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Examining the Quality of Technology Implementation in STEM Classrooms: Demonstration of an Evaluative Framework

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Abstract

Technology applications aligned with science, technology, engineering, and math (STEM) workplace practices can engage students in real-world pursuits but also present dramatic challenges for classroom implementation. We examined the impact of teacher professional development focused on incorporating these workplace technologies in the classroom. Because existing measures primarily use only presence or type of technology as proxies for implementation quality, we developed an expanded framework that incorporated (a) the type of technology used; (b) the degree of alignment to STEM practices; (c) the use of student-centered pedagogical practices; and (d) the degree of relevance to real-world contexts. While our framework successfully described the variation in technology implementation in our study group, we found no statistically significant difference between teachers with and without extensive training on STEM workplace technologies. Our results provide evidence that the framework captures quality of technology use and point to the need for additional research on effective teacher education around technology applications. (Keywords: teacher professional development, STEM workplace technology, measuring quality of technology implementation, technology in classrooms)

Technology use in the classroom has great potential to transform student learning. This is particularly true for science, technology, engineering, and mathematics (STEM) workplace applications of technology, such as robotics, computer modeling and simulations, digital animation, multimedia production, biotechnology, and geospatial technologies. These applications offer opportunities to align classroom activities with real-world STEM practices, while engaging students in authentic investigations and design-based pursuits and promoting student-centered learning and interest in STEM careers (Brophy, Klein, Portsmore, & Rogers, 2008; Hayden, Ouyang, Scinski, Olszewski, & Bielefeldt, 2011; MaKinster, Trautmann, & Barnett 2014; Miller, Chang, Wang, Beier, & Klisch, 2011).

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However, while teachers frequently use technology in their existing instructional practices, they rarely take advantage of its full potential or apply technology affordances to teach in new ways (Bebell, Russell, & O'Dwyer, 2004; Dawson, 2012; Ertmer, Ottenbreit-Leftwich, Sadik, Sendurur, & Sendurur, 2012; Tsai & Chai, 2012; Wright & Wilson, 2011). A recent national survey found that only 24% of 1600 surveyed teachers and administrators reported integrating technology of any type at a high level (based on 20 different benchmarks that ranged from administrative use of technology to classroom uses; MMS Education, 2012).

Integration of STEM workplace applications of technology into K–12 classrooms presents significant challenges for teachers, including steep learning curves and the daunting task of gaining confidence and skill at guiding students through complex activities within the constraints of the K–12 classroom. Intensive professional development focused on increasing teachers' skills and comfort with using technology in innovative ways offers one possible avenue to increase integration of complex STEM workplace technologies into the classroom. The Innovative Technology Experiences for Students and Teachers (ITEST) program, funded by the National Science Foundation (NSF), is one program effort that targets such professional development. It provides teachers with extensive training and support on STEM workplace technologies and ways to implement these technologies in classrooms. More than 50 professional development projects were funded in the first five years of the ITEST program (2003–2008), working with thousands of teachers across the United States. We used the ITEST effort as a case study to explore whether teachers who participated in extensive professional development focused on STEM workplace technologies actually integrated one or more of these technology applications into their classes and whether their technology use aligned with STEM practices, student-centered teaching, and relevance to real-world contexts. Specifically, our study asked the following research question: *How do ITEST teachers differ in their classroom technology implementation compared to teachers who have not participated in an intensive technology professional development?* This comparison is part of a larger research project on ITEST professional development designs and teacher participants (McAuliffe, Parker, & Stylinski, 2013; Parker, Bonney, Schamberg, Stylinski, & McAuliffe, 2013; Stylinski, Parker, & McAuliffe, 2011, 2012a, 2012b).

Literature Review

Professional Development Impacts on Teaching Practices

A number of researchers have identified best practices in teacher professional development, such as active learning, opportunities to reflect on teaching practices, a focus on content knowledge, proximity to classroom practices, and sufficient time to learn and to implement what has been learned (Capps, Crawford, & Constas, 2012; De Rijdt, Stes, van der Vleuten, & Dochy, 2013; Desimone, Porter, Garet, Yoon, & Birman, 2002; Garet, Porter, Desimone, Birman, & Yoon, 2001; Heller, Daehler, Wong, Shinohara, & Miratrix, 2012; Ingvarson, Meiers, & Beavis, 2005; Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2003; Penuel, Fishman, Yamaguchi, & Gallagher, 2007). For example, Supovitz and Turner (2000) found that the intensity and duration of teacher professional development has a significant positive impact on inquiry-based teaching practices and investigative classroom culture. Our prior research characterizing the design of ITEST-based professional development found that project leaders incorporated many of these commonly cited elements of effective teacher education (Stylinski et al., 2011, 2012a, 2012b). The ITEST professional development designs also included elements that are uncommon in regularly cited best practices, and particularly relevant for professional development focused on STEM workplace technologies, such as an emphasis on collaboration, not only among participating teachers, but also including STEM professionals, community members and even students.

Classifying Technology Types

To address our research question, we needed clear definitions of both the type of technology used in the classroom and the quality of how that technology was implemented. There is currently no single accepted taxonomy of technology types, and definitions vary across research studies. Some researchers have defined technology type by a particular hardware such as studies that address computer use (Britten & Cassady, 2005) or use of that hardware, such as computer technologies for instructional purposes (Miranda & Russell, 2011), or student or teacher use of Internet-connected laptop or desktop computers (Ritzhaupt, Dawson, & Cavanaugh, 2012). Inan and Lowther (2010) split technology use into three distinct applications: for instructional preparation, for instructional delivery, and as a learning tool. Lei (2010) divided technology use into subject-specific and social-communication.

Few researchers have included STEM workplace technologies in their definitions of technology types. However, its inclusion is critical given its potential affordances in the classroom and the increasing attention being given to the development of STEM workplace skills and exposure to STEM careers (Feller, 2011; Nugent, Barker, & Grandgenett, 2014). Cox and Graham (2009) used a taxonomy of technology types that addresses the rapidly changing world of technology; they divided technologies into (a) those that are emerging and not yet part of a teacher's repertoire and (b) those that are ubiquitous and commonly used in educational settings. In this study we have expanded Cox and Graham's definition and have identified three technology categories: instructional technology (e.g., clickers or Smartboards), ubiquitous technology (e.g., word processing or Internet search engines), and technologies that are emergent in the classroom (e.g., STEM workplace technologies such as geospatial technologies or robotics). We use this breakout of instructional, ubiquitous, and STEM workplace technologies in our study.

While this taxonomy of technology types provides a useful way to describe what technology is used, it does not effectively capture the quality of technology use in the classroom. Maddux and Johnson (2006) attempted to incorporate quality into their definition; they contrasted Type I technologies, which make traditional teaching strategies "faster, more efficient, or otherwise more convenient," with Type II technologies, which "make it possible to teach or learn in new and better ways" (p. 3) and lead to individualized instruction, but their categories lack detailed and operationalizable definitions. In the next sections, we explore key characteristics that can contribute to operationalizing a definition of high-quality classroom technology use.

Technology Use and STEM Practices

To effectively define quality of technology use, we needed to consider how technology use can lead to changes in teaching practices that allow students to engage more actively with content and learn through doing and through inquiry (Hickey, Moore, & Pellegrino, 2001; Inan & Lowther, 2010). According to the National Science Education Standards, inquiry-based teaching consists of "developing and practicing both scientific inquiry skills as well as knowledge of content" (National Research Council, 1995). The Next Generation Science Standards (Achieve, 2013) have advanced this definition of inquiry by focusing on eight practices of science and engineering:

(1) Asking questions (for science) and defining problems (for engineering);
(2) Developing and using models;
(3) Planning and carrying out investigations;
(4) Analyzing and interpreting data;
(5) Using mathematics and computational thinking;
(6) Constructing explanations (for science) and designing solutions (for engineering);
(7) Engaging in argument from evidence; and
(8) Obtaining, evaluating, and communicating information.

Similarly, the Common Core State Standards in Mathematics (CCSS-M; National Governors Association, 2010) also has a list of standards for mathematical practice that is focused on developing students' proficiencies in the process of problem solving. These practices include:

(1) Make sense of problems and persevere in solving them;
(2) Reason abstractly and quantitatively;
(3) Construct viable arguments and critique the reasoning of others;
(4) Model with mathematics;
(5) Use appropriate tools strategically;
(6) Attend to precision;
(7) Look for and make use of structure; and
(8) Look for and express regularity in repeated reasoning.

Technology applications can provide opportunities for tackling these high-quality STEM practices through interactive learning opportunities that mirror professionals' use of digital tools (Moeller & Reitzes, 2011). For example, students might use digital probes to collect environmental field data or use computer-assisted design tools to create blueprints. Online Web resources provide almost limitless sources of data that can be used in designing lessons around real-world issues and topics. Crippen and Archambault (2012) provided examples of teachers developing inquiry-supportive learning environments for their students using "cyberlearning materials that enable them to extend learning beyond the confines of the brick and mortar classroom" (p. 170).

Furthermore, De Jong (2006) noted that computer simulations can help scaffold students' understanding and learning during inquiry-based activities. Such scaffolding provides guided inquiry opportunities, which may be more effective for STEM learning (Devolder, van Braak, & Tondeur, 2012; Hmelo-Silver, Duncan, & Chinn, 2007; Kuhlthau, Maniotes, & Caspari, 2007; Mayer, 2004; Rutten, van Joolingen, & van der Veen, 2012). Additionally, the scaffolding afforded by different technologies allows students to learn methods of STEM practices, including data collection and interpretation of findings (Bertram, 2010; Chen, 2010; Lu, Ma, Turner, & Huang, 2007), and development of critical thinking skills (Hmelo-Silver et al., 2007; Hsu, 2008; Miller, McNeal, & Herbert, 2010). As such, students can learn to engage with real-world, ill-defined problems and make informed decisions about scientific issues that affect their lives (Barnett, Houle, Mark, Strauss, & Hoffman, 2010; Crippen & Archambault, 2012).

Project-based learning (PBL) is yet another way technology can be utilized to facilitate STEM learning in ways that align with real-world practices. PBL has long been recognized as an effective constructivist teaching approach that actively engages students in inquiry-based processes around authentic questions and tasks (Blumenfeld, Fishman, Krajcik, Marx, & Soloway, 2000; Blumenfeld, Soloway, Marx, Krajcik, Guzdial, & Palincsar, 1991; Savery, 2006). As Verma, Dickerson, and McKinney (2011) suggest, PBL also "'bridg[es] the gap' between academics of a profession and practice of that profession" (p. 26). For example, MarineTech is a program of study for middle and high school students that provides instruction and hands-on learning experiences in marine engineering, physical science, and information technology focused on shipbuilding (Verma et al., 2011). Marine kits with simulations allow students to perform both open-ended and structured activities that address different shipyard operations and construction scenarios; the curriculum also includes such enrichment activities as field trips to shipbuilding companies, marine science museums, and career-day events.

Technology and Student-Centered Teaching

Maddux and Johnson (2006) noted that the most successful implementations of technologies that change teaching practice lead to individualized instruction and move away from teacher-centered classrooms and toward student-centered teaching. Student-centered teaching, sometimes also referred to as student-centered learning, or learner-centered teaching or learning, allows students more flexibility to explore their creativity and engage in deeper thinking (e.g., Costa, 2013; Motschnig-Pitrik & Holzinger, 2002; Weimer, 2013; Wright, 2011). In this form of teaching, students' interests drive the materials and activities; students are self-directed, have increased responsibility and accountability for their own learning, and engage in active learning (Gningue, Peach, &

Schroder, 2013; Hsu, 2008; Russell, O'Dwyer, Bebell, & Miranda, 2004; Smart, Witt, & Scott, 2012). In student-centered teaching, the teacher acts as facilitator, the learning environment is resource and activity rich, and students collaborate and share with each other (Hsu, 2008; Jansen, 2011; Park & Ertmer, 2008; Russell et al., 2004; Smart et al., 2012).

Technology and Relevance to Real-World Contexts

Using technology in the classroom provides teachers with opportunities to make learning more relevant to students' own lives (Brophy et al., 2008; Hayden et al., 2011; Miller et al., 2011). This aligns well with the Next Generation Science Standards, which emphasize applying science concepts and skills to real-world problems as described earlier, as well as with CCSS-M. Relevance includes engagement in activities that produce concrete artifacts (Stearns, Morgan, Capraro, & Capraro, 2012). Integrating technology in the classroom can also provide opportunities to introduce students to careers across STEM fields (Ejiwale, 2012) and introduce them to STEM professionals. For example, in STEM-themed specialty schools and early college programs, students often interact with engineers, inventors, and scientists (Thomasian, 2011).

Technological Pedagogical Content Knowledge (TPACK)

Unifying frameworks that incorporate the above categories (STEM practices, student-centered teaching, relevance to real-world contexts) are needed to measure the quality of technology integration in the classroom. One particularly useful framework relevant for STEM workplace technology application is the Technological Pedagogical Content Knowledge (TPACK) framework (Koehler & Mishra, 2009; Koehler, Mishra, & Cain, 2013; Mishra & Koehler, 2006). TPACK considers how teachers use the unique affordances of technology to transform content and pedagogy for learners (Baran, Chuang, & Thompson, 2011; Jang & Tsai, 2013; Lin, Tsai, Chai, & Lee, 2013). The TPACK framework integrates the dimension of technological knowledge with Shulman's original construct of pedagogical content knowledge (PCK) (Shulman, 1987). It separates technological content knowledge from technological pedagogical knowledge (Cox & Graham, 2009). Technological content knowledge refers to understanding how technology and content interact with each other and requires that teachers understand how content is affected by technology, how technology is impacted by the content, and which technologies are best suited to address specific subject matter. Technological pedagogical knowledge refers to understanding how to use a given technology application to support pedagogical strategies, and how teaching and learning can be affected by using particular technologies. TPACK encompasses all of these elements by addressing the ability of teachers to effectively select and use appropriate technology applications that help their students understand specific content. One of the strengths of TPACK is its emphasis on the seamless and appropriate integration of technology (rather than an "add-on") as evidence of high-quality teaching.

While TPACK addresses some of the key aspects of quality that we expected to find in classrooms using STEM workplace technology applications (i.e., integration of technology, pedagogy, and content), it lacks a focus on real-world contexts and student-centered teaching. Furthermore, Brantley-Dias and Ertmer (2013) suggest that the TPACK framework is too big to be practical, embodying seven different knowledge types, which are difficult to measure simultaneously with the same instrument. They point out that even if teachers are able to demonstrate that they have TPACK, this does not mean that they use it in their instruction.

In addition, the framework alone is not necessarily applicable to technology-specific and subject-specific domains. In a meta-analysis of empirical studies involving TPACK, more than half of the studies analyzed focused on teachers' non-subject-specific TPACK (Wu, 2013). Science and mathematics were the two major subject domains examined in the domain-specific TPACK studies; however, these still only accounted for 20.8% and 12.5% of the empirical studies, respectively.

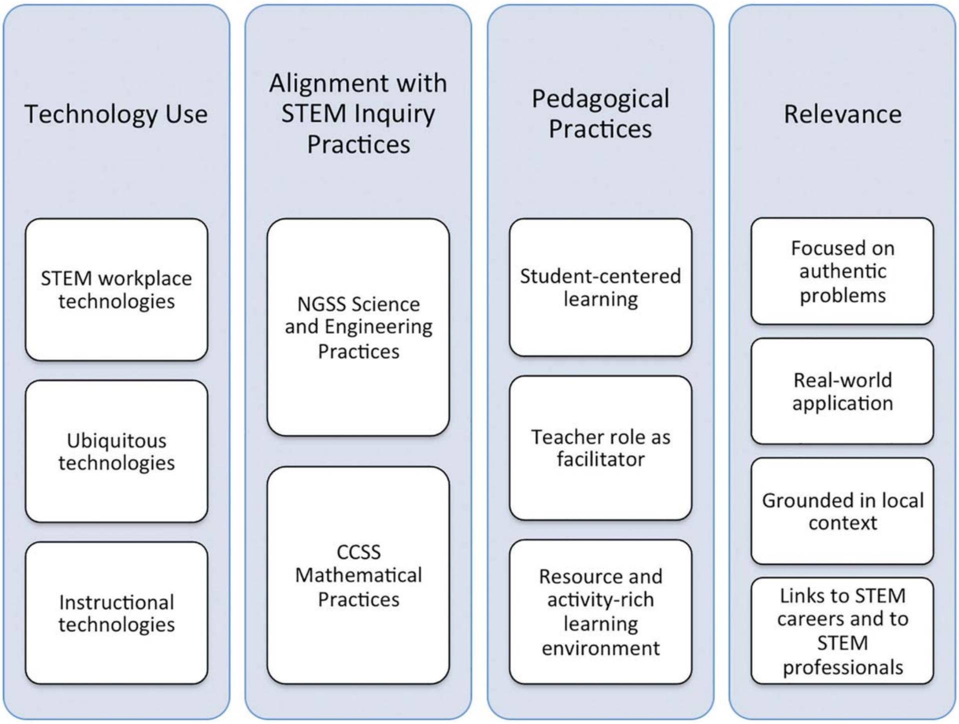

Figure 1. Defining quality technology implementation in STEM classrooms.

As noted earlier, our study disaggregated technology applications by type rather than treating them as a single entity because STEM workplace applications offer unique affordances for teachers to expand beyond instructional and ubiquitous technologies. Additionally, while TPACK-based observation instruments have been developed (e.g., Hofer, Grandgenett, Harris, & Swan, 2011), they are not aligned with NGSS and do not account for the use of technology in classrooms in a relevant and authentic way. Thus, in order to address our research question, we adapted the TPACK framework by incorporating the type of technology used and measures of real-world contexts, and operationalizing content knowledge as the NGSS science and engineering practices, and pedagogy as student-centered learning (see Figure 1; additional description in the Methods section).

Methods

Sample

The ITEST (intervention) sample consisted of 24 participants drawn from teachers who participated in one of 51 NSF ITEST professional development projects focused on STEM disciplines (e.g., computer science, environmental science, and biological sciences) and funded from 2003 through 2008. All projects offered year-round professional development including a summer institute where teachers worked with students outside of the classroom setting. The non-ITEST (comparison) sample consisted of 35 teachers drawn from STEM teachers who responded to an open call and indicated that they used technology in their teaching but had not participated in ITEST-like professional development (i.e., training focused on STEM workplace technologies). We gathered demographic data on both samples (see Table 1). Using chi-squared tests, we found no significant difference between the two samples in terms of gender, ethnicity, or highest degree earned. Using an independent-samples *t* test, we also found no significant difference between the two groups in mean years of teaching experience.

Table 1. Teacher Characteristics

Teacher Characteristics	ITEST ($n = 24$)		Non-ITEST ($n = 35$)	
	Frequency	Percentage	Frequency	Percentage
Gender				
Male	6	25	10	28.6
Female	18	75	25	71.4
Ethnicity				
American Indian or Alaska Native	0	0	0	0
Asian or Pacific Islander	1	4.2	1	2.9
African American	1	4.2	4	11.4
Hispanic	0	0	0	0
White	21	87.5	29	82.9
Other	1	4.2	1	2.9
Highest degree earned				
Bachelor's	7	29.2	7	20
Master's	16	66.7	28	80
Doctorate	1	4.2	0	0
Years teaching experience				
Less than 5 years	0	0.0	6	17.1
5 to 9 years	8	33.3	4	11.4
10 to 14 years	6	25.0	7	20.0
More than 14 years	10	41.7	18	51.4
Years since completing ITEST professional development				
1 year	14	58.3	n/a	n/a
2 to 3 years	8	33.3	n/a	n/a
4 or more years	2	8.4	n/a	n/a

Teachers were asked to choose one class for the fall 2011 semester in which they planned to use technology; this served as the focal class for all data collection. They picked classes that spanned a range of content areas and grade levels (see Table 2). Again, using a chi-squared test of independence, there was no significant difference between ITEST teachers and non-ITEST teachers in the grade span or content area of the focal class.

Data Collection

In lieu of classroom observations, we used a modified "scoop portfolio," which has been demonstrated to provide reliable documentation of classroom practices (Borko, Stecher, & Kuffner, 2007). The scoop process included (1) teachers' submission of classroom artifacts and instructional materials from a five-day period when they felt they were making the best use of technology (thus, the data represent each teacher's self-defined example of "best practices"); (2) teacher reflections

Table 2. Focal Classroom Characteristics

Classroom Characteristics	ITEST ($n = 24$)		Non-ITEST ($n = 35$)	
	Frequency	Percentage	Frequency	Percentage
Grade span of focal class				
Elementary	1	4.2	0	0
Middle	10	41.7	13	37.1
High	13	54.2	22	62.9
Content of focal class				
Biology or Life Science	6	25.0	7	20.0
Chemistry	2	8.3	4	11.4
Earth Science or Environmental Science	3	12.5	3	8.6
Engineering or Technology	1	4.2	3	8.6
English Language Arts	0	0.0	1	2.9
General Science	2	8.3	3	8.6
Mathematics	6	25.0	4	11.4
Physics or Physical Science	1	4.2	9	25.7
Social Studies	3	12.5	1	2.9

before, during, and after the five days; and (3) a post-scoop interview when researchers requested additional materials for the scoop or clarified teachers' reflections and artifact descriptions.

Data Analysis

Guided by the four literature-based characteristics described in the previous section (also see Figure 1), we analyzed and coded the scoop data from the 59 study subjects. The data were randomly divided among three coders, who coded blindly (i.e., they did not know if the teacher was ITEST or non-ITEST). Coding fidelity was maintained by coding one interview independently and then comparing and reconciling codes. This process of multiple coding, comparing, and reconciling was repeated twice more during the coding process to make sure that the coding was well aligned. Additionally, the coders met weekly during this process to identify and resolve challenges.

We purposefully did not define "technology use" to teachers during the recruitment phase of our study. As such, we did not limit the range of technology implementation types that teachers might consider appropriate. Consequently, teachers described a wide range of technology use (see Table 3), which we assigned to one of three distinct technology application groups using our taxonomy of technology applications: STEM workplace (commonly used in STEM fields but not widely implemented in classrooms), ubiquitous (commonplace in both the classroom and STEM and other workplaces), and instructional (designed to support classroom instruction).

For the second category in our coding framework in Figure 1, we used existing descriptions of high-quality STEM practices (Moeller & Reitzes, 2011; Ritzhaupt et al., 2012) from the Next Generation Science Standards (Achieve, 2013), the National Science Education Standards (National Research Council, 2000), and the Common Core State Standards in Mathematics (National Governors Association, 2010) to code teachers' written reflections and submitted artifacts. Examples of high-quality STEM practices include students asking questions in science, defining problems in engineering, exhibiting curiosity, proposing hypotheses, gathering evidence, constructing explanations, and reasoning abstractly, among others.

The third coding category involved pedagogical practices that encouraged student-centered teaching (Hsu, 2008; Lu et al., 2007; Ravitz, Wong, & Becker, 2000). Examples of such pedagogical

Table 3. Technology Application Groups

Groups	Technology Applications
STEM workplace technology applications: common in STEM fields but not common in classroom[a]	Biotechnology
	Computer modeling and simulations
	Computer programming
	Digital animation and multimedia production
	Engineering design
	Gaming design
	Geospatial technologies
	Image data analysis
	Probeware for field data collection
	Robotics
	Virtual reality
Ubiquitous technology applications: commonly used in STEM and other workplaces and other contexts, including the classroom	Numerical data analysis
	Presenting information
	Social networking
	Web-based information retrieval
	Word processing
Instructional technology applications: designed specifically for use in instruction	Assessing
	Instructing

[a]When teachers used technology applications designed for the classroom that mimic STEM workplace technology applications, we placed them in the STEM workplace technology application group.

practices included students presenting to others, exploring their creativity, engaging in deep thinking, being accountable for their own learning, and engaging in active learning, among others.

The fourth category coded teacher reflections or scoop submissions that indicated they used technology applications to engage students in addressing real-world problems (Stearns et al., 2012). This was operationalized as student learning focused on authentic problems, focusing on topics grounded in local contexts, and having links to STEM careers or STEM professionals.

Each of the codes was included only once (e.g., if teachers used probeware in more than one lesson during the scoop, it was only coded once). This allowed us to develop total counts of the codes for each teacher without duplication, and to use the total counts to determine the degree to which the teachers implemented each of the categories (i.e., technology application type, alignment with STEM practices, student-centered pedagogical practices, and relevance to real-world contexts). Repeated codes would have biased the results toward teachers who gave more detailed descriptions of their activities but did not necessarily do more of the targeted practices. Researchers also wrote a one-sentence description of each scoop portfolio that included a description of the content area and grade of the scoop class, as well as the technology application(s), the STEM practices, and any student-centered teaching or incorporation of local contexts. Finally, while the codes effectively described the presence of the targeted teaching practices, there were also instances of practices that "took away from" the high-quality technology implementation. These included using technology as a substitute for other tools without any corresponding evidence of changes to teaching practice; using technology within teacher-centered rather than student-centered instruction; and using STEM practices without including a technology focus. These practices were coded and subtracted from each teacher's total. Thus, each scoop portfolio resulted in a single "scoop total index" that represented the teachers' level of "technology implementation quality," with higher indices describing higher quality. The mean scores were then compared using an independent samples t-test.

In addition to comparing the ITEST and non-ITEST teachers, we used the scoop total indices and the one-sentence descriptions of each scoop to better understand the range and characteristics of technology implementation practices across the full sample. The descriptions and the scoop indices were triangulated, and when the two were not aligned, researchers went back to the data to reconcile differences. We divided the descriptions and scoop indices into three groups, which we identified as teachers who had "minimal" implementation (10 or fewer points), teachers who had "medium" implementation (11 to 16 points), and teachers who had "intense" implementation (more than 16 points).

Results

Comparing ITEST and Non-ITEST Teachers

Using an independent-samples *t*-test, we found no significant difference in the mean scores of the scoop total index for ITEST teachers compared to non-ITEST teachers (see Table 4). This suggests that, despite their extensive training, ITEST teachers did not use technology in ways that differed from teachers without such preparation (in terms of the characteristics examined in this study).

However, the scoop indices did demonstrate a wide variation in the quality of technology implementation across both teacher samples with regard to the total index (see Figure 2). The scores ranged from 0 to 25, with a standard deviation of 6.4. Almost half (28) of the teachers' scoops fell into the minimal group, while just 20% (11) met the criteria for intense. In the next section, we describe the variation across the teachers in each of the framework categories.

Table 4. Descriptive Statistics for the Scoop Total Index

	N	Mean (*SD*)	Min	Max
ITEST teachers	24	10.5 (6.5)	0	21
Non-ITEST teachers	35	9.3 (6.4)	0	25

Note. $t(57) = 0.750$, $p = .456$.

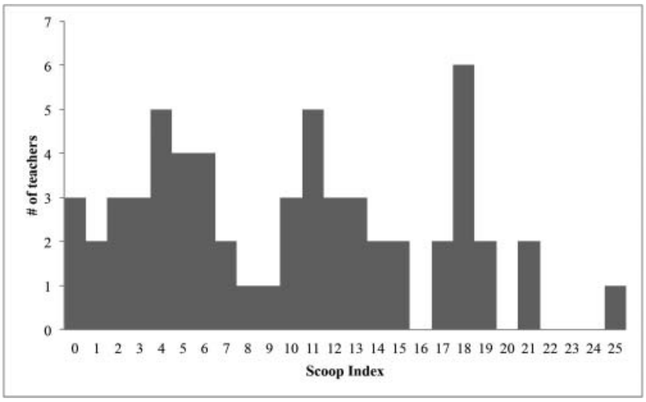

Figure 2. Distribution of scoop index values.

Range of Technology Implementation Practices

Overall, the intense teachers, both ITEST and non-ITEST, were characterized by their extensive use of STEM workforce technology applications and connections to local communities and to students' lives, as well as their high scores in the other categories. Specifically, in the intense teachers' scoops, students tended to actively engage in STEM practices that were relevant for their lives, such as using geographic information systems (GIS) and historical census data to answer self-designed questions about historical processes in the local community. In contrast, minimal teachers tended to mostly use instructional technologies and limited this use to presenting content, such as using videos and online demonstrations for instruction. Table 5 provides a selection of scoop results, including the one-sentence description and the breakdown of the scoop index results for representative ITEST and non-ITEST minimal, medium, and intense teachers; in the next sections, we examine differences between the minimal, medium, and intense teachers in each of the scoop index subcategories.

Technology type. On average, minimal teachers used fewer STEM workplace technology applications, while teachers with medium or intense indices used more STEM workplace technology applications (see Table 6). The use of ubiquitous technology applications was more uniform across the three scoop groups. Similarly, there was only a small difference between the three groups in terms of their use of instructional technology, although minimal teachers used, on average, more instructional technologies than medium or intense teachers. By contrast, all intense teachers used STEM workplace technologies with only one exception: Tenth-grade biology students used online resources to learn about the ecological impact of the Gulf Oil Spill, and then had to develop a Gulf Restoration Plan for presentation. The teacher using the Gulf Restoration Plan qualified as intense despite not using STEM workplace technologies because of the use of all available technology (the school had minimal technology resources) and because of the high scores in the other subcategories.

Relevance. Making connections to real-world contexts was a hallmark of intense teachers, and in many cases differentiated them from medium teachers. Minimal teachers rarely had indicators of relevance in their scoop portfolios. The most common example of relevance among all teachers was providing a real-world application for student learning, such as the teacher who required that students design a plan for addressing the impact of the Gulf Oil Spill. There were fewer instances of relevance that linked to STEM careers or STEM professionals, even among intense ITEST teachers, despite the programmatic emphasis on promoting STEM careers.

STEM practices. Minimal teachers used far fewer STEM practices than the medium or intense teachers: Minimal teachers had a mean of 1.3 STEM practices, as compared to 5.8 for medium and 9.6 for intense teachers. For all three levels of teachers, three STEM practices were identified more than the others: *students gather evidence from observations*; *students analyze and interpret data*; and *students explain based on evidence*.

Table 5. Scoop Ratings and One-Sentence Descriptions by Group and Teacher Level for 12 Scoops

Group and teacher level	STEM workplace technology	Instructional/ Ubiquitous technology	STEM practices	Relevance	Student-centered pedagogy	Teacher-centered pedagogy	Sum: Scoop total index	Scoop summary
Non-ITEST intense	3	0	7	2	6	0	18	College prep physics students used Vernier probes and other technologies to learn the physics of local lighthouses, and then developed science demonstration kit to teach wider audiences.
	3	3	5	1	5	0	17	Seventh-grade earth science students identified point sources of local water pollution, used GPS and cameras to collect field data, analyzed results, and used their findings to present proposals to address the issue at local community meeting.
ITEST intense	4	1	14	1	4	−3	21	Eleventh- and twelfth-grade biotechnology students used polymerase chain reaction (PCR) machine and other technologies to isolate their DNA cheek cells, analyze the samples, enter data into Allele Server Database, and compare data with other schools.
	1	1	9	1	6	0	18	High school geography students used GIS and historical census data to answer self-designed questions about historical processes in local community.
Non-ITEST medium	3	4	5	1	2	−1	14	Sixth grade science students learned to use wikis, conduct online research, and create their own photostory on natural disasters.
	1	1	7	1	4	−2	12	High school engineering students used Vernier probes to collect data on model boats to learn physics concepts.
ITEST medium	1	2	7	0	6	−3	13	AP biology students used NCBI database to explore different proteins and their structures.
	3	2	3	1	2	0	11	Sixth-grade geography students used GIS to map coordinates in their neighborhood.
Non-ITEST minimal	0	3	1	0	2	−2	4	Eighth-grade chemistry students did Web quest and presented information on chemical elements in PowerPoint.
	0	2	0	0	1	−2	1	Ninth-grade physical science teacher used videos and online demonstrations for instruction.
ITEST minimal	0	4	0	0	4	−3	5	Eighth-grade algebra 1 students used PowerPoint to prepare a presentation on integers, coordinate planes, and graphing.
	1	1	0	0	0	−2	0	Seventh-grade science teacher used Smartboard to present content to students.

Table 6. Average Classroom Technology Implementation Framework Indices by Teacher Level

Framework Index	Minimal ($n = 28$)	Medium ($n = 20$)	Intense ($n = 11$)
STEM workplace technology	0.4	1.8	2.0
Ubiquitous technology	1.1	1.2	1.5
Instructional technology	1.5	1.3	0.7
STEM practices	1.3	5.8	9.6
Relevance to real-world contexts	0.1	0.6	1.5
Student-centered pedagogical practices	1.3	3.6	4.6
Teacher-centered teaching (technology use not aligned with framework)	−1.7	−1.3	−0.9
Overall score	4.0	12.9	18.8

Student-centered teaching. Within the student-centered teaching category, four characteristics were more common than the others: *engaging in active learning*, *holding students accountable for their learning*, *encouraging deep thinking*, and *encouraging student autonomy*. While medium and intense teachers had means that were within one point of each other (3.6 and 4.6, respectively), minimal teachers had a mean of only 1.3.

Teacher-centered teaching. As noted earlier, while our framework focuses on the positive characteristics of classroom teaching, in our coding we also found examples of teachers doing classroom activities that did not fit into those positive characteristics. The most common example was when teachers used technology to replace other teaching tools without engaging in student-centered activities or using any of the other aspects of the framework. In particular, minimal teachers tended to use instructional technologies like Smartboards or clickers with traditional teaching methods. A number of teachers talked about using technology to maintain student interest, but they did not describe fundamental differences in their teaching.

Discussion

Key Findings

In this study we were interested in whether teachers who participated in technology-intensive professional development integrated STEM workplace technology applications into their classes and whether they aligned these applications with relevant real-world contexts and STEM practices while promoting more student-centered pedagogical practices. Our findings revealed no significant difference between teachers who participated in such professional development and those who did not in terms of our stated measures of high-quality technology integration. When we grouped all teachers together, however, we did find large variation in terms of the quality of their technology use. The intense teachers integrated STEM workplace technology applications into their classes and aligned those applications with relevant real-world contexts and STEM practices while promoting student-centered learning, while minimal teachers had few of these characteristics.

Implications for Practice

These findings have important implications for professional development. First, they suggest that a year-long professional development program (even with up to 120 contact hours as required by ITEST) may not be sufficient to ensure high-quality implementation in the classroom. The training period may need to be extended, perhaps with extensive follow-up support over several years. Additionally, strong relationships with school administrators may be necessary to ensure support for teachers attempting to implement these complex tools in meaningful ways. Alternatively, school policies may be too much at odds with the student-centered teaching around technology tools and real-world practices that define high-quality technology implementation in this study. For example, in a broader survey of ITEST teachers, the most common barriers to technology implementation were related to school culture and policy (level of colleagiality, standized testing requirements, flexibility in curriculum, access to technology) (Stylinski, Parker, & McAuliffe, 2013). Ertmer et al. (2012) also found external barriers such as lack of resources or administrative support, and the pressures of standardized testing, although their study also highlights that teachers' attitudes and beliefs can be the biggest barrier to technology integration and thus professional development efforts should focus on reducing fear associated with using technology in the classroom.

Second, our study elucidates a framework and method that effectively describe the wide range of technology implementation practices found in classrooms. Through the scoop method, teachers in this study were able to provide evidence of their best use of technology. Our framework captured the wide range of these applications by integrating types of technology applications (instructional, ubiquitous, and STEM workplace) with the alignment to STEM practices, student-centered pedagogical practices, and relevance. That is, it provides a comprehensive description of the myriad ways that teachers used multiple technology applications in the classroom as well as the relationships between technology use and teaching practices. For example, in our study the majority of teachers at the minimal level focused on the use of instructional technologies, and their technology use was not associated with student-centered pedagogies or an emphasis on STEM practices. In contrast, those teachers who used STEM workplace technologies tended to fall into the intense level because their use of STEM workplace technologies was accompanied by an alignment with STEM practices, student-centered pedagogies, and/or a focus on learning in a locally relevant context. Intense teachers, and even some medium teachers, were "mak[ing] it possible to teach or learn in new and better ways" (Maddux & Johnson, 2006, p. 3); they were fostering student use of STEM practices (Crippen & Archambault, 2012), helping students to apply science to real-world problems (Stearns et al., 2012), and promoting student-centered teaching (Ertmer et al., 2012; Moeller & Reitzes, 2011). The importance of making content relevant to students and making connections to STEM careers is often cited by those who advocate pedagogical practices that lead to student-centered learning (Lea et al., 2003; Moeller & Reitzes, 2011; Ravitz et al., 2000; Stearns et al., 2012), while other researchers have noted the association between the implementation of STEM practices and pedagogical practices fostering student-centered learning (Chen, 2010; Hsu, 2008; Lu et al., 2007; Park & Ertmer, 2008).

Limitations of the Study

Our study results should be considered within the following constraints. Although all non-ITEST teachers indicated that they had no prior ITEST-like professional development at the start of the study, follow-up interviews revealed that some of them had in fact participated in professional development resembling the ITEST projects, particularly professional development that encouraged the incorporation of real-world contexts and local issues in their teaching. As a consequence, the two groups may not have been sufficiently different on the key characteristic of previous professional development experiences. An additional limitation was the small size of the final sample, which made it difficult to use statistical analyses to triangulate the more qualitative findings. Finally, while the use of the scoop portfolio enabled extensive data collection across a wide geographic area with limited funds, direct classroom observations would have provided data in addition to the self-reports of the scoops.

Recommendations for Future Research

Future research is needed to delve more deeply into why teachers differ on these measures of technology implementation: both to look more into the possibility that professional development makes a difference or does not, and to examine the role of other teacher, school, or local characteristics. Additionally, while the scoops provided an indirect view into the classroom, the framework presented here could be developed into a classroom observation tool to describe and measure the classroom implementation of STEM workplace technologies. A properly validated tool could facilitate higher quality data collection to improve our understanding of the factors that contribute to high-quality classroom technology integration and barriers to that integration. Use of the tool with a larger sample would allow for tests of statistical significance of subgroups. The differences in teaching practices between those teachers who implement STEM workplace technologies and those who implement primarily instructional technologies (in our study, the differences between intense teachers and minimal teachers) deserve further investigation. Finally, further research should include measures of student impact to make the connection between teaching practices and student outcomes.

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