson than the one they prepared. In order to have high quality teaching, it seems imperative to prepare high quality lesson plans. Further, the importance of planning can be noticed from the score that the teachers received for their first lesson plan. The teachers received the highest score for the lesson that they spent the most time preparing and the one that they received the most feedback from the group facilitator. Therefore we recommend collaborative work, time, and guidance as necessary components for successful lesson planning. In fact, Olebe, Jackson, and Danielson (1999) recommend such components as necessary in creating better schools.

Further, one of the characteristics of the present study was that during the lesson planning workshops for PD, the teachers were actually authoring the content of their lessons. Content authoring is something that all teachers do to various degrees (Ainsworth, & Fleming, 2006); it can just include the customizing of a textbook for a particular classroom to the actual development of activities, as was done in the present study. Moreover, the authoring never occurred by one teacher but was always the work of either the whole team or a pair of teachers. The fact that the scores teachers received for lesson planning were higher than the ones received on actual lesson teaching could be attributed to higher quality lessons created by the authoring group, and perhaps the lack of comparable pedagogical skills by individual teachers as apparent in the classroom itself (i.e., PCK might have been lower than other skills). Such an assumption requires further testing through studies that will assess the different components

of TPACK separately. Overall, the finding that teachers receive higher scores on lesson plans than on classroom teaching – in other words, the fact that teachers do not teach better than their plans – underscores the importance of lesson planning. If teachers do not exceed in class the lesson that they have prepared, they can teach at best at the same level of TPACK as the lesson plan, or they teach below that level.

The second conclusion relates directly to teacher TPACK development. Analysis of TPACK levels of lesson plans and classroom observations showed two things. First, after one year of PD, none of the teachers reached the two highest TPACK level (Exploring or Advancing). Adapting was the highest level attained. This represents the fact that teachers were only able to adapt technology to the traditional curriculum, by replacing tools used to solve standard problems and tasks with technology. The transition to higher levels of TPACK requires teachers to change what curriculum they teach and how they teach with the technology. Further investigations are necessary to explore the effect prescribed curriculum and rigid pacing calendar typical of public school on teacher's ability to challenge the traditional curriculum when new tools become available. Second, the pattern of growth of TPACK is non-linear – that is, teachers did not improve with every lesson. Instead they vacillated within a range of the first three levels of TPACK for a whole year. Since ours is a pioneer study, no other empirical study has as yet investigated the question, so we don't know if these finding would occur again in replicated studies. As things stand, it is difficult to interpret these findings at this time, due to the lack of empirical evidence in the field. Niess (2010) makes note of the progressing through levels of acceptance and implementation as teachers develop their TPACK. She took it upon herself to describe the differences and how they influence a teacher's growth and development in TPACK for teaching within a technology-enriched curriculum. Such descriptions came out of teacher observations, but the TPACK levels were never

used to assess an entire group of teachers. Thus it's difficult to compare our teachers' respective TPACK development with other samples.

The third conclusion relates to our study's second research question, that is, whether there is a relationship between student achievement – through scores and passing rates on the NY Regents exam – and teachers' TPACK level. Results indicated that although there were no significant differences in NYS Regents exam scores, teachers with a higher TPACK level taught students who obtained a higher average score on the Regents exam. A medium effect size however, suggested that the lack of significant differences might be due to the small sample size of the study. With a larger sample, this trend could become significant. It is also supported by the fact that the percentage of students who passed the Regents exams at both levels is much higher for the teachers with higher overall TPACK level, as determined by the highest observation TPACK score achieved during the year. We can thus, tentatively conclude that possibly a teacher's TPACK level can predict his/her students' passing rates in the Regents. The small number of teachers in the study does not allow analysis of between group variance which presents a threat to the internal validity of the study. If such a pattern can be observed with larger samples it will provide more evidence that the TPACK Rubric has predictive validity. Thus, the conclusion about the relationship between teacher TPACK and student achievement is tentative and requires further investigations with larger sample that will allow for analysis of between group variance.

Discussion on the Development and Validation of the TPACK Levels Rubric

The significance of the study doesn't just lie on the findings presented above but also on the fact that the authors developed and did the preliminary testing of the *TPACK Levels Rubric* which was used to assess both teacher artifacts and teacher

behaviors. TPACK is a conceptual framework that applies to technological, pedagogical, and content knowledge of teachers in general (Margerum-Leys, & Marx, 2002; Mishra, & Koehler, 2006; Niess, 2005a; Pierson, 2001; Zhao, 2003). In order to be able to assess teacher TPACK, the construct has to be defined within specific context. Of course the quantification of any construct, in this case TPACK, entails a reductionist process. Does a single TPACK score reflect the complexities of teacher knowledge? In our study we defined this construct for teachers teaching Integrated Algebra with TI-Nspire technology. When specific context is defined, a teacher's growth in integrating technology into teaching of a specific content with specific technology could be assessed. Having one instrument that measures such knowledge both through teacher artifacts and classroom observations has important implications and can enhance teacher preparation and training. We don't claim that the TPACK score that a teacher receives is a number that can be used for every subject and all technology. The TPACK score that a teacher receives when teaching algebra with graphing calculators, is not generalizable to teaching algebra with different technology, or to teaching different subject with TI-Nspire technology. The score is context specific and it is valuable only as such. In this study our goal was to measure the effects of content authoring in algebra taught with TI-Nspire technology on the growth of TPACK – and the score represents just that. Finally, the *TPACK Levels Rubric* tested and used in this study is specific to the subject of mathematics and TI-Nspire technology only. It can be generalized to assess teachers' TPACK level for in-service and pre-service teachers and college faculty teaching any level of mathematics in any geographic setting, as long as TI-Nspire technology is used in the classroom. The rubric can be easily adapted to be used in a classroom where mathematics is taught with different instructional technology.

While researchers in the area of TPACK have done a good job describing the body on knowl-

edge that this construct entails (Margerum-Leys, & Marx, 2002; Mishra, & Koehler, 2006; Niess, 2005a; Pierson, 2001; Zhao, 2003) there has not yet been a tool that measures TPACK both through artifacts and observed behaviors. Most instruments are self-report surveys (e.g., Schmidt, Baran, Thompson, Mishra, Koehler, & Shin, 2009; Archambault, & Crippen, 2009). Therefore, a single instrument that actually assesses teacher artifacts as well as behaviors is needed. But the process of validation of this instrument for now should be considered preliminary due to the small sample size of the study. We confirmed that the rubric has moderate inter-rater reliability and content validity. Further, we have the initial indication that the *TPACK Levels Rubric* has a potential for predictive validity since the study determined the higher TPACK level could have been one of the factors related to higher average scores on the Regents exam. This new instrument requires future studies with larger randomized samples that will re-examine reliability and address the instrument's internal consistency. Further, more evidence needs to be provided for content, predictive as well as construct validity of the rubric.

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ENDNOTE

- ¹ TI-Nspire™ is a registered trademark of Texas Instruments

APPENDIX

Table 6. TPACK levels rubric for TI-Nspire technology applications

TPACK Components	TPACK Levels				
	Recognizing (1)	Accepting (2)	Adapting (3)	Exploring (4)	Advancing (5)
An overarching conception about the purposes for incorporating technology in teaching subject matter topics.	• TI-Nspire technology is used for motivation, rather than actual subject matter development. All learning of new ideas presented by the teacher mostly without technology. • TI-Nspire activities do not include inquiry tasks. TI-Nspire technology procedures concentrate on drills and practice only.	• TI-Nspire technology is used for motivation, rather than actual subject matter development. Larger part of TI-Nspire technology use is for demonstrations, which include presenting new knowledge. • TI-Nspire activities do not include inquiry tasks. TI-Nspire technology procedures concentrate on teacher demonstration and practice.	• Teacher is one who is using TI-Nspire technology in a way that is new and different from teaching without this technology (dynamic nature, linked representations) and used for learning new knowledge by students) • TI-Nspire activities include inquiry tasks. TI-Nspire technology procedures concentrate on mathematical tasks with connections and on inquiry activities that use or develop connections.	• Larger part of TI-Nspire technology use is by students who explore and experiment with it for new knowledge and for practice • TI-Nspire activities include inquiry tasks. TI-Nspire technology procedures concentrate on mathematical tasks with connections and doing mathematics – and on inquiry activities that use or develop connections (especially between multiple representations).	• TI-Nspire technology tasks provide students with deeper conceptual understanding of mathematics and its processes. • TI-Nspire activities include inquiry tasks of high cognitive demand. TI-Nspire technology procedures concentrate on mathematical tasks with connections and doing mathematics – and on inquiry activities that use or develop deep mathematical knowledge representing connections (especially between multiple representations) and strategic knowledge.
Knowledge of students' understandings, thinking, and learning in subject matter topics with technology	• TI-Nspire technology is used primarily for student practice. • A TI-Nspire document does not present any new material, and only provides space for applications and drills.	• TI-Nspire technology is mostly used for teacher demonstrations or teacher-led student-follow work with technology, it is rarely used for students' independent explorations. Teacher sees the technology as a motivational tool for student rather than a learning tool. • A TI-Nspire document mirrors the structure of the textbook presentation of mathematics without active explorations.	• Teacher focuses on students' thinking of mathematics while students are using TI-Nspire technology on their own – both for learning new knowledge and review of prior knowledge • A TI-Nspire document provides an environment for students to do mathematics with teacher guidance.	• TI-Nspire teacher focuses on students' mathematics conceptual understanding and serves as a guide of student learning with technology, not a director. • A TI-Nspire document provides an environment for students to deliberately take mathematically meaningful actions on objects. Teacher guidance is necessary in order for students to see the mathematically meaningful consequences of those actions.	• Teacher facilitates students' high level thinking with TI-Nspire technology (linked representations, reasoning and proofs) • A TI-Nspire document provides an environment for students to deliberately take mathematically meaningful actions on objects and to immediately see the mathematically meaningful consequences of those actions.

continued on following page

Table 6. continued

Knowledge of curriculum and curricular materials that integrate technology in learning and teaching subject matter topics	• Teacher does not use TI-Nspire technology for learning mathematics. • TI-Nspire technology if used is not aligned with one or more curriculum goals.	• Teacher uses standard approach to the curriculum topics with TI-Nspire technology being used as add-on. • TI-Nspire technology is partially aligned with one or more curriculum goals. Teacher has difficulty in identifying topics in mathematics curriculum for including TI-Nspire Technology as tool.	• The TI-Nspire technology is used as a replacement for non-technology based tasks in a traditional curriculum approach. Teacher only adapts experiences that he/she has personally experienced in his/her learning. • TI-Nspire technology is aligned with one or more curriculum goals. Teacher chooses topics from school mathematics curricula; however, TI-Nspire technology use is not always appropriate for the chosen curriculum topics.	• Teacher envisions on his/her own as to how curriculum might be taught with the technology. Students are given problem solving tasks with TI-Nspire technology and are asked to expand math ideas on the basis of TI-Nspire technology explorations. • Technology is aligned with curriculum goals. Teacher chooses important topics of school mathematics curricula and technology use is appropriate for the chosen curriculum topics.	• Teacher uses TI-Nspire technology in a fully constructive way, including tasks for development of higher level thinking and deepening understanding of mathematics concepts. Teacher challenges the traditional curriculum - engaging students in learning quite different topics with the technology and eliminating some of the topics that have traditionally been taught. • TI-Nspire technology is strongly aligned with curriculum goals. Teacher chooses essential topics of school mathematics curricula. TI-Nspire technology use is effective for the chosen curriculum topics.
<i>Knowledge of instructional strategies and representations for teaching and learning subject matter topics with technologies</i>	• Teacher focuses on how to use TI-Nspire technology rather than how to explore math ideas, using teacher-directed lectures followed by student practice. • TI-Nspire document provides students only with opportunities for drill and practice.	• The instructions are teacher-led. Teacher structures lesson plan with limited student explorations with TI-Nspire technology. • TI-Nspire document is not built around learning objects and does not promote student reflection.	• Teacher uses deductive (teacher-directed) approach to teaching with TI-Nspire technology to maintain control of the progression of the activities. • TI-Nspire document is built around learning objects but does not promote student reflection – especially the posing of questions for sense-making.	• Teacher uses various instructional strategies (deductive and inductive) and focuses on students thinking about mathematics. Teacher's use of TI-Nspire technology is beyond traditional approaches to curricular topics. • TI-Nspire document is built around learning objects and must explicitly promote student reflection – especially the posing of questions for sense-making.	• Teacher focuses on students' hands-on and experimentation of new mathematics ideas with TI-Nspire technology, and focuses on conceptual development. • TI-Nspire document is built around learning objects and must explicitly promote student reflection – especially the posing of questions for sense-making and reasoning, including explanation and justification.

Chapter 14

Making the Grade: Reporting Educational Technology and Teacher Knowledge Research

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ABSTRACT

This chapter examines issues surrounding the design of research in educational technology and teacher knowledge. The National Research Council proposed a set of principles for education research that has not been applied consistently to teacher knowledge and education technology research. Although some studies address reliability of measures, few adequately address validity or threats to validity or the trustworthiness of their designs or findings. Special attention is given to the need for explicit connections between the study purpose and guiding theoretical frameworks and previous research. This volume provides examples of studies addressed these design issues and includes a checklist of questions and additional resources to aid future researchers in developing rigorous, scientific research.

INTRODUCTION

This handbook shares a variety of educational technology research studies to demonstrate not only current trends in educational technology, but also current practices of educational research. Education research is a highly contested field

(Shavelson & Towne, 2002) and has been criticized for a lack of structure and rigor (Brickhouse, 2006; Levine, 2007; National Academy of Sciences – National Research Council [NAS-NRC], 1999): “In no other field are personal experience and ideology so frequently relied on to make policy choices, and in no other field is the research base so inadequate and little used” (NAS-NRC, 1999, p.1). This chapter examines evidence standards

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for reporting research and presents a checklist to help future researchers adhere to the National Research Council's six principles for conducting rigorous, scientific research.

Evidence Standards

Extensive efforts have been made to respond to the challenge laid out by NAS-NRC by improving the rigor of educational research, increasing the relevance of educational research for practitioners, and defining characteristics of high quality evidence. The No Child Left Behind Act (NCLB, 2001) defined scientifically-based research as requiring

the application of rigorous, systematic, and objective procedures to obtain reliable and valid knowledge relevant to education activities and programs; and includes research that (i) employs systematic, empirical methods that draw on observation or experiment; (ii) involves rigorous data analyses that are adequate to test the stated hypotheses and justify the general conclusions drawn; (iii) relies on measurements or observational methods that provide reliable and valid data across evaluators and observers, across multiple measurements and observations, and across studies by the same or different investigators; (iv) is evaluated using experimental or quasi-experimental designs in which individuals, entities, programs, or activities are assigned to different conditions and with appropriate controls to evaluate the effects of the condition of interest, with a preference for random-assignment experiments, or other designs to the extent that those designs contain within-condition or across-condition controls; (v) ensures that experimental studies are presented in sufficient detail and clarity to allow for replication or, at a minimum, offer the opportunity to build systematically on their findings; and (vi) has been accepted by a peer-reviewed journal or approved by a panel of inde-

pendent experts through a comparably rigorous, objective, and scientific review (p. 1964-1965).

Criteria iii and iv speak to the quality of evidence used to make inferences. The six Scientific Principles from the National Research Council (Shavelson and Towne, 2002) mirror the NCLB criteria and can serve well to guide researchers in their pursuit of educational research.

1. Pose Significant Questions That Can Be Investigated Empirically
2. Link Research to Relevant Theory
3. Use Methods That Permit Direct Investigation of the Question
4. Provide a Coherent and Explicit Chain of Reasoning
5. Replicate and Generalize Across Studies
6. Disclose Research to Encourage Professional Scrutiny and Critique

Whitehurst (2002) claimed that the wide array of evidence sources in research do not provide the same level of inferential validity. He laid out a hierarchy of six evidence levels from most valid for inference to least: "(1) randomized trial (true experiment), (2) comparison groups (quasi-experiment), (3) pre-post comparison, (4) correlational studies, (5) case studies, and (6) anecdotes" (p. 15). This hierarchy was not intended to narrow the scope of research as many have contended (e.g., Barone, T., 2007; Brickhouse, 2006; Donmoyer, R., & Galloway, F., 2010; Phillips, 2005; Schoenfeld, 2006; & Viadero, D., 2007), but to provide guidelines for evaluating evidence presented through research. Shavelson and Towne (2002) agreed with this principle: "What makes research scientific is not the motive for carrying it out, but the manner in which it is carried out" (p. 20). To that end, research supported through the Institute of Education Sciences includes five different goals, permitting a wide array of methodologies that have been determined to align with a particular type of evidence desired (IES, 2010). Only two

of these goals require either a randomized trial or comparison groups. The goal structure provides a framework through which a study can progress, beginning with exploration of malleable factors that may be potential targets of intervention and the development of an appropriate intervention, then testing the efficacy of the intervention and assessing the ability of an intervention to be effective at-scale. The measurement goal recognizes the need for validated instruments to reliably measure intended outcomes. These guidelines provide a way of thinking about how to collect valid and reliable evidence in education research.

In striking contrast to these evidence standards, Ronau et al. (2010) found that the evidence relied upon in educational technology research follows an exact reverse order to Whitehurst's (2002) quality of evidence hierarchy. Instead, 50.34% provided anecdotal support for integrating technology into teaching, and another 12.93% proposed theories based on non-systematic reviews of literature for a total of 63.27% articles distributing "evidence" with no systematic research foundation. Qualitative studies (including case studies, ethnographies, interviews, focus groups, observations, and action research) accounted for 26.53% of the sample. Quantitative and mixed methods studies (including experimental, quasi-experimental, pre-post comparisons, and correlational studies) accounted for the remaining 10.20% of the sample.

Ronau and Rakes (this volume) found that teacher knowledge studies suffer from a similar lack of rigorous evidence. Research on teacher knowledge has largely remained in its infancy due to a lack of coherent structures and organizing frameworks. Rather than developing a coherent framework for teacher knowledge, a myriad of frameworks were found that attempted to capture only some components of the knowledge needed for teaching. Unfortunately, no structure has yet organized these components into a structured whole that can be used to advance the field. As a result, few studies exist that empirically mea-

sure the effects of teacher knowledge on student outcomes.

Measuring Teacher Knowledge

The lack of reliable, valid measures of teacher knowledge may be one reason for such deficits:

Researchers have used a variety of different proxies for teacher knowledge and/or practice, many of which are relatively gross indicators: college majors, grade point averages, and retention (Cochran-Smith & Zeichner, 2005; Goldhaber & Brewer, 2000; Guyton & Farokhi, 1987; Monk, 1994; Wilson, Floden, & Ferrini-Mundy, 2001). Teacher tests are equally problematic (Wilson & Youngs, 2005). In the larger domain of research on teacher learning, instruments used to measure changes in teacher knowledge range dramatically in focus, quality, purpose, and utility (e.g., Kennedy, 1999; Porter, Youngs, & Odden, 2001; Seidel & Shavelson, 2007). Although variation in detail and perspective is desirable, there are few well-validated instruments. Thus, for professional development programs interested in collecting professionally responsible, publicly credible evidence of what teachers learn, there are few trustworthy methods or measures. (Bell, Wilson, Higgins, & McCoach, 2010, p. 483).

Hill (2010) also noted difficulties in measuring even a small component of content knowledge: "Even within relatively narrow topics, such as fractions, it is common for studies to focus on only a subset of problem types...there are also questions regarding which dimensions of mathematical knowledge for teaching teachers find easier and which they find more difficult" (p. 517). In developing a measure for mathematical knowledge for teaching (MKT), Hill noted that the balance of components within this facet of teacher knowledge remains unknown. We contend that if the nature of a highly-studied facet of teacher knowledge such as MKT remains

unknown, much more work awaits areas such as knowledge of Individual and Environmental Context, Orientation and Discernment. As Ronau and Rakes (this volume) pointed out, these aspects of teacher knowledge are highly complex as unique constructs, and interactions of aspects (such as TPACK) are yet again unique constructs that have yet to be measured validly and reliably. Much of the work, therefore, in educational technology and teacher knowledge has remained largely at the exploratory, descriptive phases, and has not even progressed to the exploration of malleable factors, much less the development of targeted interventions for improving teacher knowledge. The result has been that approximately 28% of all teacher knowledge articles examine the role of teacher knowledge in developing and maintaining high quality teachers and yet, “Two problems threaten teacher education’s credibility: It has minimal impact on the teaching practices of its graduates, and no one knows how to fix it” (Hiebert, 2010, p. 38). Without the development of valid, reliable measures of teacher knowledge, such a fix may be beyond the grasp of the research community.

Several texts have been produced to guide researchers interested in developing psychometrically sound measures (e.g., Allen & Yen, 2001; Crocker & Algina, 2008; Nunnally & Bernstein, 1994; Thorndike & Thorndike-Christ, 2010; Urbina, 2004). These texts provide detailed advice to researchers for issues such as content, construct, convergent, divergent, and predictive validity; and, internal consistency, inter-rater, alternate forms, and test-retest reliability.

Paradigm Wars: What Constitutes Valid Evidence?

Shavelson and Towne (2002) argued that the quantitative/qualitative dichotomous paradigm is a mistaken view and that both can be pursued vigorously and that the categorization of research as basic and applied is outmoded. Creswell (2002) pointed out that qualitative inquiry requires as

much attention to reliability and validity as quantitative inquiry. Teddlie and Tashakkori (2009) agreed with Shavelson and Towne that qualitative and quantitative inquiry methods do not form a dichotomy and instead considered them to be a continuum. The test of any conjecture in education must therefore be based on the best available data, whether quantitative or qualitative data (Shavelson and Towne, 2002). This approach closely aligns with Phillips (2005) who indicated that “skeptical communities existed ... were open to being convinced by a competently produced web of argument embodying evidence that resulted from the deployment of many methods (rather than from the use of a single ‘gold standard’ method)” (p. 595).

Shadish, Cook, and Campbell (2002) developed a framework for constructing research designs based on quantitative measures, giving special attention to the threats to validity inherent to research design choices and the trade-offs required in designing a study (e.g., many studies focus on internal validity at the expense of external validity and vice versa, depending on the goal of the research). Similarly, Creswell (2007) and Patton (2002) have outlined important decisions to be made by researchers conducting exploratory studies using qualitative methods. For both paradigms, the validity of the evidence produced is paramount. Teddlie and Tashakkori (2009) argued for a mixed-methods approach, intertwining quantitative and qualitative inquiry into a cohesive, complementary set of investigations. Such an approach allows researchers to combine the explanatory powers of each inquiry paradigm thereby adding validity to inferences made from each type of evidence to answer the questions of interest.

As primary studies accrue about a particular topic, research can also be significantly advanced by systematic reviews. As with primary analysis, these studies can be conducted qualitatively or quantitatively, depending on the nature of the available evidence. For research design issues unique to research synthesis, we refer readers to

Table 1. Checklist for reporting research from educational technology and teacher knowledge studies

<i>Principle 1: Pose Significant Questions That Can Be Investigated Empirically</i>
1. Does the introductory narrative clearly and succinctly identify the purpose of the study?
2. Can readers distinguish the research questions from the introductory narrative?
<i>Principle 2: Link Research to Relevant Theory</i>
3. Does the manuscript identify a guiding theoretical framework for the study?
4. Does the manuscript explicitly state how the guiding theoretical framework informed the methodology, analysis, and interpretation of the study?
5. Does the literature review include explicit connections between the research questions and purpose of the study with the chosen methodology?
6. Does the literature review provide an argument for the study; that is, it explicitly makes a case for present study, clearly justifies the conceptual framework used to guide the study, demonstrates how the study builds from previous research, and shares how the study contributes to a need in the current research foundation.
7. Are the connections to prior research re-visited in the discussion of results?
<i>Principle 3: Use Methods That Permit Direct Investigation of the Question</i>
8. Is the research design stated explicitly?
9. Does the manuscript provide a rationale for the type of research being conducted (e.g., quantitative, qualitative, mixed methods)?
10. Are the population specifics, sampling techniques, characteristics of the sample, and grouping assignment techniques stated explicitly?
11. Are threats to validity from the sample addressed explicitly?
12. Does the manuscript explicitly discuss how the research methodology balances relevant threats to validity?
13. Do the chosen data analysis techniques align with the research questions and purpose of the study?
14. Does the discussion of the results clearly address the research questions?
15. Does the data analysis directly support all conclusions made in the discussion?
<i>Principle 4: Provide a Coherent and Explicit Chain of Reasoning</i>
16. Are the logical connections between the research questions, methodology, analysis, and discussion stated explicitly? (i.e., Literature → Framework → Question → Design → Measures → Outcome → Framework → Literature)
<i>Principle 5: Replicate and Generalize Across Studies</i>
17. Is the necessary data reported to compare future replication studies with current results (e.g., means, standard deviations, sample sizes, effect sizes)?
18. Does the manuscript describe the measures used, the reported validity and reliability from previous studies (if applicable), and validity and reliability statistics from the current sample?
<i>Principle 6: Disclose Research to Encourage Professional Scrutiny and Critique</i>
19. Has the study been presented at one or more peer-reviewed conferences?
20. Has the study been submitted to a peer-reviewed book, journal, or other publishing agency?

Cooper (1998), Cooper, Hedges, and Valentine (2009), and Lipsey and Wilson (2001).

Reproducing the guidance found in the texts mentioned above is beyond the scope of this chapter. When used as a supplement to these excellent texts however, the checklist provided in Table 1, aligned with the six NRC principles, may provide researchers with an overview of the issues to be considered when designing studies involving educational technology or teacher knowledge.

RESEARCH DESIGNS IN THIS HANDBOOK

The chapters compiled in this handbook include a wide array of techniques, including case study, meta-analysis, research synthesis, and randomized control trials. These chapters include information about reliability and validity, tying the design of the research to the interpretation of the results. For example, Pape et al. (this volume) examined

classroom connectivity technology through a variety of teacher knowledge lenses. The literature review is not exhaustive, nor would readers desire an extensive review; instead, the development of the intervention and the appropriate frameworks focused exclusively on explaining why the study was carried out as described in the methodology section. The study reported inter-rater reliability coefficients and thus minimized concerns that the measures employed in a phone interview may have been unreliable. Because this study compiled the results from a series of studies, each statistic from the previous study was not included (e.g., exploratory factor analysis results), but references were provided to allow readers to backtrack as needed. The authors also included reliability coefficients for all student measures and included a reference for a study in which the construct validity of the instrument had been investigated. Finally, all inferential statements in the discussion and the framework of principles for classroom connectivity technology integration were tied directly and explicitly to the reported data.

The review conducted by Koehler, Mishra, and Shin (this volume) examined research from a very different perspective. Instead of synthesizing a line of research, the authors compiled studies that attempted to measure TPACK. Because of different methodology, the information needing to be reported was also quite different from the Pape et al. study. In this case, the lines of research conducted by Koehler et al. were traced in the literature review to explain how their prior research led them to this study. They also reported inter-rater reliability, but Koehler et al. also needed to include information about the databases searched to establish the representativeness of their sample of studies. By including gray literature in their sample (i.e., unpublished papers accepted for their scientific merit rather than significant effects such as dissertations, peer-reviewed conference papers), they minimized selection bias threats to the validity of their study — the inclusion of only published studies has been shown to over-estimate

effect sizes (Cooper, 1998). By including information about decisions made throughout the coding process, high quality evidence was produced that allowed the authors to offer advice for future efforts to measure TPACK that can strengthen the research field.

A third approach used by studies in this handbook consisted of case study methodology. For example, Lee and Manfra (this volume) examined issues arising from the planned integration of technology in social studies. The authors made a case through their literature review that the dynamics of such issues are highly localized and not easily generalizable, thereby lending validity to the case study approach for their questions of interest. They therefore focused on the relevance aspect of validity, concentrating their discussion on cases involving Web 2.0 technologies. Their analyses of the cases were highly structured around well-defined theoretical frameworks as was the discussion of the findings.

Lyublinskaya & Tournaki (this volume) sought to evaluate a year-long teacher professional development program involving TI-Nspire graphing calculators by measuring teacher's TPACK knowledge through lesson plans and classroom observations and comparing those measures with student achievement on state examinations. This example demonstrates a case design with clear research questions, justification for the study, alignment with a theoretical framework, and results clearly tied back to the literature. Through their literature review, the researchers demonstrate not only that there existed no instrument available to measure the TPACK knowledge that was important for their study, but also that the constructs that they needed to measure have been defined. They then used that base to form the *TPACK Levels Rubric*, which the authors validated with experts in the field. The authors also report the inter-rater reliability of this instrument.

Similar examples of research design can be found in other chapters in this handbook. These exemplars highlight a wide range of designs and

the need for scientific processes to inform each. As the fields of educational technology and teacher knowledge research advance, the degree to which authors concentrate on issues of design and scientific reporting will dictate the quality of evidence available to guide future research and practitioner decisions.

We selected the six Scientific Principles from the National Research Council (Shavelson and Towne, 2002) to guide this volume because they proposed that the quality of research should be based on the design of the study rather than the methodology, stepping beyond a qualitative-quantitative dichotomy approach to educational research. Although we have reported an overabundance of qualitative designs within educational technology and teacher knowledge research (Ronau & Rakes, this volume; Ronau et al., 2010), we do not intend to negate the importance of such efforts: Instead, we suggest that such designs should not be the stopping point for a line of research and that a more balanced approach to research by the education community at large is needed to advance the field. We were perplexed by the large number of studies we were unable to use in our research syntheses because of critical missing information that prevented a valid interpretation of results. We found many studies that presented well-developed, coherent arguments; unfortunately, these studies were counterbalanced by an even larger number of studies that lacked research questions or even a description of purpose. Too often, we found studies with theoretical frameworks cited, but the logical argument for how such frameworks guided the study was often missing. Very few studies addressed validity of any kind (e.g., content, construct, concurrent or predictive criterion-related, convergent, discriminant), threats to study validity (e.g., internal, external, statistical conclusion, or construct), or any methods for addressing threats to validity (e.g., member checks, triangulation, thick description, design features). Reliability, when addressed, was often limited to Cronbach's alpha measure of

internal consistency. Problems with relying solely on Cronbach's alpha have been well known for over two decades:

It is nearly impossible these days to see a scale development paper that has not used alpha, and the implication is usually made that the higher the coefficient, the better. However, there are problems in uncritically accepting high values of alpha (or KR-20), and especially in interpreting them as reflecting simply internal consistency. The first problem is that alpha is dependent not only on the magnitude of the correlations among items, but also on the number of items in the scale. A scale can be made to look more 'homogenous' simply by doubling the number of items, even though the average correlation remains the same. This leads directly to the second problem. If we have two scales which each measure a distinct construct, and combine them to form one long scale, alpha would probably be high, although the merged scale is obviously tapping two different attributes. Third, if alpha is too high, then it may suggest a high level of item redundancy; that is, a number of items asking the same question in slightly different ways (Streiner & Norman, 1989, pp. 64-65).

Cronbach himself recommended substituting alpha for generalizability theory (G-theory) as a way to measure measurement reliability (Cronbach, Gleser, Nanda, & Rajaratnam, 1972; Cronbach, Nageswari, & Gleser, 1963). Shavelson and Webb (1991) produced a primer to help researchers understand the logic of generalizability theory. Crick and Brennan (1982) designed the software GENOVA to make the computation of G-theory statistics more straightforward. This software is now available as freeware (Brennan, 2001). These efforts have provided an avenue for enhancing the validity of internal consistency reliability analyses.

These findings are similar to those reported by Whitehurst (2002) and helped place educational research in a less than favorable light (e.g.,

Brickhouse, 2006; Lagemann & Shulman, 1999), leading to the development and publishing of the NRC Scientific Principles. Our hope is that this text may provide examples and structures that encourage the production of evidence that might more readily benefit practitioners and researchers. Such enhancement of evidence and the alignment of studies with larger constructs may also help guide future research and foster confidence in educational research.

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* * *

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